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Perspectives on Wearable Enhanced Learning (WELL)

Current Trends, Research, and Practice

Springer

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Foreword

Dear Reader!

You have a copy of a new edited book about wearable enhanced learning in your hands. You may have downloaded it as an e-book on your laptop or on your tablet. In this case, you are already practicing wearable enhanced learning. Computers and smartphones are wearables indeed, but what is wearable has dramatically changed recently, from devices we use with our hands and put on our laps to devices that are worn as part of our clothing, as accessories, or as head-mounted devices. If you are entering public transportation, you are already watch people wearing earplugs and smart watches. In some countries like Japan, you may also see people wearing head-mounted devices in public transportation. The general trend of invisible computing, however, is that the devices are vanishing from our views since they are more and more integrated into our business suits and sport dresses. They may even get – ethically debatable – inside our bodies, below our skins, or into our eyes and ears.

What is the relationship to learning? And what does enhancement mean? First, there is a return to physical activities in learning. While over the last decades, enhancing learning basically meant the enhancement of our memories and (meta-)cognitive abilities, wearable enhanced learning is about on-demand and context-based learning. It is also about our kinesthetic experience, the way we move, we walk, we run, and we dance. We are not only turning super smart but also into superheroes. We get feedback from our body-worn sensors, and we learn to listen more to our bodies. We wear body prostheses and can lift more than ever before; we can even fly. What is the price for that? We do not know yet. Second, we learn to transform our environment in a new way. We start to live in smart cities in smart homes. We interact with smart environments using all the sensors available in buildings, in nature, and in appliances and worn by other people and worn by robots. We can control and monitor more than ever before, but we are also more controlled and monitored than ever before. Learning to live, to work, and to learn in such smart environments is the next challenge. The future will answer how we can cope with the vast amount of data and adopt these emerging technologies.

In this book, you will find amazing examples of learning, much knowledge about current trends, hardware, software, but also links to pedagogical models and how they are changing under the new regiment. You will find a comprehensive and multi-perspective view on wearable enhanced learning put together from an experienced team of scientific editors, written by a crowd of researchers and practitioners in the field. I am quite convinced that your view is missing in the book, but this is only the beginning of a long journey to find efficient ways to use relevant technologies and envisioning new tools for learning experiences.

Books are treated by publishers like music nowadays. They rip the book in different chapters available for download and create playlists based on popularity. In that case, you might not have read this foreword anyway. Have fun with the whole book!

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Introduction to the Volume

Wearable technologies – such as smart glasses, smart watches, smart objects, or smart garments – are potential game-changers, breaking ground, and offering new opportunities for learning. These devices are body-worn and equipped with sensors and integrate ergonomically into everyday activities. With wearable technologies forging new human-computer relations, it is essential to look beyond the current perspective of how technologies may be used to enhance learning.

This edited volume *Perspectives on Wearable Enhanced Learning* aims to take a multidisciplinary view on wearable enhanced learning and provide a comprehensive overview of current trends, research, and practice in diverse learning contexts including school- and work-based learning, higher education, professional development, vocational training, health and healthy aging programs, smart and open learning, and work. This volume will feature current state of the art in wearable enhanced learning and explore how wearable technologies begin to mark the transition from the desktop through the mobile to the age of wearable, ubiquitous technology-enhanced learning.

The edited volume is divided into seven parts:

Part I The Evolution and Ecology of Wearable Enhanced Learning

This part includes chapters describing an evolution of technology-enhanced learning from the desktop to the wearable era, the different phases in the evolution of technologies for learning, introducing in the technological and conceptual shifts from e-learning through m-learning to ubiquitous learning. This part introduces the reader to the topic and provides both a historical perspective and a conceptual framework for a sociocultural ecology of learning with wearables.

Introduction to Wearable Enhanced Learning – Trends, Opportunities and Challenges

Ilona Buchem • Ralf Klamma • Fridolin Wild

Wearable enhanced learning (WELL) is an emerging area of interest for researchers, practitioners in educational institutions, and companies. But also, many grassroot movements are providing new sensors, devices, prototypical ideas, and innovative learning solutions. Deeply rooted in the traditions of technology-enhanced learning such as self-regulated learning and mobile learning, WELL is generating new challenges and opportunities. Fragmentation, scalability, and data aggregation are among the main challenges. The authors inspect some of the domains in WELL such as gaming and entertainment, health and sports, and business and industries as well as some technology trends such as e-textiles, smart accessories, and head-mounted display. The authors broaden the perspective on learning with wearables and learning about wearables with insights from related fields as the philosophy of technology, sociology, and business management.

Part II The Topography of Wearable Enhanced Learning

This part includes chapters giving an overview of current trends and uses of wearable enhanced learning including examples of projects, use cases, and case studies. This part provides an overview of real-life examples and aims at illustrating the breadth of the uses of wearable technologies for learning in different application contexts such as education, work, health, and open learning.

Smartglasses as Assistive Tools for Undergraduate and Introductory STEM Laboratory Courses

Martin P. Strzys • Michael Thees • Sebastian Kapp • Pascal Knierim • Albrecht Schmidt • Paul Lukowicz • Jochen Kuhn

Learning is known to be a highly individual process affected by learners' individual previous experience and self-directed action. Especially during laboratory courses in university Science, Technology, Engineering, and Mathematics (STEM) education, all channels of knowledge construction become relevant: students have to match their theoretical background with experimental hands-on experience, leading to an intensive interaction between theory and experiment. Realizing augmented reality scenarios with see-through smart glasses allows to display information directly in the user's field of view and creates a wearable educational technology, providing learners with active access to various kinds of additional information while keeping their hands free. The framework presented here describes the use of augmented reality learning environments in introductory STEM laboratory courses aiming to provide students additional information and real-time feedback while sustaining their autonomy and the authenticity of their action. Based on the principles of the cognitive-affective theory of learning with media (CATLM), we hypothesize that this tool can structure students' hands-on experiences and guide their attention to cue points of knowledge construction.

Wearable Technology – Meeting the Needs of Individuals with Disabilities and Its Applications to Education

Cindy L. Anderson • Kevin M. Anderson

Wearable technology offers opportunities for individuals with disabilities to engage with their environment with greater success and to be included in learning opportunities to a greater degree. "Wearables" mean digital devices and/or computers that can be worn and used in the real world (Borthwick, Anderson, Finsness, & Foulger, 2015). Some wearable technology that works for individuals with disabilities is worn on the body as an accessory, such as a Fitbit. Other wearables for individuals with disabilities involve smart clothing or clothing interwoven with sensors that can help maintain health and help the individual with disabilities be more successful in their environment. Some individuals with disabilities even have wearables with microprocessors that directly attach to the body. These wearables can play an important role in the classroom that is following the principles of universal design for learning to enhance the learning of students with disabilities. The chapter outlines wearables for disabilities and finishes with two case studies of students with disabilities who are recommended wearables to help their success in the classroom.

Toward Wearable Devices for Multiteam Systems Learning

Brenda Bannan • Samantha Dubrow • Christian Dobbins • Stephen Zaccaro • Hemant Purohit • Mohammed Rana

This chapter provides an overview of an exploratory case study involving a multiteam system in the fire and rescue emergency context incorporating human sensor analytics (e.g., proximity sensors) and other data sources to reveal important insights within and between team learning and training. Incorporating a design research approach, the case study consisting of two live simulation scenarios that informed the design and development of a wearable technology-based system targeted to capture team-based behavior in the live simulation and visualize it during the debriefing session immediately following to potentially inform within and cross-team behavior from a multiteam systems perspective informed by theory and practice.

Engaging Students in Co-designing Wearable Enhanced Learning Kit for Schools

Marge Kusmin • Kadri-Liis Kusmin • Mart Laanpere • Vladimir Tomberg

The Estonian Lifelong Learning Strategy 2020 aims to implement ambitious digital turn toward 1:1 computing; schools are expected to explore new ways of using novel technologies (including wearables) to facilitate creative and collaborative learning through interdisciplinary projects. This case study summarizes a pilot project that engaged 7th–12th grade students in research-based design of a mobile kit for wearable enhanced learning, under the guidance of university researchers. Five groups of students, four from urban and one from a small rural school, were involved in testing, redesigning, and expanding the initial set of wearables: trackers, Arduino boards, Adafruit Gemma sensors, cables, tools, etc. This case study followed design-based research approach that involved composing four personas (two students, a teacher, and an entrepreneur) and three usage scenarios as input for iterative prototyping and experimentation process. We also conducted a design experiment with university students to get confirmation of suitability of these IoT kits. In the next step of the pilot project, students are going to be engaged in an iterative process of learning, researching, experimenting with, and prototyping these mobile kits of wearable technology that could help them to carry out inquiry-based learning (IBL) of their own learning process and environment.

Part III Technological Frameworks, Development and Implementation

This part includes chapters providing insight into different technological aspects of wearable enhanced learning focusing both on the hardware and the software. This part also gives an overview of different development and implementation methodologies applied in wearable enhanced learning.

Requirement Analysis Towards the Deployment of Architecture Incorporated with IoT for Supporting Work-Based Learning and Training – On the Threshold of a Revolution

Dan Kohen-Vacs • Gila Kurtz • Yanay Zaguri

Internet of Things (IoT) is an emerging technology expected to transform the way we live, work, and learn. It consists of devices endowed with sensors as well as information and communications technologies (ICT) capable of transmitting information across networks. This technology can sense and communicate data from various sources like the human body, food, and clothing. IoT could also be incorporated to sense data from household appliances, commodities, landmarks, buildings, and roads. Even though IoT is in its early stage of development, organizations recognize its potential applicability and therefore incorporate it in their efforts to improve word-based learning and training. For example, organizations can use IoT as personal learning centers based on worker preferences. IoT also enables adaptive learning based on business needs. To empower learning with these affordances, we propose to exercise a system analysis based on four scenarios focused on work-based and enhanced by IoT. Accordingly, we propose a design process emerging from the discovery of requirements emerging from the analysis on the scenarios. Finally, we propose to deploy an architecture combined with IoT devices connected to reasoning points, that is, addressing the scenarios and its corresponded analysis. This approach is suggested as part of our efforts to address activities based on reasoning systems exploiting big data used for providing optimized learning that is empowered by IoT. We foresee that this architecture will provide employees with exciting opportunities to exploit valuable data in order to react to and refine an ongoing process that produces personal, meaningful, and in-context learning experience. We believe that our efforts to deploy such architecture provide new, flexible, and efficient opportunities for exercising innovative approaches for practicing work-based learning and training.

Using the Internet of Things for Enhanced Support of Workers in Manufacturing

Carsten Ullrich • Cédric Donati • David C. Pugh • Alex Gluhak • Anthony Garcia-Labiad • Xia Wang

Work processes such as assembly in manufacturing are often highly complex and change frequently due to today's high rate of technological innovation. Thus, the usage of assistance services to support workers in assembly can result in significant benefits. However, adequate assistance requires knowledge about the actual actions of the workers. In this chapter, we present a use case in aviation, where a manufacturing environment that carries no sensors at all is extended with off-the-shelf sensors that enable capturing the effect of physical actions and, in consequence, adequate reactions of a support system. We also give an overview of technologies of the Internet of Things and a category of human errors in industry to simplify the replication of the described digitization in other workplaces.

Part IV Pedagogical Frameworks and Didactic Considerations

This part includes chapters providing insight into different pedagogical frameworks and didactic/instructional design approaches applied in wearable enhanced learning. This part also discusses pedagogical affordances of wearables as technologies for learning and the consequences for a didactically sound design and integration of wearables in learning settings/environments.

Pedagogical Frameworks and Didactic Considerations. On the Feasibility of Using Electronic Textiles to Support Embodied Learning

Olivia Ojuroye • Adriana Wilde

Electronic textiles (e-textiles) have already proven their practical use in wearable garments and are now also beginning to feature in non-wearable items, such as in furniture and shared surfaces inside a smart home or driverless car interiors. E-textiles, whether worn or not, have the potential to support their users' embodied learning on a variety of topics. Embodied learning can be supported with e-textiles being part of an Internet of Things (IoT) ecosystem, providing contextual information within a network capturing traces of behavioral and even biological data about its users. Individuals' "digital identity" expands as the number of connected devices each individual possesses grows. Furthermore, using artificial intelligence (AI), increasingly personalized experiences can be tailored to users through the very devices they interact with. To ensure e-textiles' data can be useful for this purpose, e-textiles need to be engineered to integrate with everyday activities and lifestyles. In particular, this chapter will examine e-textiles' potential to be used as pedagogical conduit to facilitate individualized embodied learning experiences.

Embodied Learning – Somatically Informed Instructional Design

Jessica J. Rajko

Wearable technology is moving closer to and even into human bodies, effectively rendering it invisible. Coined by Mark Weiser (1999) as invisible computing, wearable technologies now “weave themselves into the fabric of everyday life until they are indistinguishable from it.” While technologies may appear invisible to the naked eye and continue to demand less of our visual attention, our understanding of the world is created not just through our eyes but through our multisensory, corporeal experiences. Therefore, the movement of technologies from our hands onto our skin should, but often does not, account for broader, felt experiences. Entering into the wearable technology design field as a professional dance and somatic practitioner, I place somatically informed practices at the center of the wearable technology design process. This is made possible by handmade rapid prototyping wearable technology bands I designed specifically for pedagogical use. In this chapter, I share my curricular model for engaging somatically informed practices in wearable technology design. More specifically, I provide a brief overview of the field of somatic practices, describe my curricular design methods, and discuss my in-class experiences teaching the curriculum.

A Conceptual Framework for Supporting Expertise Development with Augmented Reality and Wearable Sensors

Bibeg Limbu • Mikhail Fominykh • Roland Klemke • Marcus Specht

Experts are imperative for supporting expertise development in apprentices, but learning from them is difficult. In many cases, there are shortages of experts to train apprentices. To address this issue, we use wearable sensors and augmented reality to record expert performance for supporting the training of apprentices. In this context, we present the conceptual framework which outlines different instructional design methodologies for training various attributes of a task. These instructional design methodologies are characterized by their dependencies on expert performance and experts as model for training. In addition, they exploit the affordances of modern wearable sensors and augmented reality. The framework also outlines a training workflow based on the 4C/ID model, a pedagogic model for complex learning, which ensures that all aspects of conventional training are considered. The chapter concludes with application guidelines and examples along with reflection of the authors.

Learning Manual Skills with Smart Wearables

Ekaterina Kutafina • Marko Jovanović • Klaus Kabino • Stephan M. Jonas

Intensive development of e-learning methods still struggles with domains where feedback on manual and physical skills is necessary, for example, crafts or physiotherapy movements. Most of such training is currently done exclusively through direct teacher-student interaction. The traditional approach minimizes the possibilities for remote learning, requires long-term investments, and contributes to high costs of education. While human feedback remains very important, modern wearable sensors allow to transfer part of the workload to e-learning. In this chapter, we present an overview of available solutions with particular focus on wearable sensors. We argue that wearable devices have the ability to enable a new step in e-learning, not only allowing the acquisition of theoretical knowledge but also training of manual and physical skills.

Part V Design of User Experience

This part includes chapters providing insight into different aspects of user experience design including approaches for enhancing user engagement such as gamification and information visualization as well as human-computer interaction and interface design. This part also discusses how current insights from research and development in wearable computing, which represents the forefront of HCI innovation, may be applied to designing user experience in learning settings.

Smart City Learning Solutions, Wearable Learning and User Experience Design

Brenda Bannan • Jack Burbridge

This chapter provides an overview of an applied research and development process for engineering smart city learning solutions that incorporates a user experience (UX) design and research approach that has been leveraged in an emergency response and management context. The four-phase model represents an iterative, progressive, and agile prototype design process applicable for generating, refining, deploying, and scaling wearable devices and Internet of Things (IoT) solutions to improve learning and performance at the city services level. The described user experience (UX) integrative design and research process was employed in the development of an emergency management and response smart city solution prototyping process in the mid-Atlantic region of the USA. Insights and lessons learned related to designing for user experience in smart city learning solution research and development through prototyping a specific wearable technology learning system will be addressed in the chapter.

Designing Wearables with People in Mind

Vladimir Tomberg • Daniel Kotsjuba

Wearable computing devices enter into different areas of our life. Among others, the most prominent themes are biotech fusion, synced lifestyle, organic computing, human enhancement, health empowerment, and learning. Design of wearables implies the tangible, wearable, and sometimes ubiquitous interfaces, as for input, as well as the output, of a data. The screen-based laws, rules, and guidelines often have nothing to do with such nonstandard types of human-computer interfaces. The nature of user interfaces for wearables is versatile and different to the traditional, screen-based human-computer interfaces. For designing wearables, it is not enough to apply the usability rules. The wearable devices are worn on a body, and that is the main distinction to screen-based devices. People have different sizes of clothes, mental and physical abilities, and social and cultural background. These properties start to play an important role in interaction design for wearable computing. In this chapter, we review a hierarchical model for universal design principles that we propose to use for the evaluation of prototypes of the wearable devices. We describe different groups of the universal design principles and propose a combined tool for use in the evaluation of the design of prototypes for the wearables.

Experience Capturing with Wearable Technology in the WEKIT Project

Puneet Sharma • Roland Klemke • Fridolin Wild

In this chapter, the authors focus on capturing an expert's experiences using wearable sensors. For this, first, we outline a set of high-level tasks that facilitate the transfer of experience from an expert to a trainee. Next, we define a mapping strategy to associate each task with one or more low-level functions such as gaze, voice, video, body posture, hand/arm gestures, bio-signals, fatigue levels, haptic feedback, and location of the user in the environment. These low-level functions are then decomposed to their associated state-of-the art sensors. Based on the requirements and constraints associated with the use cases from three different industrial partners, a set of sensors are proposed for the experience-capturing prototype. Finally, we discuss the attributes and features of the proposed prototype, along with its key challenges, constraints, and possible future directions.

Wearables for Older Adults – Requirements, Design and User Experience

Robert Klebbe • Anika Steinert • Ursula Müller-Werdan

This chapter presents insights into current research about the use of wearable technologies by older adults. The results of requirement analysis, laboratory tests, and pilot studies with different quantitative and qualitative methods are presented and discussed. The authors refer to the high expertise from various publicly funded projects with activity tracking devices and Google glasses. The last section presents specific requirements and suggestions, relevant to researchers, designers, and developers working with the target group of older adults. The authors argue that wearable technologies are predominantly adapted to the needs of younger target groups who are already familiar with intelligent technologies. Older adults, on the other hand, often have poor access to technology, which derives from a low belief in technology control and competence as well as sensory, physical, and cognitive impairments. The authors conclude that wearables can support seniors in the process of learning health-related competencies for self-management and health-relevant behavior in the context of age-associated diseases for a self-determined lifestyle.

Learning for a Healthier Lifestyle Through Gamification – A Case Study of Fitness Tracker Applications

Aylin Ilhan • Kaja Joanna Fietkiewicz

Nowadays, many people have to increasingly deal with the question "How can I improve my health?" Fortunately, the market for wearable technologies (e.g., Fitbit or Garmin) supports people by enabling them to track, monitor, and analyze their physical activity. Despite the technological component, in order for the wearables to be successful, important are the user engagement design and (enhancing) users' motivation. This can be achieved with well-conceived integration of gamification elements in the fitness tracker mobile applications. A successful user engagement design of the fitness tracker applications can not only motivate the users to continually apply the service but also inspire them to be more active for the long term. There are several theories dealing with user motivation and which were considered relevant for this research: the goal orientation theory, the self-determination theory, and flow theory. This study concentrates on ten wearable products and their fitness tracking applications, (1) to compare the integrated gamification mechanics, (2) to analyze possible dynamics triggered by these mechanics, and (3) to identify user engagement designs supporting long-term learning and engagement in a healthier lifestyle.

Part VI Research and Data

This part includes chapters providing overview of current empirical research results in wearable enhanced learning touching upon the different dimensions of learning including cognitive, social, and embodied dimensions. This part also discusses how data can be gathered and exploited in wearable enhanced learning which includes such topics as wearable learning analytics, turning data into information and data-driven approaches to enhancing learning in wearable enhanced learning.

Virtual Reality as an Environment for Learning – Facilitating a Controlled Environment for Pupils with Diagnosed Concentration Disorders

Eva Mårell-Olsson • Thomas Mejtoft • Jenny Kinert

Pupils with concentration disorders need an education that is adapted for them for fulfilling the goals of their education. They often need an adjustable learning environment with fewer distractions. Unfortunately, the public education system often fails in providing such pupils the aid and the support they need. This chapter presents a study regarding how virtual reality (VR) can be used as a learning support for pupils aged 16–18 years with diagnosed concentration disorders and how this technology can support them in accomplishing their educational goals. This study was performed as a case study with three sources of data – (1) observations during a key task test, (2) qualitative interviews with the participants, and (3) a survey. The findings are presented in three themes: (1) increasing the ability to concentrate, (2) the suitability of using VR technology in learning, and (3) developing knowledge acquisition with the support of VR technology. The findings indicate that the level of concentration can be increased while using VR technology due to a controlled environment and that VR technology can be suitable as a complement in education for pupils with concentration disorders and can support pupils in developing their own knowledge according to their specific needs.

Real-Time Auditory Biofeedback System for Learning a Novel Arm Trajectory – A Usability Study

Sophie Hall • Fridolin Wild • Tjeerd olde Scheper

There is increasing interest in employing immersive virtual reality or augmented reality and wearable technology to provide real-time motor performance feedback during rehabilitative arm exercises. Biofeedback systems have been shown to improve motor error, fluidity, and speed while increasing patient engagement and motivation to persevere. Preliminary research on using sound to provide performance feedback has shown it can provide spatiotemporal information in a motivating and engaging way. This research presents a proof-of-concept auditory biofeedback system that provides error corrective sonification of the arms' spatial orientation and acceleration throughout a reaching task in order for users to learn and follow a novel trajectory. In the evaluation method, seven healthy participants (three male, four female) from a healthcare background completed the reaching task while using the auditory biofeedback system, both blindfolded and with full vision. Using a System Usability Scale (SUS) study, a quantitative score on the systems usability was calculated. The results showed that the mean SUS score was 74.64 (standard deviation = 12.28), indicating that the prototype provides an above average usability score (Avg. across 5000 surveys = 68). This research concludes that further investigation into the concept within a clinical environment as a tool for upper-arm stroke rehabilitation is recommended.

Exploiting Wearable Technologies to Measure and Predict Students' Effort

Barbara Moissa • Geoffray Bonnin • Anne Boyer

Effort is considered a key factor of students' success, and its influences on learning outcomes have been studied for decades. To study this relationship, researchers have been measuring it in several different ways. One traditional way to measure effort is to rely on indicators such as the time spent on a task. This solution is not entirely reliable, as divergent results can be found in the literature. Additionally, it is not possible to know the internal and external conditions that led to these observations and how they can influence the results. Being able to accurately measure and predict students' effort can contribute to the understanding of its relationship with learning outcomes and allow teachers to identify students who are struggling or not truly engaged into learning through new tools. One promising way to acquire information about students' internal phenomena is to exploit wearable technologies.

In this chapter, after reviewing different definitions of effort, we present a landscape of students' effort measurement and prediction. Then, we discuss how wearable technologies can be exploited to enhance the accuracy of these measurements and predictions.

Wearable Technology in a Dentistry Study Program – Potential and Challenges of Smart Glasses for Learning at the Workplace

Eva Mårell-Olsson • Isa Jahnke

Wearables such as smart glass technologies with augmented reality functionalities have the advantages of being voice-controlled and hands-free. The person, for example, the dentist, has both hands available for doing the actual work while using smart glasses to retrieve augmented information or to communicate with others. To understand the potential of smart glasses for enhancing workplace learning, we conducted a study in a dentistry study program. The study goal was to explore the use of smart glasses in order to inform future workplace learning designs. The central research question focused on facilitating communication, coordination, and cooperation in student's clinical practice of becoming a dentist. In this book chapter, we describe the case and demonstrate the need to reconsider the established concepts of technology-enhanced learning from traditional course-based learning into learning processes. The results are organized along five themes – communication support, coordination support, information management, technical issues, and future designs – that illustrate new ways of digital workplace learning with wearable technology.

Part VII Synopsis and Prognosis

The final part includes a chapter providing a synopsis and a prognosis for the future development in the field of wearable enhanced learning.

The Bigger Picture

John Taxler

In this piece, we ask readers and authors to stand back from the achievements, actors, and activities described in the book and look at the wider context and critical issues. These include, first, the relationships of wearables with other established and emerging trends in technology-enhanced learning and educational technology, asking about the need to collaborate, compete, and co-opt in order to embed and endure; second, the place of wearables and the learning they afford within the rapidly changing global higher education environment and the place of wearables and research into the learning they afford in the rapidly changing financial and ideological constraints of research funding and the policy that informs it; and finally, the place and responsibilities of researchers in wearables as part of the technology-enhanced learning and educational technology within the global context of crises and change. These crises and changes are being exemplified in economics, ecology, governance, and legitimacy, among others, and sometimes characterized as indicators of a wider crisis in late global capitalism, or some transition into postmodernity that unsettles our minds and our methods.

The editors would like to thank all authors for their work and insights into the diverse aspects and perspectives of wearable enhanced learning (WELL). We wish to thank our board of reviewers for the great help with reviewing the chapters. Our thanks go to Michaela Klamma for preparing the artwork for the cover of this volume. We would also like to thank the members of the Special Interest Group on Wearable Enhanced Learning at the European Association of Technology-Enhanced Learning (SIG WELL @EATEL) for inspiring contributions and feedback on this volume.

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Marge Kusmin (margek@tlu.ee) is PhD student at the School of Digital Technologies at Tallinn University, Estonia. She has been Head of Educational Technology Center at Tallinn University of Technology for years. Her research area is related with smart schoolhouse concepts – to find hardware (IoT) and software for "smart schoolhouse" that enables automatic data collection from physical learning environment. This data can be used in STEAM education for different analyses as raw data; this data, integrated with the digital footprints of learners (in their own devices and online platforms), could be used for learning analytics and, finally, to automatically adjust the environment.

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Part I
The Evolution and Ecology of Wearable Enhanced Learning

Introduction to Wearable Enhanced Learning (WELL): Trends, Opportunities, and Challenges

Ilona Buchem, Ralf Klamma, and Fridolin Wild

1 Introduction

Wearable enhanced learning (WELL) has emerged as a concept in technology enhanced learning (TEL) at the beginning of the twenty-first century. The name was coined by the Special Interest Group on Wearable Enhanced Learning (SIG WELL)[1] of the European Association of Technology Enhanced Learning (EATEL) in 2014 to describe a specific type of technology enhanced learning which applies wearable technologies to support learning based on data captured by wearable sensors and devices both worn on or in the body of the learner and embedded in the environment of the learner. This type of wearable enhanced learning, especially its potential for the co-construction of knowledge required for competence development, has been an emerging area of interest, research and development. WELL combines technical disciplines like wearable computing, artificial intelligence, and cyber-physical systems with pedagogical, design-related, sociological, and philosophical

[1] http://ea-tel.eu/special-interest-groups/well/

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disciplines such as instructional design, user experience design, or technology impact assessment. Since all these contributing disciplines have developed their own discourses and own methods of research, it is important to ask whether the study of WELL as an area of interest on its own is justified and whether there is anything notably different, unique, or emergent in this new interdisciplinary to justify specific research and development in WELL.

The authors of this chapter have posed this question, identified pockets of innovation in a wide range of fields, and consequently established the Special Interest Group on Wearable Enhanced Learning (SIG WELL) of the European Association of Technology Enhanced Learning (EATEL) in 2014 to stimulate joint research and bring together the disciplinary subgroups from the fragmented community. SIG WELL has aimed to establish a dialogue between education and training organisations, vendors of solutions, and research organisations in order to proactively promote the use of wearable learning technologies and research methodologies in diverse environments such as education, manufacturing, or health. SIG WELL has been bringing different stakeholders together in order to enhance knowledge exchange, sharing, and cooperation around wearable enhanced learning.

This edited book is one of the activities of the EATEL Special Interest Group on Wearable Enhanced Learning. With research and development in WELL still in an experimental and exploratory phase and with the landscape of wearable enhanced learning still diffuse and hazy, this edited book aims to bring together the state of the art of this emerging area of interest. With this opening chapter, we aim to ask what are the main *drivers*, *affordances*, and *challenges* of our field.

1.1 Drivers of Wearable Enhanced Learning

The key *drivers* of wearable enhanced learning can be grouped into *socio-technological* and *cognitive-motivational factors*.

Socio-technological drivers include a number of factors ranging from an increase in media use in a society, battery size and life, to human-centred technology design. The increase in the use of personal consumer technologies, especially the high level of penetration of smartphones, has been considered to drive the usage of wearable technologies in general (Nagtegaal et al. 2015). This is also reflected in wearable enhanced learning with most scenarios and prototypes combining smartphones and wearables as a general socio-technological trend. The technological advancements of battery life and size determining the size of wearables have been seen as a further key driver for the adoption of wearables (Nagtegaal et al. 2015), which also influences the readiness for adoption of wearables for learning. Human-centred designs of wearables, especially fashionability and uniqueness, has been considered as a key driver for the mainstream adoption of wearables in the consumer markets (Nagtegaal et al. 2015) and may to some extent influence the acceptance of wearables for learning in particular user groups (e.g. younger learners). The key obstacle to the adoption of wearable technologies in general has been related to privacy concerns (Nagtegaal et al. 2015), with perceived privacy risk considered as a key factor hindering usage of wearable devices (Rheingans et al. 2016). Negative perceptions of wearables in terms of privacy risks may be also an important impediment for a wider-scale usage of wearables for learning as shown by Bower et al. (2015). Further socio-technological and cognitive-motivational obstacles of wearable enhanced learning include technical problems such as network connectivity and development of software for wearable enhanced learning as well as cognitive problems such as distraction through viewing non-subject-related materials and overreliance on wearable technology (Bower et al. 2016).

Cognitive-motivational drivers of wearable technologies have been analysed among others by Ernst (2016) based on multiple research articles studying potential drivers of wearable device usage. The identified key cognitive-motivational drivers include subjective norms such as perceived usefulness, perceived enjoyment, perceived design aesthetics, past product expectation confirmation and social image (Ernst 2016). Based on this research, wearables can be perceived as partly hedonic and partly utilitarian technologies providing both instrumental and self-fulfilling value to the user (Van der Heijden 2004). These and other factors may play a similar role for the adoption of wearables for learning. For example, as mentioned by Ojuroye and Wilde in this book, in the chapter titled “Pedagogical Frameworks and Didactic Considerations. On the Feasibility of Using Electronic Textiles to Support Embodied Learning”, the adoption of specific wearable technologies such as e-textiles may be driven by their inherent familiarity, interaction, and comfort associated with textiles in general. Nevertheless, further empirical research about factors driving and impeding the use of specific wearables for learning, such as e-textiles, smart accessories and head-mounted displays, building on studies such as the one by Bower and Sturman (2015) is still needed.

1.2 Affordances of Wearable Enhanced Learning

The key affordances of wearable enhanced learning may be compared to the affordances of mobile learning. Building on the theory of affordances by Gibson (1979), Norman (1988) described an affordance as a design aspect of an object. According to Norman (1988) the term “affordances” describes properties (especially perceived properties as opposed to real properties) of an object which determine its use. Mobile learning affordances include such properties as *portability*, *data gathering*, *communication*, *interaction* with the interface, and *contextual and active learning* (Parsons et al. 2016). While these affordances also apply to wearable enhanced learning, wearables bear the potential to substantially reorganise the way we learn, removing further restrictions in time and space, capturing data directly from the body of the learner and embedding learning directly in any *real-world context* by using the information from the context to support learning.

Bower and Sturman (2015) analysed the perceptions of 66 educators to determine the key educational affordances of wearable technologies. The key pedagogical affordances of wearable technologies included: the in situ contextual information, recording of information, simulation, communication streams integrated into daily routines, engaging immersive educational experience, first-person view, in situ guidance, hands-free access to contextually relevant knowledge, unobtrusive and contextualised feedback, greater efficiencies in learning and teaching context, enhanced sense of presence, distribution of resources, to be freed up from the requirement to be at a desk, and *gamification* (Bower and Sturman 2015).

Attallah and Ilagure (2018) discuss the affordances of wearable technologies in education and emphasise that the *hands-free* characteristics of wearables is one of the key affordances of wearable computing. Hands-free affordance allows learners to liberate their hands and at the same time to remain connected, to move in an environment which becomes an educational/learning space and to interact with the real environment. Thus, wearable technologies provide hands-free access to information and learning resources and can effectively enhance interactivity, self-directed learning, and engagement with learning (Attallah and Ilagure 2018). Applying wearable technologies in education makes also a big difference in the delivery of instruction compared to traditional learning methods, which require learners to learn at a defined time and location. Potentially, WELL can be used to improve the quality of delivery of instruction (Attallah and Ilagure 2018).

Furthermore, wearable technologies for learning using augmented reality (AR) and virtual reality (VR) enable learning experiences that would otherwise be difficult, impossible or even risky in real life, e.g. medical, chemical, engineering, or aviation VR (Attallah and Ilagure 2018). The use of VR wearables for learning is characterised by a number of further affordances, such as *immersive and embodied affordances*, characterised by immersive experiences, engaged and interactive participation, and embodied learning experience embedded or immersed in a virtual reality environment (Shin 2017). For example, Cordeil et al. (2017) explored embodied affordances of AR in context of the construction of rich, immersive data visuals for exploring multivariate datasets. Immersive affordances are related to the extent to which a technology is capable of delivering an illusion of reality (Cordeil et al. 2017). Embodied affordances are related to the capability of a technology to enable the user to see through the eyes of a virtual body and the virtual body to react based on user actions (Cordeil et al. 2017). The notion of embodied affordances may be also extended to relate to the objects in an environment and the capability of a technology to allow the user to act upon a represented entity, e.g. artefacts in a AR/VR environment can be picked up, examined, manipulated, and/or rearranged by the user (Cordeil et al. 2017).

Augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies also have *collaborative* affordances as they allow learners to see and interact with virtual artefacts regardless of the location of learners (Rehring et al. 2018). Dunleavy, Dede, and Mitchell (2009) have reported on collaborative problem-solving affordances of AR simulations as well as further affordances of AR such as technology-mediated narrative, interactive and situated affordances, and their highly engaging effects on learners. Collaborative learning supported by VR/MR wearables have been reported to positively influence decision-making (Rehring et al. 2018). Additionally, MR and VR wearables for learning enable immersive data visualisation, which facilitates interaction of learners with virtual objects as well as faster and deeper knowledge construction (Rehring et al. 2018).

Finally, wearables are also characterised by *augmentation affordance,* i.e. sensory properties related to seeing, hearing, feeling, etc. capable of determining the use of wearable as a supplement or substitute for reality. The augmentation itself can be used to provide an experience embedded in the real environmental context surrounding the observer. When during the active reconstruction of reality from perception both augmentation and real world become indistinguishable, one might conclude that wearables can afford to use *reality as a medium,*[2] creating a subjective reality, which can be perceived as "true" by the user. Scientists have been attempting to achieve such unity between reality and representation for millenia. The quality of augmentation achieved with current technologies can very closely resemble reality. The "correspondence theory" (David 2015) postulates that truth is a relational property of reality. Consequently, best quality augmentation can be expected to advance foraging for information, support decision-making with analytics, help generate feedback automatically, facilitate creating personalised learning environments, and support a wider variety of further information systems applications. The augmentation affordances of wearable technologies thus have a potential to help bridge a societal divide by allowing many to share the experience previously limited to a few. Especially, wearable augmented, virtual and mixed reality media (AR, VR, MR) allow to combine compositional elements to cultural layers augmented with reality, which according to Manovich (2001) can be perceived as cultural interfaces reflecting both conventions of cultural forms and the conventions of HCI. With augmented human-computer interfaces becoming a semiotic code of the information society, wearable AR/VR/MR allow users to create subjective experiences of reality, creating a new hybrid language of cultural interfaces (Manovich 2001).

1.3 Challenges of Wearable Enhanced Learning

The key *challenges* of wearable enhanced learning are closely related to the challenges of wearable technologies in general. The challenges described below encompass both technological challenges of wearable computing and the resulting pedagogical challenges of wearable enhanced learning.

The first significant challenge related to wearable technologies and hence affecting the field of wearable enhanced learning is *fragmentation*. Fragmentation in computer sciences usually refers to memory fragmentation, meaning that parts of the memory that belong together logically are stored physically in separate parts of

[2] https://www.youtube.com/watch?v=oATPdmuFAPQ

the main or secondary memory of a computer.[3] In the field of wearable enhanced learning, fragmentation means that research and development that belongs together is carried out in isolation; that products and markets are scattered, even despite market opportunities; and that stakeholders are not exploiting the full potential of wearable enhanced learning. The result is a dispersed R&D landscape, making it hard even for experts to identify major trends, potentials, and roadmaps. A book like this is surely a step in the right direction, helping to overcome the current fragmented landscape of WELL. Further necessary steps include standardisation, lighthouse projects, best practices, and roadmapping, as well as adequate support for practitioners including interdisciplinary teacher training. In view of fragmentation, authors emphasise the need for more inclusive user studies, especially related to adoption based on privacy concerns and effectiveness of wearable enhanced learning (Ezenwoke and Ezenwoke 2016) as well as a better validation of long- and short-term effects of using wearable technologies on learning outcomes (Kutafina et al. in this volume). A more cohesive and less fragmented approach to research and development in wearable enhanced learning is important for the advancement in pedagogies applied in WELL.

The second challenge is *scalability*. Since a lot of research and development takes place in isolation, many studies in WELL are not designed for scaling-up, sometimes not even for replication. Due to the limitations of the resources, most research studies in WELL are inherently of exploratory nature, experimental, and with limited results. An example of an experimental scenario on a smaller scale is the application of WELL described by Rajko in the chapter in this volume titled "Embodied Learning: Somatically Informed Instructional Design". Scaling-up requires more extensive resources. Large-scale projects, industry collaboration, and cooperation among different stakeholder groups are necessary to establish a sound body of work on the effects of WELL on learning outcomes which could provide significant implications for the development of curricula, pedagogical models of teaching and learning, assessment of learning, as well as organisation at organisational and system levels. Processes and partnerships for scaling-up promising concepts, approaches, and scenarios in WELL have to be yet established. Many projects underestimate the effects of hidden agendas, not-invented-here syndromes, and passive resistance to wearable technologies in education. Some of the challenges to scalability are related to organisational issues, as outlined by Mårell-Olsson, Mejtoft and Kinert in the chapter in this volume titled "Virtual Reality as an Environment for Learning: Facilitating a Controlled Environment for Pupils with Diagnosed Concentration Disorders" and related to the availability of the WELL technology at the place of learning (e.g. at school) with issues arising around responsibility and maintenance of the WELL hardware and software. Given the incapability of educational organisations to absorb new solutions and project management issues related to sustainability, even large budgets can be wasted easily. The deep socio-technological nature of large-scale implementation of WELL at

[3]https://en.wikipedia.org/wiki/Fragmentation_(computing)

the level of educational organisations (e.g. schools, universities) and in educational systems (e.g. primary, secondary, tertiary education) needs to be considered. Social requirements engineering, open and voluntary participation, participatory design, co-design, agile methods of development and management, intensive field testing, monitoring, feedback tools and many more measures are available and have to be integrated in WELL as assets, as proposed by Limbu et al. in the chapter in this volume titled "A Conceptual Framework for Supporting Expertise Development with Augmented Reality and Wearable Sensors". Pedagogical and instructional design patterns of using wearable technologies to support teaching and learning need to be comprehensively investigated and documented.

The third challenge is *data aggregation*. Wearable devices generate large quantities of data about users on different levels, with different speed, in different formats with different size and frequency. This data is often synchronised and/or sent to further devices such as smartphones or tablets for further analysis. Wearables like mobile devices can also augment the learning experience, allowing learners to access data from the Internet (Freitas and Levene 2003). These different modes of data aggregation have implications on how educational resources are developed and how educational scenarios are designed, e.g. supporting conversational learning and seamless learning, facilitating collaboration, and providing an interface between the learner and the user datasets (Freitas and Levene 2003). Aggregation and integration of data in the fabric of everyday life, as described by Ojuroye and Wilde in the chapter in this volume titled "Pedagogical Frameworks and Didactic Considerations. On the Feasibility of Using Electronic Textiles to Support Embodied", provides unique opportunities for teaching and learning in an active, experiential and tangible way, allowing to capture behavioural, biological and real-time knowledge in a dynamic environment. While educators and students can obtain valuable data through the use of wearable devices for learning such as level of engagement and cognitive focus, data aggregation also poses a number of challenges with respect to legal issues (e.g. recording informal interactions, spontaneous capture in real-time) and data privacy and security (e.g. publication and exposure of sensitive information). The five capital Vs of Big Data, i.e. velocity, volume, variety, veracity, and value, can be also applied to wearable enhanced learning, as the data aggregation challenges are very similar to those in the Big Data field. Wearable data fusion is one of solution patterns to the data aggregation challenge. The increasing "quantification" and "datafication" with newer development such as data lakes and data fusion additionally enhanced by the use of mobile and wearable devices may pose a significant challenge on wearable enhanced learning. Learning analytics, educational data mining, and academic analytics focus on using data in educational settings, e.g. discovering and visualising data, examining patterns, and supporting decision making (Avella et al. 2016). While these methods bring a number of benefits for education such as helping to understand learning experience, revealing learning behaviours, determining learning outcomes, providing real-time feedback and personalising learning, adjusting educational practices and helping to identify areas for improvement, they also pose a number of challenges. Key questions asked in WELL include the following: How to turn captured data into empirical evidence of learning? How to preserve meaningful data aggregates? How to share situation-based, contextual data packages in the network to enhance the personalisation of the learning experience? Some of the key challenges related to data aggregation and the use of analytics methods are related to resolving privacy, legal, and ethical issues in monitoring, tracking, data collection, and data ownership. Moreover, challenges remain in leveraging learning analytics optimally, especially those related to difficulties in evaluation and interpretation of the data (Avella et al. 2016). An example described by Moissa, Bonnin and Boyer in the chapter in this volume titled “Exploiting Wearable Technologies to Measure and Predict Students’ Effort”, focuses on the challenge of accurate measures of data to predict student effort and shows how predictions of effort can be inferred from the available data about to support teachers in identifying learners struggling or not engaging with learning. The authors list some of the key challenges in the area including the assessment of reliability and accuracy of data gathered through different devices/sensors and the need to develop policies to address safety, privacy and ethical issues.

As described above, the challenges in wearable enhanced learning related to fragmentation, scalability, and data aggregation affect pedagogies for teaching and learning on a number of levels including conceptualising wearable technologies as pedagogical tools; taking decisions about appropriate instructional design methods; designing learning experiences; supporting knowledge, expertise, and competency development; gathering and using data to support learning; and measuring learning outcomes. These and further pedagogical challenges are addressed by the chapters in this volume, which cover a broad range of concepts and application contexts in wearable enhanced learning.

2 Evolution of Technology Enhanced Learning

While certainly historic roots and other precursors of Technology Enhanced learning (TEL) could be identified way before the introduction of computers or the Internet, the historic discourse described in this section starts with the digitisation and sharing movement made possible by the widespread availability of personal computers in teaching and improved connectivity over email and other file transfer means. This triggered a wave of *TEL 1.0* aiming at *digitisation* of learning and teaching materials, enhancing point-to-point and peer-to-peer sharing between individuals or small groups (cf. Fig. 1).

The second phase or the second wave of TEL characterised by mass delivery can be called *TEL 2.0* with *scaling* as the main objective and design principle (cf. Fig. 1). The human tendency for rationalisation and scaling postulates the invention of learning management systems (LMS), which until today form the dominant technology to support the management of learning in learning organisations. Learning management systems will play an important role also in the future because of the reliability of the software, large user and developer communities, the availability of commercial as well as open source providers, the huge number of available training materials, the know-how and support of university staff and the reasonable value proposition. Before the LMS, (digital) teaching/learning resources used to be shared among learners in many ways in different media. One idea was to share learning objects in learning repositories in which instructors could upload annotated learning materials for further usage. However, sharing of teaching/learning resources was limited by many factors like language versions, difficulty level, pedagogical underpinnings, copyright issues, quality issues and many more. To address these challenges, a first wave of learning object standards for the description of learning object metadata, e.g. IEEE learning object metadata (LOM), emerged together with a growing interest in the modelling of formal learning processes. This has been reflected by IMS learning design (LD), a specification for a metalanguage which enables the modelling of learning processes. Learning management systems picked up on those ideas and delivered institutional systems for the coverage of formal learning processes together with quality assurance, legal binding and copyright management in the form of complex content management systems centred around the "course" as the cornerstone of technology enhanced learning design. The main goal of LMS development in the recent years has been to improve management of teaching/learning resources and communication between instructors and learners in the context of traditional face-to-face courses. LMS have also supported distant and online learning including intelligent tutoring systems which have been deployed to support learners in distant and online courses, especially in self-learning scenarios in which teachers/instructors are absent. The integration of LMS with other organisational information systems in higher education and in commercial contexts created synergies which go beyond the single systems and mass delivery of learning courses. In consequence, both commercial and open source implementations of LMS have become very successful and popular. Moodle has become the most prominent open source LMS with currently 100,233 registered sites from 229 countries and altogether 15,758,601 Moodle courses (cf. Moodle statistics, September 2018).[4]

The next phase, *TEL 3.0*, can be characterised by *adaptation*. With respect to devices, *ubiquitous, pervasive*, and *mobile learning* enters into this phase of mass personalisation (cf. Fig. 1). Mobile learning has emerged in the field of technology-enhanced learning together with the rise of mobile devices such as smartphones and tablets. Consequently, mobile (M) learning system (MLS) have been developed to complement or enhance traditional learning management systems (Rizwan and Qureshi 2013) as well as mobile learning metadata (MLM), e.g. based on the existing IEEE learning object metadata and IMS learner information profile (Chan et al. 2004). Mobile learning as a pedagogical concept has developed from the focus on the attributes of mobile technologies to more sophisticated conceptualisations which emphasise not only spatial but also temporal and contextual mobility as well as contextualised access to learning resources and learning networks (Kukulska-

[4] https://moodle.net/stats/

Hulme 2010). The availability of mobile technologies has brought about profound changes in educational concepts and practices with learners now moving about within a classroom or outside the classroom and learning becoming dispersed across formal and informal settings over time (Kukulska-Hulme 2010). Together with the advent of Web 2.0, social media and mobile devices becoming personal learning devices, the third phase of technology enhanced learning has also brought about *personal learning environments (PLE)*, which have long been proposed as an alternative to LMS because of their shift of focus from the course or teacher-centric view to the learner-centric view (Buchem et al. 2013). The designs of personal learning environments have centred learning tools, processes, and resources around the individual learner. PLE designs have aimed to support transitions of learners between learning institutions and lifelong learning as well as self-directed learning. Moreover, mash-up PLEs with user interface (UI) integration and data aggregation have emerged to cater for learner interactions with a wider variety of online tools as part of learning activities (Wild et al. 2008). Despite the huge efforts in research and development, PLEs have never made it from research prototypes to mature, scalable products in the mainstream TEL, like LMS did. Lack of business models, sustainability and scalability strategies and support from learning organisations impeded the progress from prototypes to products. Only a few technological platforms are still under development like the ROLE SDK. Additionally, PLEs were suppressed by the wave of Massive Open Online Courses (MOOCs), a web version of video-based learning with the notable exception of connectivist MOOCs (cMOOCs), which have been delivered on a smaller scale from engaged pedagogical experts, but unfortunately, like PLEs, with limited sustainability and less support from developer communities. Recently, distributed ledger technologies like blockchains, digital credential metadata standards like Open Badges as well as the trend for open educational resources (OER) have been again reinforcing interest in personal learning environments and personalised design of TEL in general. The advent of PLEs and MOOCs has also created a heightened interest in *learning analytics*. The Horizon Report 2013 denotes that "Learning analytics, in many ways, is 'big data', applied to education" (Johnson et al. 2013). Consequently, research has focused on the deployment of institutional LMS, PLE or MOOC with integrated learning analytics. Learning analytics can be performed on the individual (micro)level to predict and steer the learning progress of learners; on the (meso-)level of cohorts, classes, communities, and institutions, to predict the success of groups of learners; and on the regional, national, or international (macro)level to predict the success of institutional systems and processes (Buckingham 2012). *Community learning analytics* is an example for learning analytics on the meso-level that can be also related to wearable technologies (Koren and Klamma 2017). The focus on the development of evidence-based feedback and interventions raised a lot of interests both on the side of researchers and on the side of practitioners as well as policy makers. However, more research is needed to show how learning analytics can replace more established methods known from psychology of learning and based on deep insights in human memory and performance. Learning analytics can be applied to diverse sources of information. Data sources can be, for example, learning traces

	TEL 1.0	TEL 2.0	TEL 3.0	TEL 4.0
innovation:	DIGITISATION	SCALING	ADAPTATION	DISINTERMEDIATION
technology:	email, file transfer	web	web, apps, ebooks	AR, VR, MR
standards:	MIME, FTP, HTTP	SCORM, LOM, DC	LD, WIDGETS, CC/LTI	ARLEM, XAPI
devices:	terminal, pool PC	PC, laptop	mobile, tablet	glasses, wristband, e-textile
systems:	mail/ftp client, browser	LMS	PLE, LA, apps	embedded systems, 360, holograms

Fig. 1 Evolution of technology enhanced learning (TEL) towards WELL

stored in the learning systems but also any kind of learning materials produced by learners, e.g. texts, videos, pictures, drawings, and chat protocols. Moreover, collection, storage and processing of sensitive data about the learning process have created many concerns about privacy and data security. Educational institutions bear both legal and ethical responsibility if learning analytics discloses sensitive information about individual learners.

Finally, TEL has arrived at the verge of a new wave of *TEL 4.0,* which can be characterised as a phase of *disintermediation* (cf. Fig. 1). In this phase new technologies and approaches to technology enhanced learning emerge and encompass augmented, virtual, and mixed reality (AR, VR and MR) sensors and wearable computing which can be augmented into wearable enhanced learning (WELL)**.** WELL has been building on the experiences of mobile learning technologies, immersive learning environments and workplace learning. One of the major goals of WELL is the comprehensive recording of human activity on cognitive, bodily and affective levels. In consequence, diverse sensors can be used to capture data and gain insights into the learner activities. This allows for disintermediation, generating and consuming multiple representations in multiple contexts for a single learning experience, generating unprecedented grounding in sensory cues and multiple levels of multi-angulation of experience. Naturally, multimodal learning analytics has been of interest in WELL. Multimodal learning analytics combines different sensors as sources of data, merges the data sources in a fusion framework and processes data with the goal of human activity recognition. Human activities are the basic entity for further recognition of more complex processes, tasks and work situations. However, WELL is not limited to the recording of human activity. The potential value creation is vaster, with network effects emerging by connecting humans with devices in ecosystems. The speed of innovation, breadth and depth of the transformational processes have been already imposing new challenges, such as gaps between those who can adapt to the new possibilities and those who cannot. *Performance augmentation* is the other emerging developments in this phase, a new form of professional technology enhanced learning which has been most notably applied to workplace learning. Performance augmentation is the solution to up- and reskilling challenges that emerge with the widespread introduction of automation and advanced machinery in business and industry, a development colloquially named as "the rise of the robots". Performance augmentation deploys wearable technologies including augmented reality (AR) to deliver education and training in situ and to scaffold learning to support skill development to a master level of performance. Performance augmentation seeks to "close the dissociative gap between abstract knowledge and its practical application, researching radically new forms of linking directly from knowing something 'in principle' to applying that knowledge 'in practice' and speeding its refinement and integration into polished performance".[5] Consequently, this research trend includes developing novel methodologies and technologies for engagement, awareness, and collaboration.

Given the rise of wearable technologies and wearable enhanced learning (WELL) in the current phase of technology enhanced learning (TEL 4.0), some of the key wearable technologies for learning allowing for capturing, storing, processing, analysing, and visualising cognitive, biological, and affective data can be grouped as follows (cf. Fig. 2):

- *E-textiles*. E-textiles include smart fabrics and are in direct contact with the skin of the user/learner. E-textiles can track, for example, the heart rate, the breathing (respiration rate), and walking patterns (activity and posture) both in health monitoring and sports. Hajo and Galinsky (2012) explore the effects of wearing clothes and propose the concept of "enclothed cognition" which may be relevant for using e-textiles for learning. Electronics can be embedded into the garments or the textile substrates of e-textiles, while many prototypes are using both ways (Windmiller and Wang 2013). Electronics are integrated later in finished garments, while smart materials are created in the production process of garments (Stoppa and Chiolerio 2014). Fibretronics uses conductive and semi-conductive textiles to create organic fibre transistors or organic solar cells (Gilliland et al. 2010). Hexoskin[6] is a smart garment including monitoring devices for ECG and heartbeat, heart rate variability (HRV), QRS events, breathing rate (RPM), and minute ventilation. Additionally, it has an open data API allowing users to download raw data and use own analytics software for health monitoring. LilyPad and other Arduino platforms serve the integration of product development of WELL – maker style – into classrooms. Innovation in material science will surely yield further breakthroughs in the field of e-textiles (e.g. fabric-printable batteries, piezo elements for recharging using movement, conductive fabrics, circuit embroidery) in the future. The term "enclothed cognition" is introduced here to describe the systematic influence that clothes have on the wearer's/learner's psychological processes.
- *Smart accessories* (also smart watches, fitness trackers and other accessories) are designed for combining aesthetics, style and functionality. They are worn

[5]Mission statement of the Performance Augmentation Lab, https://pal.cct.brookes.ac.uk/about/
[6]http://www.hexoskin.com/

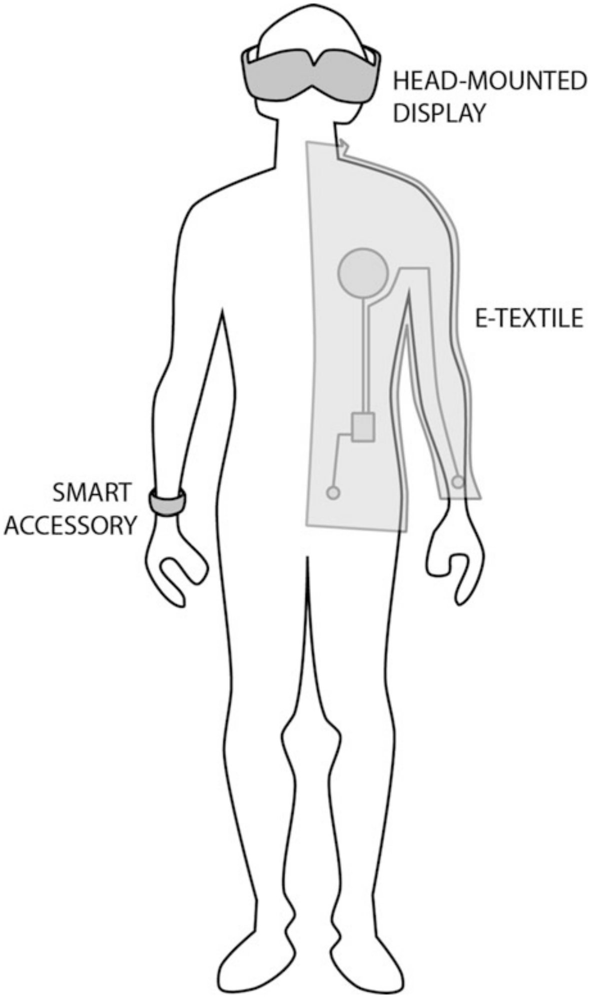

Fig. 2 Key wearable technologies in wearable enhanced learning (WELL)

as clothes and accessories (watches, wristband, and rings). Smartwatches and activity trackers are wearable computers with touchscreens to monitor and track fitness metrics. Also earbuds and headphones can be utilised for measuring body data. The overall power of these devices is in their connection with other devices, social networks, and analytic apps. Smart accessories have been applied in wearable enhanced learning in a number of ways. For example, Buchem et al. (2015) describe the use of fitness trackers as part of a MOOC to support senior learners in learning how to age healthy. Ilhan and Fietkiewicz in the chapter in this volume titled “Learning for a Healthier Lifestyle through Gamification: A Case Study of Fitness Tracker Applications” present the results of a study on fitness trackers with implications for user engagement designs supporting long-term learning and learner engagement. Beyond fitness trackers and smartwatches,

new smart accessories have been developed in the recent years. Iris van Herpen's water dress[7] printed from a 3D model in a 3D printer from 2011 is an example of new emerging concepts, even if it has no sensors or computational devices attached. Project Jacquard,[8] announced in 2015 by Google, is a jacket tailored for urban cyclists with several functionalities to use mobile phones while moving and mobile apps monitoring and supporting navigation. Further examples include wearable devices such as Kinemata for training movements for learning, or Feeler for promoting reflection about learning and well-being (Pejoska 2016).
- *Head-mounted displays (HMD)* and augmented helmets can be used in combination with smart fabrics and accessories. Earbuds and headphones could be seen as a category falling between the two categories. Wearable glasses, virtual reality glasses, augmented reality (smart glasses), bionic contact lenses, or helmet-mounted displays are examples of HMD. Modern HMD are equipped with LCD or OLED monitors for stereoscopic fields of view, some even with virtual retinal displays. With a head tracker the image can be adapted to the momentary gaze. Delays in the tracking of the resolution of the image can lead to simulator sickness and degrade the presence or grade of immersion. Most augmented reality applications work with optical, magnetic or acoustic trackers to relate objects in the environment with the augmented display. Trackerless applications are under development.

The above list is not exhaustive and is likely to be complemented by the yet unknown or just emerging technologies, e.g. intelligent plasters with integrated sensors, smart contact lenses, bioimplants, or blue-sky technologies such as smart dust, neural dust, or utility fog (Warneke et al. 2001; Kiourti et al. 2016; Neely et al. 2018). These include tiny robots or microprocessor swarms that wirelessly operate on computer networks and perform tasks, such as sensing through radio-frequency identification. In general, it can be concluded that the emerging technologies for learning will continue to include various sensors which will be integrated into the environment (environmental sensors) and onto/into the body of the learner (body-worn sensors). The applications of wearable, implantable, and ambient sensors to support wearable enhanced learning (WELL) will most probably focus on workplace learning, monitoring of learning and performance, as well as learning in the context of health and well-being. Future work is required to advance the field towards robust research results and scalable deployment. To achieve this, stakeholders in wearable enhanced learning will have to partner and cooperate in a less fragmented and more sustainable way.

[7]https://i.materialise.com/blog/en/time-magazine-names-iris-van-herpens-3d-printed-dress-one-of-the-50-best-inventions-of-the-2011/

[8]https://atap.google.com/jacquard/

3 Stakeholders in Wearable Enhanced Learning

The large number of different stakeholders in the field of wearable enhanced learning (WELL) has created a diffused landscape of the field. Early drivers in the field were coming from health, entertainment, sports and business. Many of these areas are only loosely related to learning in general and WELL in particular. But, traditional formal education institutions are quite late in the process of adopting wearable technologies in their curricula. In the meantime, the general trend towards digitalisation has begun to transform whole industries and businesses with the key stakeholders in the field of wearable enhanced learning (WELL) being enterprises and start-ups, vocational training providers, higher education, and maker communities (cf. Fig. 3).

The industry sector, start-ups, enterprises, and other businesses are the biggest driver of innovation in wearable enhanced learning at the moment. Hunn (2015) identified some of the key market segments for wearable technologies. These include sports, fitness, hearables, personal medical, assisted living, kids, pets and fashion. The coverage of the wearable technology ecosystem by Hayward (2018) looks into applications of wearable technologies in the various industry sectors, e.g. healthcare, fitness, sports, infotainment, enterprise, military, and fashion, and discusses the current trend which is an increasing cross-industry collaboration and product development. The pressing need for productivity gain and the lack of trained workers at the same time have led to a huge number of research and development projects in search for wearable enhanced learning at the workplace in all lines of production, logistics, assembly, and related fields. A number of studies have shed light on different aspects of wearable technologies in industrial contexts. For

Fig. 3 Key stakeholder groups in wearable enhanced learning (WELL)

example, Awolusi, Marks, and Hallowell (2018) explored the adoption of wearable technology within the construction industry in context of personalised construction safety monitoring and concluded the potential of wearable technologies for a data collection and provision of real-time information to construction personnel. This review indicates that wearable technologies can be applied in a number of industrial sectors to monitor and measure a wide variety of metrics including multi-parameter monitoring of safety performance. Ras et al. (2017) address an emergent topic of human-robot interactions in context of industry 4.0 and the current push for automation in smart factories and cyber-physical systems (CPS). The authors describe the use of performance augmentation tools such as wearable AR in context of the increasing complexity of tasks and the need for continuous knowledge and skills development of shop floor workers, especially related to increased requirements in higher-order thinking and decision-making skills. Ras et al. (2017) provide a vision on how wearable AR can support handling complexity in a cyber-physical system, which includes intelligent assistance systems for learning and performance assessment at the workplace. Maurata (2009) addresses the application of wearable technologies for learning at the workplace aimed at improving the conditions in which workers perform their activities. The wearable enhanced learning scenarios mentioned by Maurata (2009) include workers carrying out maintenance tasks in the aeronautical sector, firefighters in emergency situations, workers in hospitals and workers working on the assembly line in the automotive industry. The chapter in this volume titled "Multiteam Systems and Wearable Devices for Learning" by Bannan addresses the use of wearable enhanced learning in the medical sector and describes a scenario of a multi-team system of fire and rescue, emergency medical services, and hospital trauma teams involved in high-fidelity, live simulation training scenarios leveraging wearable proximity sensors and digital bands.

Vocational training is becoming the next key stakeholder in the WELL landscape. For example, Kreft et al. (2009) described the approach to wearable computing in the automotive assembly training and a concept for a wearable AR to facilitate the trainee's understanding of complex assembly tasks. Kreft et al. (2009) describe the potentials of automatic and context-sensitive gathering and presenting of relevant information to the trainee in combination with augmented reality (AR) to facilitate the understanding of complex tasks. Furthermore, dual education systems combining apprenticeships in a company and vocational education at a vocational school like the one in Germany could be a way to introduce new technologies in traditional apprenticeship-based work qualification processes. The motivation here is quite clear. Even without the presence of the expert, the apprenticeship should be able to perform self-regulated and/or self-directed learning with the support of wearable technologies. A typical example here is the development of spatial sense in carpenting (Limbu et al. 2018). A carpenter apprentice uses augmented reality head-mounted devices supporting three-dimensional previews of, for example, furniture in the moment of creation. A wearable technology enhanced learning environment is more flexible, e.g. when the apprentice could not take part in the training because of illness. It can create a safer but more realistic learning environment. The chapter in this volume titled "Conceptual Framework for Supporting Expertise Development with Augmented Reality" by Limbu et al. also addresses the shortage of experts in supporting expertise development in apprentice context and proposes to use wearable sensors and augmented reality to record expert performance for supporting the training of apprentices. The proposed instructional design methods exploit the affordances of wearable sensors and augmented reality. Physical operations can be experienced in an experimental setting without the danger of being harmed. The challenge is however to support such processes in a pedagogical meaningful way to fully develop the needed competences on the side of the apprentice and to fully exploit the possibilities of the technology. The four component instructional design model (4C/ID-Framework) by Van Merriënboer, Clark and De Croock (2002) is one possible answer to this challenge. This framework including a training workflow based on the 4C/ID model is also addressed in the chapter "Conceptual Framework for Supporting Expertise Development with Augmented Reality" by Limbu et al. in this volume.

Higher education institutions have had an emerging interest in assessing student data from sensors, but they also have a broad interpretation of sensors. Next to body-worn or fabric sensors, higher education has been also interested in social sensors from Web 2.0 platforms like Facebook and WhatsApp or LMS sensors. In many educational scenarios outside traditional classrooms in medicine, engineering, architecture, and so on, sensors are already used in pilot studies and emergent teaching and learning concepts. Problems are the lack of availability of sensors and devices on a sufficient scale as well as the lack of training of higher education instructors for meaningful pedagogical use of the new technologies. The number of studies and pilot projects in higher education are limited because the necessary devices are expensive to be purchased in sufficient numbers for meaningful evidence-based research. Academic versions of smart glasses such as Hololens are costly and many higher education organisations can purchase only a few pieces of such hardware, usually for experimental or project-related applications. Different labs at a university can potentially pool resources together, but even if equipped with hardware, a lot of training, technical skills, and experience is needed for maintaining, utilising, and programming wearable devices. When different wearable devices are needed to be utilised, the amount of necessary training may get overwhelming. When devices and training are in place, the organisational implementation of wearable enhanced learning is an additional challenge. The chapter in this volume titled "Smart Glasses as Assistive Tools for Undergraduate and Introductory STEM Laboratory Courses" by Strzys et al. also addresses the high costs of using wearable AR technologies like smart glasses in higher education, including STEM laboratory classes.

This chapter describes a wearable enhanced learning scenario during laboratory courses in university science, technology, engineering and mathematics (STEM) education. The wearable AR scenario with smart glasses focuses on a real-time supporting system for university students in STEM laboratory courses, which ranges from detailed instruction, interactive tutorials, to safety guidelines and real-time representations of measurement data. Such research and development may contribute to the uptake of wearable enhanced learning in higher education. Wearable computing also seems to increase the current issues in technology enhanced learning in higher education, in particular issues related to privacy and data security. Applying wearable technologies for learning in higher education can turn any implementation process into a serious legal and ethical challenge. There are however inspiring examples of using wearable technologies for learning in higher education. For example, the chapter in this volume titled "Embodied Learning: Somatically Informed Instructional Design Entering" by Rajko provides an insight into how wearable rapid prototyping and custom software can be integrated into higher education curriculum. The model focuses on a set of handmade wearable prototyping bands designed to allow students to engage in physical and experiential learning. Students design own wearable technologies based on personal explorations. Through prototyping and exploration of wearable enhanced learning students both learn about wearable technologies and enhance own awareness of embodied learning experience.

Prototyping and building exploratory prototypes has also become popular in *maker communities* which have become highly visible in creating new combinations of hardware and software for diverse pedagogical scenarios. As a grassroots movement, maker communities have fewer links to traditional higher and secondary education and position themselves in niches. The amount and diversity of approaches in maker communities around the world makes it difficult even for researchers to keep an overview of the current developments. Maker communities are a blend from the tradition of DIY communities of hobby creators and users, e.g. in building remote-controlled aircraft or boat models with real flight or swim capabilities and from the tradition of hacker communities. 3D printers, laser cutters, 3D modelling software, and programmable microcontrollers among others extended the possibilities, but due to the high price of the necessary maker hardware, the fab lab movement concentrated on the purchase of resources and opened the labs for the makers. Moreover, makers organised themselves in communities and met in fab labs or in other maker spaces and maker fairs to interact and exchange knowledge. Maker communities are highly innovative on the one hand, but because of their often anti-establishment attitude they do not focus on marketable products in the consequence. Even if a product would have a larger market, the maker communities would not be able to produce them in scalable numbers. Here, digital fabrication with a high amount of automation indeed would be an alternative for makers. Because of their deep rooting in social movements, maker communities promote learning about wearables. Many projects are based also on the Arduino platform. The Arduino board consists of a microcontroller with usable I/O pins as well as USB interfaces that can be used for power supply or as a serial device emulation. Arduino comes with an integrated development environment (IDE) written in Java. Many other similar Arduino boards are available, but also different physical computing sets like the Raspberry Pi or the BBC micro:bit. The micro:bit system has been rolled out for one million pupils aged 11–12 in the United Kingdom free of charge. This is also an example for an initiative for wearable computing education in schools on the national level. Maker communities are in principle promoting both open hardware and open source software. Because of their credibility, maker communities often interact with artists and start-ups. However, there seems to be a natural tension between maker communities and start-ups, especially in regard to business opportunities based on patentable innovations and closed knowledge.

4 Perspectives on Wearable Technologies

While computing was defined by the needs of desktop and laptop devices for many years, today digital technologies become increasingly defined by smartphones, wearables and smart devices connected to or even embedded in objects and human bodies (Waldrop 2016). Since the seminal paper by Weiser (1991) about ubiquitous computing and technologies that disappear into the background, the technological development has speeded up driven by the availability of mobile bandwidth in several iterations (GSM, 3G, 4G, 5G) and the availability of affordable mobile and wearable devices. With wearable technologies becoming cheaper, smaller, more efficient and more specialised (each suited to a particular task), wearable devices also become seamlessly integrated into the world and interconnected in ubiquitous networks (Internet of Things, IoT) as already noticed by Weiser in 1991. With billions of small, smart and networked devices, connectivity and security are becoming the key to sustain and enhance the wearables revolution (Weiser 1991).

The *increasing speed of technological development* has also become an analysis in itself with some authors forecasting a *technical singularity* where the control over the development process gets out of human hands (Vinge 1993; Kurzweil 1999). According to the idea of technical singularity, technological advances may result in computers achieving or even exceeding the computational capacity of the human brain. In consequence humans may engage in relationships with automated personalities which will take on different roles such as teachers and partners (Kurzweil 1999). Vinge (1993) lists a number of developments which may enhance the singularity such as development of artificial intelligence, computer hardware, computer networks, intimate computer-human interfaces, and biological science.

However, these views have been also described as *cybernetic totalism* and some authors have voiced their concerns in propagating technological singularity as a perspective for human development. One of them is Jaron Lanier, who criticises the stream of publications and dogmatic beliefs leading to the propagation of such ideas as technical singularity (Lanier 2000). While cybernetic totalists dwell upon a future fantasy, currently and in reality disproportionate economic power accumulates around companies who own access to best technologies and most information (Lanier 2010).

Android for example, the mobile operating system belonging to Google that is partly open source and royalty free, has been the technology with the quickest adoption on a global scale ever (Annapurna et al. 2016). Accordingly, Android is installed on the majority of smartphones, ranging from low-price phones up to high-end smartphones. Google has been also criticised in view of its monopoly power and network effects due to online business models such as sponsored search (Clemons and Madhani 2010). Some less developed countries do not invest in landlines for communication any more but in mobile infrastructures. Most current users of Internet and web services consume them from a mobile device. However, we are in the middle of a turbulent development process. More and more devices are equipped with communication means based on different communication protocols like Bluetooth, NFC, and TCP/IP. The Internet of Things (IoT) is a vision of connected smart devices on different levels. The IOT is having a major impact on consumer product and industrial processes but also on learning and education (Aldowah et al. 2017; Elyamany and Alkhairi 2015). Also, it led to a big *fragmentation* mainly caused by the fierce competition in the field. Many wearable devices have nothing in common with our traditional understanding of computing devices, they start to vanish, in our fabrics, in other devices like watches, bionic contact lenses and wrists, or even in our body as implants (Lingley et al. 2011).

We see major areas where wearable technologies have changed their domains significantly including *entertainment* and *games*, *health* and *sports*, and *business* and *industry*. Below we highlight some of the trends and show the implications for wearable enhanced learning.

4.1 Wearables in Entertainment and Games

In *entertainment* the major use of wearables are mobile games. Pokémon Go is an example of an augmented reality game that was a huge success worldwide. Pokémon Go is a smartphone game available on iOS and Android. The game allows mobile phone users to catch virtual creatures from the well-known Japanese anime series. Catching is realised by manipulating a virtual ball on the multitouch screen of the phone. With different balls and additional fruits the success of the catch can be improved as well as through gained experience. One of the new features of the game is that the game elements can be displayed in the camera view of the device, resulting in the impression that the user interacts with the environment. This is not really true, since the game also works when the "augmented" camera view is disabled. Augmented reality games, like Pokémon Go, have had impact on the physical constitution of mobile phone users, since they motivate gamers to walk around and catch pokémons in different places. Augmented reality games have gained much attention in the mainstream media and created awareness for upcoming virtual and augmented reality devices like the Oculus Rift and the Microsoft HoloLens. On the negative side, there are virtual reality devices which are mostly connected to computer games, at least recently, and professional use cases have been pushed back in public awareness. The bridge from gaming towards learning can be expressed in three relevant areas in technology enhanced learning: game-based learning (game plays with defined learning outcomes), serious games (games with a purpose) and gamification (use of game elements in non-gaming situations) of learning (Foreman 2004; Abt 1970; de Freitas and Liarokapis 2011; Kapp 2012). However, all these areas have not been widely researched in respect of wearable technologies for learning yet, and only few approaches exist (Colpani and Homem 2015; Hensen et al. 2018).

4.2 Wearables in Health and Sports

Health is a natural application domain for wearable devices, since many of them can track physical activities but also measure body signals like the heartbeat/pulse, the skin temperature, the skin resistances, brain signals and many more. In particular, rehabilitation measures can be effectively supported by wearable devices. Stroke patients need a lot of support in rehabilitation by physiotherapists. In times of lacking labour forces, wearable devices can also give patients feedback on their physical activities and smart tools suggests changes in the training programmes based on the analysis of different wearable devices. But not only in rehabilitation do wearable technologies play a major role but also in prevention of diseases through health promotion. For example, fitness trackers based on different technologies have created a big market. Fitness trackers use smart technologies to collect, analyse, and visualise data to the user or a user community, such as the long-term motivation of the user and the community are kept on a high level. Here again, gamification strategies can provide help (Steinert et al. 2018). Also the quantified self is a kind of lifelogging collecting data about personal food consumption, skin conductance, pulse oximetry and performance using wearable self-monitoring sensors. The Quantified Baby is collecting data about baby's daily activities, e.g. sleep trackers for preventing sudden infant death syndrome (Wang et al. 2017). More invasive sensors are also used for personal genetics, e.g. by body hackers Duarte (2013). Critics speak about data fetishm. Smart glasses like Google Glasses which have been proposed in healthcare, for example, by the Glass Explorer programme (Sharon and Zandbergen 2016). Eye-tracking or gaze-tracking functionalities are often built in head-mounted or helmet-mounted camera systems (Witzner and Qiang 2010). Gesture recognition can be supported by wired gloves, depth-aware cameras, stereo cameras, or gesture-based controllers like the Myo armband. Brain-computer interfaces are implementing direct communication between the brain and external devices often used in assisting and repairing human cognitive or sensory-motor functions (Várkuti et al. 2013).

There is only a small step from preventive health measures to sports for the masses and competitive sports. Again, fitness trackers are the basis of many sports-related applications but also in competitive amateur and professional sports; more and more wearables are used for measurements in training and competitions. In extreme sports, action camera systems like GoPro as *body-worn video* are recording unique experiences for later self- and brand marketing on special web and TV channels like the Extreme Sports Channel. This links already to privacy concerns in particular when used in combination with large-scale data collection and facial recognition systems. Sousveillance, coined by Mann (2013), techniques like inverse surveillance, personal sousveillance, and alibi sousveillance are under heated debate at the moment (Rheingold 2002). Inverse surveillance follows the principle of following the watchers (police and security forces) and crowdmapping surveillance camera. Personal sousveillance is using lifelong audiovisual recording and weblogging or cyborglogging (Mann et al. 2006). Alibi sousveillance is generating evidence for defence, e.g. when police officers are wearing body cameras.

4.3 Wearables in Business and Industry

The industrial and commercial development of wearable technologies is deeply connected to the Industry 4.0 and Internet of Things. Industrial applications are located in, for example, retail, automotive, agriculture, and infrastructure and have developed from supply-chain helpers like RFID tags over ubiquitous positioning to advanced sensor fusion with the ability to monitor and control distant objects. Operating in hazardous areas, on the ground of the ocean or on the surface of deep space objects depend on our technical capabilities in these areas. In the consumer-oriented businesses, lifestyle applications for cooking, pets, gardening, etc. and home automation are added to health, fitness, and family-related applications. In this area privacy, autonomy and control are big issues but also the platform fragmentation and the lack of technical standards (Noura and Renaud 2016). Location tracking, data sharing and profiling are the main concerns within the privacy threads related to the IoT (McEwen and Cassimally 2013; Guinard and Vlad 2015; Atzori et al. 2014; Al-Fuqaha et al. 2015).

5 Learning with Wearable and Learning About Wearables

The basic distinction between "learning with wearables" and "learning about wearables" is simple but important. Learning with wearables concerns mainly stakeholders and disciplines where the use of wearables make a big difference. In the scientific discourse and real projects this is sadly often connected to some assumed deficits. Learning is conceptualised as overcoming a given deficit by a technology, e.g. using augmented reality to overcome cognitive disabilities in picking processes. In design workshops, contributors come easily up with design ideas for impaired or elderly people. While all this is very important, it would be very dangerous to limit ourselves to deficit theories, e.g. as deficient being in the problematic work of Arnold Gehlen (Gehlen 1940). These theories have been developed in the philosophy of technology and postulated the replacement of human organs like the extremities or the brain through technological solutions.

In consequence, the anthropological goal of technology was to improve human performance. Again, this is still very valid and important. Learning with wearables will surely advance human performance and also brings in new perspectives with the communication, coordination and collaboration of wearable devices in supporting human performance. In extreme, such post- or transhumanism studies cyborgs from an anthropological point of view.

Performance theories have been enhanced already by more sociologically oriented theories of science and technology like structuration theory (Orlikowski 1992), systems theory (Luhmann 1997; Luhmann 2000), activity theory (Engeström 2005), communities of practice (Wenger 1998), or actor-network theory (Law and Hassard 1999). While some of these theories like communities of practice and activity theory have been widely adopted in technology enhanced learning, others are more relevant for general conception of information systems in organisations like structuration theory. But all these theories have not been widely used to research learning with wearables. According to recent social theories, technology is not limited to the improvement of human performance but to shape practices, to transform them and to support social innovations. Through the availability on a planetary scale, the technologies are able to transform whole societies for the better or the worse. Philosophies of technologies have gained insights into the dual nature of technology, e.g. in the debates about nuclear power, genetic technologies, and the web. Whole areas of learning with wearables like Industry 4.0 (Koren and Klamma 2017), smart cities, and smart healthcare cannot be understood without referencing to these theories. We do not know if we can forget about the distinction between nature and culture and enter into a new discourse about the interaction of people, things, and concepts in the sense of Latour's "Parliament of Things" (Latour 1993), but definitely, the debates about digitalisation have already started. Who will be the spokesperson for all the sensors and actors around us?

Learning about wearables adopts a multi-perspective view. First, there is scientific and technological basic knowledge helping to understand the underlying physical and technical principles. Second, there is engineering and design knowledge to master the creation, fabrication, and utilisation of wearable technologies in many ways. Third, there is the necessary pedagogical knowledge to transform these complex settings in manageable learning scenarios and processes, e.g. for higher education curricula. Here, wearable enhanced learning can learn from traditions of science and engineering education as well as from more recent knowledge about computer science education. We should not forget about wearable enhanced learning in non-formal educational settings like in maker communities.

What could be promising ideas to connect the different stakeholder groups? One of the big challenges of wearable enhanced learning is the lack of scalability of solutions. Initiatives like the BBC micro:bit are a step in the right direction to scale-up learning. In different countries and regions regulations about the use of wearable technology for learning in schools are handled differently. While some schools have strict bans of mobile phones in classrooms, other schools promote the use of smartphones, tablets and laptops. Also in apprenticeship training there are gaps between the affordances in professional practices and regulations in the training centres. The European Learning Layers project (http://results.learning-layers.eu) for scaling-up technologies for informal learning in SMEs partnered with an institution for continuing apprenticeship training in construction. While the project was about the adoption of mobile learning, the institution did not allow the apprentices to use their own smartphones on their premises. Bring your own device (BYOD) is an initiative to overcome current regulations and allow the use of personal devices in schools, universities, libraries and other educational institutes. The use of private smartphones and wearable computers is often not allowed in companies, mostly because of security reasons and lack of control. Here corporate-owned, personally enabled (COPE) is a similar initiative.

Like in the ecological development before, the speed of development is much higher than the adoption of technologies in teaching practices. This can be argued by, for example, capacity theory (Kahneman 1973) and dynamic capabilities (Teece et al. 1997). Schoolteachers are not trained to use wearable technology. When the organisation of training is ready, the technology is already outdated. Different adoption speed in primary school, K12 schools, higher education, continuing education and workplace training may create gaps in the knowledge chain in context of wearable technologies and beyond. On the contrary, we strongly recommend that already in schools, the children learn basic knowledge and skills about wearable computing as well as practising learning with wearables. In the end, technology is in danger of getting obsolete, if it cannot be adopted by the major educational institutions. This has become already quite obvious when schools just forbid their pupils to use mobile phones. We hope that this is not the final answer to the practice gap.

6 Conclusions

In this introductory chapter, we have outlined the different affordances of wearable technologies for learning and the different phases of evolution of technology enhanced learning with the early phases of sharing learning materials with repository technologies, the phase of learning management systems with course-centric sharing and collaboration for mass delivery of learning resources, the phase of personal learning environments and learning analytics for the mass personalisation of learning resources, and finally the phase of wearable enhanced learning with open interaction of learners and learning devices. We have reviewed the different application areas of wearables like healthcare, sports, entertainment and business, and the emerging trends in wearable computing. We have characterised the different stakeholder groups including the industry sector, vocational training, higher education, and maker communities. We have also sketched some of the prominent perspectives on wearable technologies as well as current challenges in learning with and learning about wearable technologies. The challenges described in this chapter resemble challenges from EU proposals for networks of excellence in professional learning, technology enhanced learning, and game-based learning that the authors of this chapter have been involved in as proposers and principal investigators. Therefore this chapter can be viewed as an introduction to a proposal for a network of excellence. Unfortunately, networks of excellence are not funded anymore under the EU Horizon 2020 programme, despite the given evidence that they generated significant impact on a trans-European level.

We conclude that both utopian (optimistic) and dystopian (pessimistic) views on wearable technologies are present in the field wearable technology enhanced learning (WELL) and are inherently connected to the current discussions about the impact of technologies in general. The optimistic view on wearable technology enhanced learning (WELL) is based on the premise that advances in wearable technologies can benefit learners in a number of areas such as well-being, healthy lifestyle, expertise development and support of special needs of diverse groups of learners including learners with disabilities. The optimistic view is manifested in designs for wearable technology enhanced learning which focus on using wearable technologies as assistive tools, e.g. supporting ageing learners and/or learners with impairments; as interactive tools, e.g. engaging learners or facilitating communication; or as feedback tools, e.g. providing contextual or bodily information as part of the learning process. While these approaches do not disregard possible challenges of wearable technologies such as gathering and processing large amounts of personal data, they focus mainly on positive change and possible improvements that wearable technologies may contribute to, such as enhancing ubiquitous and seamless learning by allowing learners to integrate learning experiences across various contexts, environments, and dimensions (Wong and Looi 2011). On the other hand, based on numerous research studies which seem to confirm the increasing dependence on technologies and profound changes in the ways humans learn, communicate, and collaborate, the dystopian views critically discuss socio-economic effects of the increased pervasion of technologies in society in general. Some of the key concerns include the loss of specific human abilities and cultural techniques such as the ability to engage in face-to-face conversations, the ability to self-reflect, or the ability to read maps. The pessimistic view on such developments is manifested in discussions about emerging technologies, including wearable technologies, inhibiting rather than liberating users by, e.g. shifting and dividing user attention, disconnecting the user from other parts of life, with users feeling "handcuffed by the technology" or developing addictive behaviour patterns (Cecchinato and Cox 2017). With some of the transhuman visions becoming more and more realistic due to rapid advances in technologies such as artificial intelligence, wearable technologies are also beginning to be used to enhance human intellect and physiology. Even bionic implants and other types of surgical enhancements are beginning to be used to transform human bodies! From this perspective the discussion about the ethical implications of using wearable technologies for learning becomes essential, especially with its ability to lead research on ethically aligned collecting and sharing of user data, on learner agency and regulation of behaviour, while using and recording contextual information in public spaces.

The starting point is to understand the diverse and oftentimes contradictory perspectives on wearable technologies and how they may influence designs for wearable enhanced learning, be it in formal education, workplace training, or informal learning. Based on a deeper understanding of the evolution of technologies for learning, the chapters in this volume provide insights on current practices in using wearable technologies for learning.

The chapters' authors review technological and pedagogical frameworks and reconstruct lines of argumentation about potentials and challenges of wearable technologies. They synthesise available research results in this context. A balanced and informed approach to wearable technology enhanced learning (WELL) is yet to emerge in the future.

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Part II
The Topography of Wearable Enhanced Learning

Smartglasses as Assistive Tools for Undergraduate and Introductory STEM Laboratory Courses

Martin P. Strzys, Michael Thees, Sebastian Kapp, Pascal Knierim, Albrecht Schmidt, Paul Lukowicz, and Jochen Kuhn

1 Starting Point

1.1 Physics Laboratory Courses

The worldwide physics education research community seems to be in agreement that laboratory experience is an essential part of a physicist's education—during both school and university education (cf. Lunetta et al. 2005; Karelina and Etkina 2007; Hanif et al. 2009). Especially during the introductory courses at universities, the interplay between theoretical foundations and experimental reality builds up the basis for further lab work, professional work in industry, and higher education.

In this section, we want to identify key aspects of laboratory activities and experiences using the recommendations for introductory lab courses formulated by the American Association of Physics Teachers (AAPT) (cf. AAPT 2014) and a competency model by Schreiber et al. (2012) to have well-founded tools at hand to classify our own approach dealing with smartglasses as assistive tools in lab courses presented in this chapter. Using these recommendations and the competency model also allows us to formulate our approach in such a way that different institutions with their own lab course structure may identify key aspects to integrate our design.

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Studies show evidences that positive learning outcomes in lab courses are not guaranteed per se (cf. Hofstein and Lunetta 2004; Holmes and Bonn 2015; Wieman and Holmes 2015). For example, different aspects of the design and implementation like focusing on expert-like attitudes, developing epistemologies, or experiencing authentic scientific processes could not be reached. Other studies showed a lack of implementation of appropriate concepts concerning scientific measurement and corresponding uncertainty aspects (cf., e.g., Volkwyn et al. 2008). During the last decades, aspects of the design and implementation of laboratory courses at school or university seem to be ineffective concerning their impact on students' learning processes (cf., e.g., Wieman and Holmes 2015). During the last decades, many different approaches tried to close the research gap of missing criteria for positive learning effects in lab courses by trying to implement new design principles based on new ideas and former research work, leading to a broad variety of how to do lab courses and practice them (cf., e.g., Zwickl et al. 2013; Karelina and Etkina 2007; Finkelstein et al. 2005; Kontro et al. 2018).

To be able to categorize our approaches of using AR technology and smartglasses in the context of lab courses, which will be discussed in detail in the following section, there is a need for a generalized view of what can be learned during a lab course. Because of the variety of learning environments concerning this topic, it is hard to cover all aspects of lab courses without losing the view on the special features of each design approach. However, the curriculum goals formulated in AAPT's associated recommendations (AAPT 2014) are precise enough to provide a certain base structure to design a lab course, and they are abstract enough to enable different institutions to implement them with respect to their available resources, student population (major and nonmajor), or specific pedagogical intentions. That means, these goals are a universal tool to compare different lab course arrangements according to the key aspects of their learning intentions, because several learning outcomes, that are claimed to be reached by students during lab courses, are being described. These include constructing knowledge, modeling, designing experiments, developing technical and practical laboratory skills, analyzing and visualizing data, and communicating physics. It is obvious that not all of them can be addressed during one single lab course.

However, these recommendations picture some general aspects on a macro level without highlighting their connection or the mutual conditions. An even more student-orientated perspective is needed to operationalize disjoint areas of activities that represent self-contained parts of the proceedings during a lab course, e.g., planning, performing, and analyzing the experiment.

The structure model for experimental competencies according to Schreiber et al. (2012) describes fundamental competencies and skills students might foster during laboratory courses. It is almost congruent to AAPT's recommendations, but it follows a certain schedule of a laboratory course beginning with the preparation and ending with the interpretation of the results (Table 1). Therefore, it is useful to operationalize each step taken during a laboratory activity without demanding the compliance of the plot. Hence, these disjoint steps may be used to describe the key aspects of different design approaches and to characterize them.

Table 1 Model of the experimental competencies according to Schreiber et al. (2012) as found in Theyßen et al. (2014)

Preparation	**Performance**	**Data Analysis**
Clarify a question	Collect devices	Prepare data for processing
Develop a question	Assemble the experimental setup	Process data
Express expectations	Perform measurements	Interpret the results
Phrase a hypothesis	Document measurements	
Create an experimental design	Cope with problems and errors	

To make our wearable approach connective to the variety of lab courses, an analysis of its specifications concerning learning experiences has to be done. To do so, smartglasses are being described as a multimedia learning tool and its characteristics are investigated under the perspective of cognitive science.

Although we present the possibilities of smartglasses with respect to a general use in lab courses, we also want to phrase a concrete way to realize these ideas. In order to show that the technology is ready to be implemented in higher educational settings, we present the adaptation of a traditional experiment dealing with the thermal conductivity of metal rods as a first step to illustrate our approach.

1.2 AR Learning Environments and Smartglasses

During the last decade the development of modern digital media, such as smartphones and tablet computers, have triggered an experimental revolution in STEM education. These devices include numerous sensors covering different physical quantities and have been successfully established as portable minilabs for use in schools and in university courses in the last years. Today, integrated sensors allow to perform experiments in almost all fields of physics, e.g., mechanics, optics, acoustics, or even nuclear physics (cf., e.g., Vogt et al. 2011; Schwarz et al. 2013; Kuhn et al. 2014; Klein et al. 2014; Kuhn 2014; Hochberg et al. 2014; Klein et al. 2015; Hochberg et al. 2018). The capabilities of these devices can even be extended if external sensors, e.g., gas sensors, are used to perform measurements. Regarding the precision of the experimental measurements, these smart media devices are certainly able to keep up with classical measurement devices used in teaching scenarios at school and university. Their high availability, however, is a huge advantage, which opens new possibilities for, e.g., informal learning settings and ubiquitous learning (cf. Johnson et al. 2014). In the last years, the developments concerning virtual reality (VR) and augmented reality (AR) have complemented these technologies and opened the doors to new worlds providing different levels of immersion of the user.

While VR totally immerses a user into a computer-generated environment, which can simulate either a lifelike experience or any other imaginary world, AR aims to enrich the real surroundings with digital enhancements, so-called augmentations. In the virtuality continuum introduced by Milgram and Kishino (1994), which spans from purely virtual environments on one end to the real world without any augmentations on the other, AR therefore ranges somewhere in the middle, combining reality and virtual elements. Thus, also the term mixed reality (MR) is sometimes used equivalently referring to AR scenarios. Following the definition of Azuma (1997), which is mostly used in the AR community, a system creates an AR experience, if three characteristics are fulfilled: It combines real and virtual, it is interactive in real-time and registered in 3D, the latter referring to the correct alignment of real and virtual coordinate systems, to create the illusion of a consistent placement of the virtual objects in real space.

Both technologies, VR and AR, address both channels of information processing, the visual via different display types and the auditive via loudspeakers. A VR experience is usually created using head-mounted displays (HMD) as, e.g., in gaming devices like Oculus Rift or HTV Vive but also simply with a smartphone inserted into a cardboard. There exist several ways to generate a more or less immersive AR experience.

One possibility is to augment the live video stream on any display, e.g., a smartphone or tablet computer, in a way that changes the content itself, like in the Google Translate app (cf. Google 2018), where text is replaced by the desired translation in real-time, or that adds digital images in the correct 3D perspective, like in the IKEA Place app (cf. IKEA 2018). This creates the illusion of the digital object actually being placed into the real world. Such a realization of AR using external displays, however, only augments the digital live video feed, not reality itself, creating a sharp "mixed reality boundary" Benford et al. (1998) at the borders of the device's display.

A more immersive realization of AR by Bimber and Raskar (2005) uses projectors to create so-called spatial AR. In this approach digital augmentations are projected onto real-world objects themselves. The quality of this approach strongly depends on the objects that are augmented; the structure and the color of the object's surface as well as the lightning of the surroundings play an important role. The huge advantage of this technique is the fact that the augmentations can be observed with the naked eye, without the need of any additional device. Moreover, this also means that all persons observing the augmented object may also simultaneously look at the projected augmentation. However, if the position of the projector is fixed, while users are allowed to move freely, the augmentations can only be optimized for a certain class of view angles. Furthermore, especially if interactions between the users and the objects come into play, occlusion can be an issue, as the light coming from the projector might partly be blocked, e.g., by the user's head or hands.

Another approach is to use the technique of HMDs. So-called video-see-through systems use HMDs—as in VR applications. However, in this case the real-time video feed of a head-mounted stereo camera is presented. This video can then simply be augmented, as in the case of the AR version with handheld displays. In this setting one has to deal with a constant parallax introduced to the fact of the camera angle being slightly different form the person's view angle. Optical-see-through setups, on the other hand, use transparent displays, which allow to see the real environment while wearing the HMDs; in this case the displays only show the virtual augmentations as an overlay to the real world. This technology is used in smartglasses like Microsoft HoloLens. Both techniques require the exact knowledge of the position of the head of the users as well as the position of the objects that should be augmented. These positions can be acquired via tracking with sensors, e.g., optical cameras or depth sensors.

A downside of today's smartglass technology is the still limited field of view. Indeed it could be shown in a recent study by Baumeister et al. (2017) that using an AR experience with a limited field of view can increase the extraneous cognitive load (CL) of the learner. This might suggest that projector-based spatial AR despite its technical difficulties could be more beneficial with respect to the avoidance of extraneous CL as AR based on HMDs. A limited field of view, however, is an issue especially for large-scale augmentations, as the angular diameter is large in this case; with regard to standard laboratory tabletop setups, this should only be a minor limitation that will be overcome in the next generation of smartglasses. Moreover, talking about learning scenarios in science laboratories for undergraduate STEM courses, one has to deal with partly complex setups of various different devices, which have to be plugged together by the students in order to perform experiments. In such a setting projection-based AR comes up against limiting factors: the different surfaces of the used devices can hardly all be augmented with the same quality due to their different distances to the projector, which moreover possibly will change during the process of experimenting. Furthermore the angle under which the setup is viewed by the students may change during the experiment and handling the devices will constantly lead to occlusion problems.

In recent years, modern AR technologies have quickly made progress (cf. Sandor et al. 2015; Schmalstieg and Höllerer 2016; Hockett and Ingleby 2016) and finally also have entered the field of education (cf. Billinghurst and Duenser 2012; Santos et al. 2014; Bacca et al. 2014). However, the results regarding learning effectiveness of such scenarios at the moment do not yield a coherent picture. While some studies report AR was enhancing motivation of the participants (Jara et al. 2011; Di Serio et al. 2013; Bujak et al. 2013; Chang et al. 2014; Kuhn et al. 2016), their curiosity or the positive attitude to the experimental topic (Kuhn et al. 2016; Akçayır et al. 2016), or it was helping to authentically discover the environment (Dede 2009) and to observe processes, which cannot be seen with the naked eye (Sotiriou and Bogner 2008; Wu et al. 2013), others state that users often have to cope with technical problems using this technology and rate it as complicated (Lin et al. 2011; Wu et al. 2013; Akçayır et al. 2016). In any case, according to Muñoz-Cristóbal et al. (2015), additional introductory lessons are indispensable to create benefits from the use of AR, but still, if user experience and usability are insufficient and the user environment is not designed in an appealing way, learning with AR technologies will inevitably fail (cf. Squire and Jan 2007).

Thus, it is crucial to make an effort to derive design principles for AR learning environments, which can be deduced from multimedia learning theories. Therefore, we present theoretical foundations from selected psychological topics and their implications for the use of AR with smartglasses, revealing advantages and limitations for the learner's experiences. Furthermore, we deduce basic design principles for the creation of a smartglass learning environment and reconsider the experimental competencies and skills under the perspective of multimedia cognitive support by smartglasses in order to highlight those subdimensions of laboratory action that might be fostered.

2 Theoretical Background

Empirically validated theoretical foundations for the process of learning with multimedia environments have been successfully established during the last decades. In this section, we will give a recap of the current theories and discuss their implications. These, however, have been developed and tested using classical multimedia learning environments that combine different representations like written text, spoken words, videos, and animations on one or more screens. Today augmented reality (AR) technology is able to combine virtual augmentations with the real world into one multisensory immersive experience, e.g., with the help of smartglasses, which address the visual as well as the auditory channel. This allows for, e.g., digital real-world annotations, interaction with virtual characters, and instant feedback to real-world actions. Today it is not clear whether all classical multimedia design principles can be directly transferred to AR scenarios; however, several of these principles seem to be of special interest in such settings, as significant improvements can be expected here, as compared to traditional multimedia settings, which have much more restrictions to obey the respective principles.

2.1 Learning with Media

Knowledge about the architecture of human cognitive structures is crucial for the deeper understanding of the organization of cognitive processes. Cognitive load theory (CLT) according to Sweller (1999) is based on this knowledge and integrates its constraints to deduce instructional design principles. A huge restriction of human cognitive capabilities is the fact that working memory capacity is severely limited as, e.g., comparison or manipulation is not possible with more than two to four items at once (cf. Paas and Sweller 2014). Therefore, it is crucial to ensure that this limitation does not hinder learning processes by creating instructional guidance taking into account human cognitive structures and thus allowing for an optimal use of working memory abilities.

CLT provides such a framework for the design of instructional material. It distinguishes three different types of CL which are additive, while total CL is bounded from above due to limited memory capacity. The first type, intrinsic CL, is due to the intrinsic complexity of a (learning) task and cannot be modified without altering the task itself. Extraneous CL on the contrary is caused by inappropriate instructional material and is not connected to the process of learning. Instead, it emerges if unsuitable learning environments, ignoring cognitive limitations and inhibiting a strong focus on the learning task itself, are presented. This is the case, if, e.g., distractions or irrelevant information are present (redundancy effect), if the learner's attention has to be split between two spatially or temporally distinct relevant sources of information (split-attention effect), or if information is only presented in one mode, e.g., the visual mode (modality effect). The last type, the so-called germane CL, is directly connected to the learning process itself. It might be understood as effective CL, which stems from meaningful learning and active construction and automation of schemata in the long-term memory. As both extraneous and germane CL depend on the presentation of the learning contents and since the total cognitive capacities are limited, according to CLT the aim in constructing instructional material is to reduce extraneous CL while simultaneously increasing germane CL. However, it is important to tailor the materials especially for the target group, as the split-attention effect as well as the modality effect may be lost in the case of more experienced learners or experts (expertise reversal effect), which can be explained with the help of the redundancy effect: For persons with a higher expertise parts of the information still relevant for novices become self-evident. In this case, a physical integration of the information or a transfer to a different modality has no positive effect as it opposes the self-filtering capabilities of the experienced learner.

Augmented cognitive load theory (aCLT) (cf. Huk and Ludwigs 2009) goes one step further and also includes affective variables into the framework of CLT. It assumes that a reduction of extraneous CL might not inevitably lead to an increase of germane CL, as free parts of the learners' working memory might not automatically be used in favor of germane CL. Instead, germane CL might change, even if extraneous and intrinsic CL are held constant. In fact, according to aCLT, cognitive as well as affective variables are able to influence the level of germane CL. Indeed, both complement each other, as cognitive assistance aims to support the construction of mental schemata in an active learning process, while affective assistance is able to increase the situational interest of the learners. It could be shown by Huk and Ludwigs (2009) that interventions combining both cognitive and affective support lead to a better understanding compared to interventions in which only one type of support is provided. This means that the influence of cognitive and affective variables on learning performance are additive and thus both should be included in the design of instructional material.

While CLT establishes a framework for the process of learning in general, Cognitive theory of multimedia learning (CTML) according to Mayer (2014b) focuses on the special case of learning with multimedia environments, i.e., learning scenarios combining different representations and modalities. In many aspects CTML and CLT effectively address similar issues and lead, as we will see, to paralleling suggestions for improving the process of learning.

According to the multimedia principle by Mayer (2014b), learning from words and pictures is more effective than learning from words alone. Taking this as a starting point, CTML tries to establish a set of rules which allow to follow and extend the multimedia principle while simultaneously taking into account human cognitive structure to ensure an optimal learning effect.

CTML is based on three main assumptions, deduced from cognitive science (cf. Mayer 2014b): First, human information processing is split into two independent channels – the visual/pictorial channel and the auditory/verbal channel. This is directly linked to the second assumption stating that both of these channels have a limited capacity. These two assumptions resemble aspects of CLT, and find their counterpart in the limitation of working memory and the modality principle. The third assumption postulates an active processing of humans, i.e., the construction of active mental representations by the learner. This expresses the ability to create a coherent picture of their experiences through active attention and further processing of incoming information, including organization and integration with established concepts from long-tern memory.

Both channels are assumed to have sensory inputs, which are able to read information, e.g., in terms of different multimedia representations. In working memory information of both channels is actively selected and organized to create a verbal and a pictorial model, respectively. However, in this process, information of the two channels may interact with each other. In the end, both models as well as prior knowledge from long-term memory are integrated into a coherent full mental model.

In addition to this framework cognitive-affective theory of learning with media (CATLM) includes further assumptions (cf. Moreno 2005; Moreno and Mayer 2007): affective variables, like motivation and interest, are also relevant during learning processes as they increase cognitive engagement and thus enhance learning. These variables might therefore actively change the process of information selection from the sensory memory as well as the process of organizing the different inputs in the working memory. Affective components are fed from the long-term memory, which is assumed to be split into a semantic and an episodic memory which correspond to the two channels, respectively. Moreover, CATLM also includes tactile, olfactory, and gustatory aspects of the sensory memory, which are assumed to be strongly linked to the episodic memory and thus also influence the active process of learning. According to Moreno and Mayer (2007) this might especially be of interest in the context of interactive learning environments, which is always the case in laboratory settings. Besides this, CATLM also includes metacognitive factors which mediate learning through self-regulation of the learners, as well as differences in pre-knowledge and abilities between different learners, which also may have an impact on the learning efficiency of a specific learning environment for the individuals.

2.2 Implications of the Multimedia Design Principles

As a result of the preceding theories, there is a need to manage the different forms of CL during a learning situation. Hence, the design of the learning environment and the instructional material are the main aspects to take care of. As mentioned before, smartglasses with AR technology are able to address both the visual and auditory channel (cf. also Sect. 1.2). Thus, all design principles for controlling and reducing CL derived from the cognitive theories (CLT, CTML, etc.; cf. Sect. 2.1) can be applied. A summary of the selection of these principles that fit the possibilities of smartglasses is presented in the next paragraphs.

According to the theories above, the outcomes of a learning situation are determined by the specifications of human cognitive architecture. In particular, the limitations of working memory led to a boundary condition for the integration of novel information received from a multimedia message. If the content of a learning material exceeds these capacities, it leads to a cognitive overload situation and the learner has no more resources to process the essential material and to create learning outcomes.

Mayer and Fiorella (2014) derived five ways to manage cognitive resources and to guide the learner's cognitive processing, to avoid overload situations. Focusing on the reduction of extraneous load, they demand (cf. Mayer and Fiorella 2014) the elimination of extraneous load (coherence principle), the insertion of signals that emphasizes the essential material (signaling principle), the elimination of redundant printed text (redundancy principle), the positioning of printed text to corresponding parts of graphics (spatial contiguity principle) which according to Fujimoto et al. (2012) simultaneously facilitates memorization, and the elimination of the need to hold essential material in memory for a longer time (temporal contiguity principle). Notably, as mentioned before, the implications from spatial and temporal contiguity coincide with conclusions drawn from the split-attention principle from CLT (cf. Sect. 2.1), and also the redundancy principle has already been deduced from CLT.

These five principles are also reflected in CATLM and have been cast into the ten design principles for learning in high-tech and multimedia learning environments by Moreno (2006), which present basic ideas for the arrangement and presentation of multimedia messages in a learning environment.

Complementary to the five-point approach of Mayer and Fiorella (2014) to avoid or manage cognitive overload, Moreno describes the chances of using multimedia to foster the learning process. Those ten design principles are shown in Table 2.[1]

[1]Further information about the theoretical rationale can be found in the original publica tion by Moreno (2006).

Table 2 Ten design principles for a multimedia learning environment by Moreno (2006)

Principle	Description
Modality	Students learn better from words and graphics when words are spoken rather than printed
Verbal redundancy	Students learn better from graphics and narration than from graphics and redundant narration and text
Spatial contiguity	Students learn better when multiple sources of visual information are integrated rather than separated
Temporal contiguity	Students learn better with concurrent rather than successive corresponding words and graphics
Coherence	Students learn better when extraneous material is excluded rather than included in a lesson
Multimedia	Students learn better from words and graphics than from words alone
Personalization	Students learn better when explanations are personalized rather than non-personalized
Guidance	Novice students learn better when given principle-based explanations than they do when asked to infer principles by themselves
Interactivity	Students learn better by manipulating the materials rather than by passively observing others manipulate the materials
Reflection	Students learn better when given opportunities to reflect during the meaning-making process

2.2.1 Implications for the Design of AR Environments for Smartglasses

Previous empirical research on multimedia principles in the context of learning situations focused on a clean study design with special instruction materials to investigate a single or a disjoint selection of the principles from Table 2. In addition, the term multimedia was used in its simplest form: materials containing texts, pictures, and narrations that can be explicitly matched to a cognitive channel (cf. Moreno 2006).

Using multimedia in combination with AR and smartglasses, however, means to be able to add information to your field of view, like an overlay on reality. Any multimedia element (e.g., text, pictures, and videos) that can be created and displayed on a 2D screen can also be displayed on a smartglasses' screens. Hence, we can extend the use of multimedia from static or separated screens to the field of view and carry this information with us. Furthermore, we can use 3D content in a real-world environment that is not an illustration or copy of reality. In addition, we can use integrated speakers to provide sound and narration such that a smartglass really can deliver a multimedia message addressing the dual channel perception system of human's cognition, resulting in the application of Moreno's multimedia and modality principles (Table 2; cf. Moreno 2006).

The technology also allows the interaction between "smart systems," i.e., the transfer of real-time data from objects in the real world to the smartglass, to process this information and to provide corresponding content to the learning environment respecting both the visual and the auditory channels. In particular, the use of technology means that instructors do not just have to create a piece of paper with instructions; they rather have to design the whole learning environment containing visualizations, their arrangement, the structure of the action, and the user's interaction with both the technical device and the learning objective.

In fact, instructors have to create and organize different plots of multimedia messages that will be presented to the learner via the smartglass. Vice versa, this effort to create the whole situation gives the opportunity to control the basic boundary conditions of multimedia messages, like the coherence of the presented material or the avoidance of verbal redundancy.

With the use of multimedia elements like text and pictures, graphics, videos, narration, etc., we add information sources that address different channels and may be seen as much extraneous material at a first glance (cf. Mayer 2014a, p. 280). But the way these materials are arranged in the learning situation may change their effect on the learner's perception completely. The most important aspect is to focus on the essential parts of the material and to prevent an overload of the learner's cognitive capacity. This load management contains the design of material with respect to the consequences for the processing in working memory and the interdependency between material and learner, resulting in the three forms of CL.

Concerning the use of smartglasses in the context of laboratory courses, we have to confront the situation that nearly all of these principles must be considered to avoid cognitive overload. Hence, we use these principles as a guideline to design the interplay between augmented content and real-ity (i.e., mixed reality) to create a learning scenario that fosters multimedia learning.

Because of the technological possibilities of smartglasses we are able to integrate texts, pictures, narration, and different static and dynamic representational forms of experimental data (like raw values, tables, graphs, animations) in real-time next to the corresponding object in the real world. This ability of visualizing experimental processes happening at the object itself picks up the ideas of preventing the split-attention effect. Even in an environment bigger than just a screen or a piece of paper, AR technology guarantees the connection between objects and the corresponding information, like experimental data observed at this object. Thus, we extend the spatial contiguity principle from a 2D setting into a 3D environment. As a first approximation, spatial integration of information yields the connection between the object as a part of the experimental setup, i.e., the physical reality and the representation of the data as a tangible visualization of a physical quantity. Because the data is visualized in real-time, every change of variables and parameters of the experimental setup has corresponding consequences for the values and the representations. This feedback loop between reality and augmented information happens with such a high refresh rate that changes appear in a continuous and dynamic way rather than in discrete steps. Hence, this lack of delay between action and visualization means that temporal contiguity is reached in order to connect observable information to conceptual ideas.

As a matter of fact, in AR scenarios reality itself also comes in as a big additional source of information, not all parts of which are relevant for the current task, e.g., in a laboratory. This might in general also lead to overload situations in such a setting. Following the signaling principle and yielding cues and signals as well as highlighting or marking objects or regions in reality is also possible with such technologies and can be used either to smoothly nudge the learner into the right direction or to immediately draw the attention to important issues, which in the case of laboratory settings might even be relevant for security issues. For example, if a component reaches a critical temperature, a signal highlighting this component as "dangerous when touched" can be visualized. In general, objects can be highlighted and connected to spoken or visualized instruction. This guidance may help learners to focus on relevant components and to organize and structure their experimental investigations. Therefore, this guiding schema gives an example of how to go through the experiment providing learners with a predesigned plot they may follow (guidance principle; cf. Table 2).

A well-designed user interface allows to control structure and pace of the action according to the learner's own capabilities. One possibility to control the multimedia messages is to simply use one's gaze. If learners want to see the spatial connected information of an object, they have to look at this object actively, when and how often they want to. Hence, learners obtain enough time (and space!) to reflect the multimedia message, i.e., what can be seen and what can be heard, and to process the inherent essential information. This reflection principle is available due to many degrees of freedom concerning the learner's interactivity. Latter is also the reason for having a personalized learning situation. What is presented in the augmented information is a consequence of the learner's action. If fundamental parameters are changed, for example, by manipulating the experimental setup, the learner gets the information of the outcomes via representations of the physical quantities. Hence, a relationship between action and outcome can be established without any spatial or temporal delay. This allows learners to interact with the learning objective in a personalized way, because changes and consequences are produced by their own action and organized in their self-chosen pace. The real-time feedback provided by the multimedia messages reduces the need to hold the information of their (complex) interaction in their working memory over a longer period of time and enables the reflection of the interplay between action and outcomes. Providing signals and cues supports this reflection processes by giving hints for the relevant structures and information.

To sum up, the use of smartglasses in combination with AR technology enables instructors to design a multimedia learning environment that includes basic design principles to manage CL and therefore a cognitive support for the learner. Designing such an environment requires to deal with cognitive psychology, instructional design, and the reflection of the user interface. However, further research has to be done to find out whether it is definitely allowed to transfer the foundations of 2D multimedia learning theories to such a complex and interdependent conglomerate of multimedia elements in 3D environments.

2.2.2 Implications for Laboratory Learning Environments

In Sect. 1.2, we claimed that using smartglasses as a multimedia learning tool may support different aspects of competencies and skills necessary for experimental actions. For the construction of knowledge, the (personal) observation and interpretative analysis of measurement data is essential. Both the spatial and the temporal contiguity principle enable students to connect the observation of data to the observation of the experimental setup in real-time and with respect to their own pace. There is no significant delay between the occurrence and detection of data—students immediately get feedback about the status of the experiment. Because this data is a direct result from their own action (interactivity principle), they may integrate this information better, because the action was founded on their own thoughts and questions concerning the learning objective. Moreover, in such scenarios, affective motivational factors might play an important role, as also the other sensory inputs, like the tactile input, as included in CATLM may be important here, which in combination with self-performed actions in a laboratory could incorporate a strong link to the episodic memory and increase the element interactivity.

Concerning the competency model of Schreiber et al. (cf. Table 1), AR works as a feedback system by integrating the "interpretation of results" into the "performance of measurements" leading to an interplay with "phrase a hypothesis." That means, while students have the opportunity to think about the (real-time) data, they interpret the results of their experimental action immediately. This enables them to change their experimental action in order to investigate these interpretations with regard to their hypotheses. Reversed, they may change their hypotheses because of their interpretations leading to the need of changing the experimental action itself.

The key aspect of this feedback system is the visualization of real-time data. Aside from being able to process the raw information, such that the visualizations will appear next to the corresponding real object, the data can be prepared in almost any kind of representation and signals or cues can be added. In fact, the visual attention of the learner can be guided by highlighting objects or parts of them in order to simplify the scenery and structure the learning process. This supporting system to filter relevant information may help students to focus on main parts of the experiment, enabling them to focus on the interpretation and conclusions of the data. The variety of possible representations reaches from raw values to complex graphs, so that a scientifically accurate visualization of data is guaranteed and there is still an educational scope to reduce the complexity of information in order to match the learner's cognitive performance level. Such a broad variety enables instructors to individualize the learning situation in such a subtle way that the structure and plot of the action during the experimental process satisfies the educational need of the learner. Eventually, with the help of the prepared graphs and the real-time data, the learner gets the possibility to think about the status of the experiment during the interaction without losing any degree of freedom concerning the control of the pace and the interaction with both the technical device and the setup itself.

To sum up, the broad variety of visualization concepts and the connectivity to the learner's performance level may particularly result in the support of the knowledge construction while performing the experiment and analyzing the data. Instead of waiting for the analysis by hand, the results of the interaction can be made a subject of discussion in real-time. Especially with respect to the contiguity and signaling principles, the learner is guided to maximize the learning outcomes of this real-time discussion and interpretation due to a support of the cognitive processing of novel information. Respecting these multimedia principles may result in a well-founded feedback design of the learning environment.

3 Toward a holo.lab

Based on the design principles deduced from cognitive theories, as presented in the preceding section, in this section we will explain how we want to benefit from the use of smartglasses in laboratory learning scenarios in our holo.lab approach.

3.1 Smartglasses as Experimental Tools

If standard smart media such as smartphones or tablet computers are used for (AR) learning environments, all design principles of multimedia learning can hardly be obeyed. Besides their high computational power and various internal sensors, the nature of devices like smartphones or tablet computers is simply that of an external handheld display. It can be assumed that this fact gives rise to a conflict with the contiguity principles. In the case of a laboratory activity, this means that if a person is working with an apparatus while further information, e.g., measurement data or explanations, is presented on an external monitor, it is simply not possible to observe both the apparatus and the screen at the same time. The user might then simply look back and forth, thereby trying to integrate the spatial discontiguity or first focus on one of the two sources of information, before turning to the other, thus integrating the data temporally; this would inevitably lead to a higher level of CL. Moreover, such a handheld device at least partly inhibits a just-in-time interaction with the experiment, since at least one hand cannot be used to manipulate the apparatus.

One can suspect that technically spatial AR using projectors and AR via smartglasses both would overcome the discontiguity problems with handheld devices as we have seen in Sect. 1.2. Despite the drawbacks associated with the limited field of view (cf. Baumeister et al. 2017), to ensure a perception of the environment which is as natural as possible, in the settings described in the following sections, we thus focus on the realization of AR content with smartglasses. In a lab setting students may then see the experimental apparatus and also their collaborators face to face and benefit from augmentations at the same time. Furthermore, in such a setting also additional augmentations, which are not fixed to surfaces of real objects, can be included, which can be crucial for inserting cues, informatory or explanatory tags, but also data visualization.

3.1.1 Visualizing the Invisible

As we have seen in the last section, smartglasses are ideally suited to realize AR learning environments, which obey basic multimedia design principles. However, when it comes to physical experiments, there exists another huge advantage of this technology, namely that of helping to visualize the invisible. While human senses are of great help when performing various experiments, e.g., in acoustics or optics, at the same time many abstract physical quantities, like energy, heat, or voltage and current, are not covered by human perception. Nevertheless, fundamental physical concepts are based on such abstract quantities, for which an intuitive understanding often is lacking. This intuition deficit might be reduced, if a learner would be enabled to directly interact with the quantity under discussion, allowing to establish a feedback loop and thus a reflection of the behavior of the physical subject.

Indeed, the gap in human perception can be overcome with the help of AR technologies, which also allow for true interactivity. Today digital sensors are available for a huge number of different physical quantities, which otherwise are inaccessible to human perception, like temperature, voltage, and electrical current or electromagnetic fields. As smartglass technology is able to completely cover the virtuality continuum, leading to a true immersive virtually augmented world experience for the users, it is possible to embed virtual objects into the real environment. In such a digitally enhanced surrounding, virtual and real objects do not only co-exist, but moreover are also able to interact with each other in real-time. Hence, digital sensor data from external sensors can be used to create augmentations which are integrated seamlessly into the environment and enrich human perception with further senses.

Therefore, we use smartglasses to merge human perception of reality with digitally visualized sensor data directly in the user's field of view, thus obeying spatial and temporal contiguity. We realize this by transferring sensor data to the visual sense, which can be achieved by transforming it into different representations like various types of diagrams, symbols, or false-color representations. A learning scenario including such a technology, we call a holo.lab. An AR learning experience like this is finally able to make the invisible visible and the not observable apparent.

In general there exist two possibilities to realize real-world annotation, i.e., to present object-related data in an AR scenario. The first is to simply show a representation of the data in direct neighborhood to the real object. This could for example simply be to display the numerical value of the voltage over light bulb in some electrical circuit. In this case also other representations, e.g., all sorts of diagrams, may similarly be used. Such an augmentation in general cannot be realized with a projector-based scenario, as a corresponding surface for such a representation would have to be present in this case. In the second approach the object itself is augmented. An example for this technique is the augmentation of an object with a false-color representation of its own temperature distribution such that the color of each point of the object represents the corresponding temperature of the physical object at this point, which we will discuss in detail in the following section.

3.1.2 Using HoloLens in an Experimental Setup

In our laboratories, we use HoloLens technology to create AR learning environments as a holo.lab scenario (cf. Strzys et al. 2018). The virtual objects, which are shown on the HMDs of HoloLens—the so-called holograms—can be used to annotate real objects and to show diagrams and other representations but also for a complete augmented overlay of real objects with new digital texture. Such applications are only possible, as HoloLens itself guarantees a very high quality level of spatial registration of the virtual objects in real space and an elaborate tracking of its surroundings. Therefore, if a user has placed a hologram somewhere in real space, he is free to move around and look at it from different points of view. Even if one leaves the room one will find the virtual object still exactly at the initial position when re-entering the room.

To attach the holograms to real-world objects also an object tracking has to be implemented. The easiest way to achieve this is via visual markers fixed on the real objects. Since these markers can be tracked using the cameras of HoloLens, the positioning of the virtual content can then just be achieved relative to the marker coordinates. This is also possible for more than one HoloLens at the same time, as every HoloLens performs its own marker tracking and displays the corresponding AR objects independently.

There are many ways to interact with HoloLens and thus to interact with the virtual augmentations. All holograms can be chosen with the so-called gaze point, a cursor that can be moved with the user's gaze. As soon as the gaze point meets a hologram ready for selection, it will be highlighted. It may then be selected using the so-called air-tap gesture. This hand gesture is simply an analogue of clicking on a mouse or a touch pad and can be performed by tapping with the forefinger at any point in the gesture frame. This frame is a specific region located within easy reach of a person's hands, limiting the operational area of the gesture recognition of HoloLens. Besides gestures, there exist two more possibilities to interact with HoloLens: One is to use a clicker, a small handheld device with a button that allows to select a highlighted hologram; the other is speech recognition which allows a totally hands-free interaction.

Since lab work often is teamwork, a holo.lab scenario moreover has to be designed in a way that allows collaboration of several persons, all of them interacting with the experimental apparatus as well as with the AR content, especially with the sensor data. Depending on the conditions one possibility is to ensure that all users attending the experiment are able to see and to work with the same representations which allows to discuss the measurement data on a common basis of virtual annotations and evaluations presented in their shared MR experience. The other possibility would be to allow for individual representations, either chosen on purpose by the single user, or suggested automatically by the system based on the evaluation of the user's behavior. This individualized scenario would follow the personalization principle (cf. Table 2) and should effectively meet the special needs of different learning types. In an ideal version all these possibilities should be included in a holo.lab realization.

3.2 holo.lab for Heat Conduction

As a first holo.lab example, we have implemented an AR version of a standard experiment on heat conduction in metals for an introductory STEM laboratory course in thermodynamics (cf. Strzys et al. 2017, 2018). The experiment consists of different metal rods, which are electrically heated at one end while simultaneously cooled at the other end. Each rod exists in two versions, an uninsulated one and a second one with a PVC insulation layer (cf. Fig. 1a, b). An infrared (IR) camera is used to access the temperature data along the rod, which is then passed to the students' HoloLens. The educational potential of IR cameras and their ability of visualizing thermal phenomena on the level of primary school up to university physics (cf., e.g., Vollmer et al. 2001; Möllmann and Vollmer 2007; Vollmer and Möllmann 2013; Haglund et al. 2016a, b; Nordine and Weßnigk 2016; Palmerius and Schönborn 2016) can be merged with the benefit of spatial and temporal contiguity in a holo.lab setting. To achieve this, we project the real measurement data of the IR camera in real time as a HoloLens hologram directly onto the rod using a false-color representation (cf. Fig. 1c, d). As these augmentations are mutually 3D and registered in real space, students can observe the heat flux through the rod from all angles without the problem of occlusion. Additionally, other augmented representations, a temperature graph and numerical temperature values, can also be switched on and off during the experiment using virtual buttons (cf. white squares at the right end of the rod in Fig. 1c, d). This allows for virtual interactivity and enables the learners to choose their own preferred representation which according to the personalization principle also prevents overload situations. However, representations used by all of the learners can also be included in the discussions among the group members, creating new possibilities for collaboration. Additionally, the current temperature data can also be exported to CSV file at any time for later traditional analysis.

With this holo.lab setup, a just-in-time evaluation of the physical process in this experiment can be achieved: all stages of the heating procedure, beginning with the initial state, in which the rod uniformly is at room temperature, and ending with the formation of a stationary state with a hot end, a cold end, and a temperature distribution depending on the insulation conditions of the rod, can be observed and evaluated in real-time, using all three representations of the sensor data. As we have discussed in Sect. 2.2, this is the key to establishing a feedback system. This feedback can be used to critically reflect on the performed procedures as well as the results of the measurements, since in such a scenario the time-consuming

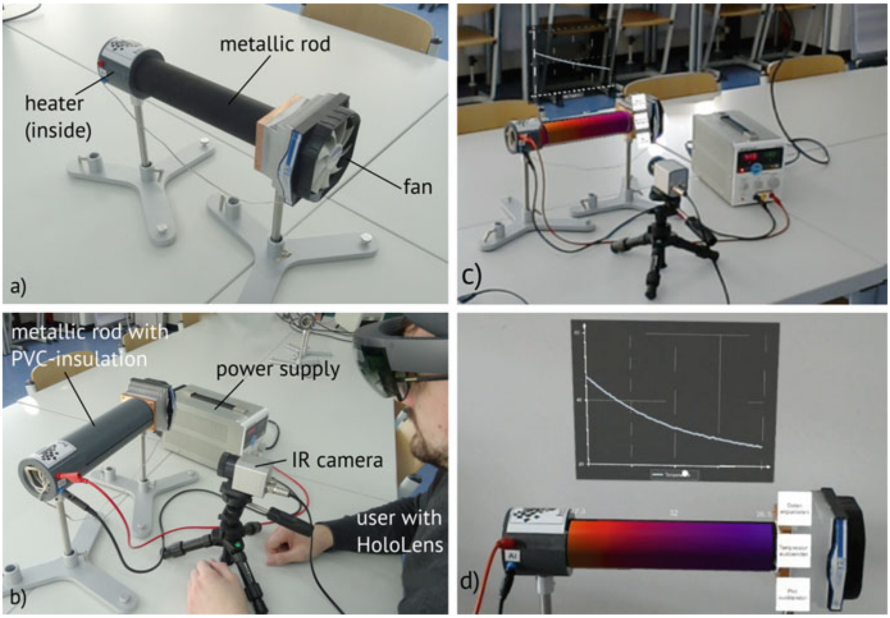

Fig. 1 (**a**) Experimental setup (uninsulated rod); (**b**) experimental setup (rod with PVC insulation) and user wearing a HoloLens; (**c**) holo.lab setup (uninsulated rod) with AR experience; augmented representations: false-color representation of temperature along the rod, numerical values at three points above the rod, temperature graph; (**d**) detailed view of the augmentations, three buttons at the right: "Export Data," "Hide Temperature," and "Hide Plot"

procedure of processing the data and casting it into the appropriate representation is taken care of by the learning environment itself. This frees cognitive resources of the students, allows them to pause and reflect on the observations, and thus fosters their learning progress according to the reflection principle. Moreover, the virtual content might also provide representations of theoretical predictions and thereby enables a direct comparison of the experimental outcome with the idealizations of theory. As both of them possibly might not coincide with the students' own expectations, such feedback can trigger cognitive activity and might lead to a critical reexamination of concepts, to reduce cognitive dissonances (cf. Munnerley et al. 2012).

As our holo.lab setting is completely smartglass-based, students still have their hands free to interact with the physical apparatus and simultaneously focus on the system's response via AR informations in their field of view. Therefore, students' individual expectations concerning the outcome of an experiment resulting from personal preconcepts as well as from theoretical implications can also start an experimental feedback loop including new experimental actions and reactions due to critical reflection to achieve verification, which according to the interactivity principle enhances learning possibilities and might eventually even trigger a conceptual change (cf. Brown and Hammer 2013).

To evaluate the learning efficiency of our holo.lab approach, we conducted a first pilot study with a treatment and a control group (cf. Strzys et al. 2018), which indeed showed a positive effect on the conceptual understanding of students using the described setup for the thermal conduction experiment. While the control group performed the experiment with a traditional setup, using a handheld IR camera and a PC, which excludes a just-in-time feedback loop as well as real object annotation and augmentation, the treatment group used the holo.lab setting. We compared students' performance in a concept test on heat and temperature in a pre- and post-test design and found a small positive effect of the holo.lab setting (effect size Cohen's $d = 0.43$), indicating an improvement of the understanding of the underlying physical concepts. As in this experiment the theory-experiment interactions are relatively limited, one may expect that complex experiments could benefit even more from AR technology.

This first realization of a holo.lab scenario mainly focuses on the idea of real-world augmentation to overcome the limitations introduced by the split-attention effect by avoiding discontiguities and on establishing the possibility of a real-time feedback loop with regard to theoretical implications as well as experimental actions. However, the inclusion of guidance elements via cues, hints, and explanations could also be included in a straightforward way. Moreover, as true experimental interactions are rather limited in this relatively static setup, more engaging layouts combining more components would yield a plenty of possibilities for broad interactivity. This could also be embedded into a problem task, if, for example, different materials should be combined in a way to ensure a heat transfer as fast as possible, or different insulation strategies should be compared to achieve minimal energy loss. Such an affective support via goal-based scenarios would finally also enhance learning according to CATLM (cf. Moreno 2005; Moreno and Mayer 2007; Huk and Ludwigs 2009).

4 Discussion and Outlook

The positive results of our first evaluations of the conceptual understanding of students support the assumptions concerning the beneficial value of AR scenarios in laboratory courses and encourage us to continue the development of the holo.lab. In fact, smartglass technology can be established for general use in STEM laboratory courses, but it addresses in particular some special phases like the performance of measurements or the interpretation of results. Concerning our experimental setup, we reached the feedback mentioned in Sect. 2.2, based on the interplay between the observation of data during the performance and the interpretation of the visualizations. That means, in our case, the use of the technology allows to bring forward the main part from data analysis and integrate it simultaneously into the performance without changing the setup itself. Though, we did not touch the preparation phase in a way that the consequences of the feedback could change the underlying questions or the plot of the experiment, as this would necessitate new experimental designs. These, however, could yield additional affective support via goal-based scenarios, which could bring in further possibilities to improve learning. But just respecting spatial and temporal contiguity principle already seems to have a significant influence on the way how the experiment is performed, which is mirrored in the positive results from our pilot study.

In future experimental setups for the holo.lab, more aspects of the multimedia design principles shall be integrated to reach other competencies of experimental action. For example, the preparation done by the learner could be integrated in the visualizations of the real-time data via comparing this to a hypothesized functional interrelation. Combining the signaling principle and the modality by also considering the auditory channel could end up in an AR setting not only highlighting special objects or areas of special interest, that the learner has to assemble to set up the experiment, but also providing guidance via corresponding audio commentaries. This kind of hands-on tutorial system may benefit from the affective parameters and support the construction of coherent mental models incorporating the episodic knowledge. Although in a holo.lab scenario raw data is automatically prepared and processed for the visualization, the processing itself could be extended via giving learners all possibilities of real-time graphical analysis like statistical processing (e.g., regression analysis), enabling them to extract even more characteristic values from the data to compare it to the expectations. This would shift interpretation to a whole new level, because the performance would only be marginally interrupted.

Therefore, we expect the beneficial effect of AR using smartglasses to be even bigger for more complex experiments. This assumption, however, will have to be tested in the forthcoming scenarios. Additionally, further evaluations will certainly have to capture and analyze affective and cognitive variables of the participants, especially CL, to validate our assumptions and to help to establish extensions of the multimedia principles and implications of CATLM to AR scenarios, as sketched in this contribution. Such an analysis will also have to take into account the effects of real-time interaction with different representations and real objects in the laboratory at the same time, as well as the corresponding impact on the conceptual and representational understanding of the learners. Finally, in contrast to classical multimedia learning scenarios, which mostly are intended for single users, also the aspect of cooperation between several learners becomes important in the AR framework of holo.lab experiments.

Besides this, equipping AR learning environments with self-adapting capabilities, which always ensure the best possible support for all learners, independently of their status as novice, advanced learner or expert, will also be a future goal. This, however, needs a thorough understanding of the learning process and the accompanying change of personal parameters of the learners, which is needed to construct models that are able to use collected personal data in real-time to predict the students' behavior and to deduce their competence levels.

Although AR technology with smartglasses today still is quite costly, the basic idea of a holo.lab scenario is to augment existing standard experiments widely used in STEM laboratory classes and thus to enable an easy proliferation of this technology to other laboratories at different universities or even schools, as soon as the media reach the consumer level and the mass market. The story of AR learning environments and the holo.lab has just begun.

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Wearable Technology: Meeting the Needs of Individuals with Disabilities and Its Applications to Education

Cindy L. Anderson and Kevin M. Anderson

1 Introduction

Wearable technology refers to digital devices that can be worn on the body and used in the real world (Borthwick et al. 2015). When used by individuals with disabilities, they become part of a repertoire of devices known as assistive technology. Disability is defined by the World Health Organization (n.d.) as follows:

> Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations. Disability is thus not just a health problem. It is a complex phenomenon, reflecting the interaction between features of a person's body and features of the society in which he or she lives.

Assistive technology, also called adaptive technology, is defined, according to the United States Assistive Technology Act of 1998 (105th Congress 1998), as any "product, device, or equipment, whether acquired commercially, modified or customized, that is used to maintain, increase, or improve the functional capabilities of individuals with disabilities." Wearables can fit this definition whether or not they were specifically designed for individuals with disabilities.

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2 Overview of Wearables for People with Disabilities

2.1 Wearable Technologies Worn as Accessories for Individuals with Disabilities

Wearable technologies, worn as clothing accessories, can be of benefit to those individuals with disabilities. Some of these devices are not made specifically for those with disabilities who use them but can have a profound impact on individuals with disabilities. These accessories include watches, headbands, bracelets, rings, and other accessories.

2.1.1 Accessories for Hearing Impaired

Hearing-impaired individuals who use American Sign Language (ASL) can communicate with others who do not use ASL with a wearable called the Q band (Core77 n.d.) that translates speech to text through a band wrapped around the hand. The Q band also identifies the emotion of the speaker and helps the hearing-impaired individual feel the sound of the speaker (Core77 n.d.). The Massachusetts Institute of Technology (MIT) used 3D cameras, vibrating motors, and a Braille keyboard to create a navigation aid that describes objects around the walking individual with visual impairments (Hardesty 2017). Smartwatches for hearing-impaired individuals can be equipped with vibration to be used as an alarm clock, a notification for arriving text messages, and a fire warning (Oliver 2017). For individuals who are hard of hearing, “hearables” are being utilized. These devices amplify sound and are often equipped with additional technology such as monitoring of activities (Everyday Hearing 2017) (Fig. 1).

Phone technology offers yet another opportunity for wearable technology for the hearing impaired. The ISEEWHATYOUSAY is a device that can be worn by the hearing-impaired individual and links via Bluetooth to a smartphone into which the hearing-impaired individual speaks. This translates the spoken word into text for the hearing-impaired individual to communicate with those who are hearing abled (Szczerba 2015). Wavio is a device for the home of the individual with hearing impairments that communicates alarms, the microwave, and doorbells to their smartphone (Oliver 2017). The hearing impaired even have a sign language app for their phone or tablet that can go with them everywhere. It reads both sign language from the hearing-impaired individual and speech from the non-hearing individual and translates it to text for the hearing abled or into sign language symbols made by a robotic hand on the phone screen (Wearable Technology Digest 2014).

Fig. 1 White Apple Watch with Screen, by Justin 14, 2014, https://commons.wikimedia.org/wiki/File:White_AppleWatch_with_Screen.png. Public domain

2.1.2 Accessories for Visually Impaired

Accessory wearables can help students with visual impairments function within their environment effectively (Hardesty 2017). A Braille smartwatch due out in 2018, Dot, will communicate messages and time to the user (Oliver 2017). Alexa has now been adapted to smartwatches which can be used to control the environment of the user. The Omate Rise smartwatch has Alexa directly built into the watch; other watches interact with Alexa on their smartphone (Allison 2018). Some accessories are solely designed to aid the visually impaired individual with navigation. The Sunu Band is a headband that incorporates sonar technology to help with navigation by vibrating when there is a potential collision (Shields 2017). Maptic jewelry is designed with a sensor on a necklace that interacts with an iPhone app to assist in navigation (Tucker 2017). Other accessories help the individual with visual impairments do daily tasks. One recent development is with Aira glasses, a pair of glasses that look like a combination between Google Glasses and a virtual reality headset (Conditt 2017). These glasses work with a service where the person at the service describes what the visually impaired user sees by connecting via phones (Pardes 2017). Argus II is a bionic eye, approved by the FDA in 2013, that works through a camera mounted on glasses that communicates with new lenses implanted in the eyes. The camera emits an electrical signal that the lenses interpret (Mullin 2017). The Brainport uses light from a pair of glasses that is translated into electrical pulses that are felt on a tab worn on the tongue of the user much like the sensation of Poprocks (Dennis 2017). The user can use these to learn to navigate his/her environment. MyEye uses a camera that identifies an object and sends the information to an earpiece. Working with artificial intelligence, the device adapts to the user the longer the user wears it (The Baltimore Sun 2017). Futurists in this field predict AI is a game-changer for the visually impaired since it could adapt and change descriptions for the wearer (Reese 2017). For example, as a student continues to wear a MyEye in his school, the AI functionality will begin to more accurately enable facial recognition of classmates.

2.1.3 Accessories for Physically Disabled

Individuals with physical disabilities can also benefit using wearables as accessories. Individuals with physical disabilities can operate a computer screen with a Myo band that is worn on the forearm whose movement interacts with the computer screen as a mouse, thus enhancing game playing and control of their environment (Pepe and Talalai 2016). A wearable headmouse was recently developed for operating computers and environmental controls for individuals with no hand movements that works through Bluetooth, is worn like glasses, and has a bite clicker (Miller 2016). Lynxio makes a wearable knee brace that provides data to the user to help in knee injury recovery (Imagination Catalyst 2014). The Sesame phone uses head gestures to control the phone for individuals without fine motor skills (Sesame-Enable 2016). Wheelchair users can now manipulate their wheelchair through a device that is inserted as a tongue stud (Miller 2014). Microsoft has stepped in to help develop a wearable watch called the Emma to help those with Parkinson's reduce tremors, so they are able to regain their writing (Wong 2017). A wearable exoskeleton is being developed to allow paraplegics to walk (Bionik Laboratories n.d.). Researchers are even developing prosthetic limbs that can be directly controlled by the thoughts of the user (Krishna 2017).

2.1.4 Accessories for Emotionally Disabled

Students with emotional behavioral disorder (EBD) impairments have access to wearables to measure their emotions (Charara 2016; Kushki et al. 2013), and for those who cannot interpret the emotions of others, such as students with autism, there are wearables to help interpret the sentiments of others (Garun 2017). Students with behavioral issues or autism can use wearables to detect stress and offer alternative responses (Torrado et al. 2017). Muse is a headband, and Versus is a headphone that help individuals with stress mediation, while Thync will actually modify electromagnetic pulses to make the wearer feel better (Brinson 2017). Feel is an armband that measures emotions (Beck 2016). Reveal is a band for the leg that measures stress levels in individuals with autism, so that caregivers can help keep the individual calm (Burns 2016). The Zenta wrist-wearable is similar: it measures emotional states along with physical states (Butcher 2016).

2.1.5 Accessories for Learning Disabled

Students with learning problems such as learning disabilities or intellectual disabilities can benefit from wearables. Students with reading disabilities can benefit from wearables such as OrCam's MyEye glasses (Holton 2017) or the Reading Ring (Hardesty 2017), both using text-to-speech synthesis or reading text on the page. Herokins allows communication between parents and children to create learning activities that children can carry through after listening to instructions on their watch from a cartoon character detailing activities such as carrying out a shopping list (Brown 2015). Leapfrog has designed a similar watch for children, the Leapband, that provides thinking challenges that are also designed to get children moving (Fearn 2016). Instapaper helps poor readers by storing articles on the Apple Smartwatch that connect with the iPhone that reads the articles to the individual using text-to-speech (Fearn 2016). The Curiscope Virtuali-Tee is a t-shirt that is printed with a design that is recognized by augmented reality software on a smartphone to better teach human anatomy (Gohd 2017). The zSpace display uses virtual reality glasses interacting with a surface that produces holograms that individuals with learning problems can directly interact with (Fearn 2016). Microsoft has produced a similar headset called Hololens that will benefit those with learning problems by allowing the user to interact with holograms (Fearn 2016). For an individual with a reading disability, the hologram may provide a visual construct of the reading passage by providing visual details of the described object or location. Individuals who need to learn in a more authentic fashion will benefit from wearable virtual reality headgear such as the Oculus Rift (Chafkin 2015). The learner will be able to virtually experience an event or location that is described in the assigned text, providing a concrete example of the written description. Lectures can be recorded for those individuals with memory issues using technology like Google Glass (Boykin 2014) or the Vue glasses. The GoPro camera as a wearable can be used for authentic assessment to help determine error patterns of those with learning disabilities (Kearns 2016) (Fig. 2).

2.2 Smart Clothing

Conductive thread has become another vehicle for people with disabilities to improve their living. Conductive thread allows the development of smart clothing or e-clothing that can sense health problems, remind users of activities that will make them healthier, light up according to emotions, help the user navigate, and help individuals learn.

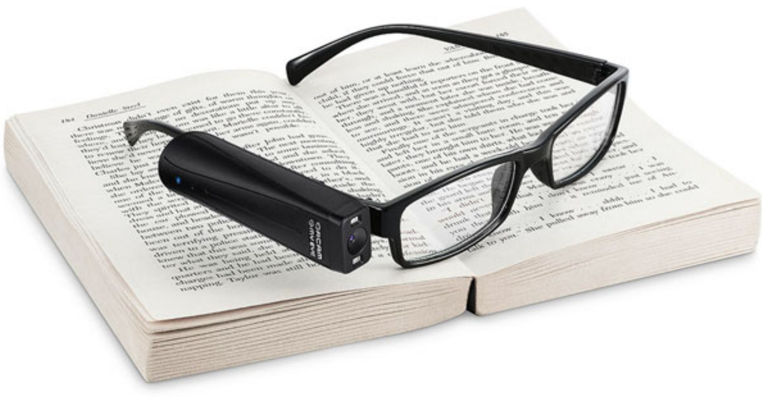

Fig. 2 OrCam MyEye 2.0 – OrCam155.jpg byYlip4, 2018, https://commons.wikimedia.org/wiki/File:OrCam155.jpg. Public Doman

2.2.1 Smart Clothing for Hearing Impaired

Hearing-impaired individuals benefit from smart clothing. A dress created with embedded microphones and tiny motors will flutter ruffles in the direction of speakers for deaf individuals to face the people to whom they are talking (Weir 2012). CuteCircuit has developed a shirt that allows hearing-impaired individuals feel the music when listening to music (Meyer 2016). Smart clothing that acts as a solar energy storage device could be used to power electrical items (Zimmer 2016) such as hearing aids. Q is a band worn on the hand of a hearing-impaired individual that allows the text of the speaker to be displayed on a small screen (Core77 n.d.) on the band.

2.2.2 Smart Clothing for Visually Impaired

Individuals with visual impairments also benefit from smart clothing. Clothing, such as the Eyeronman, can help individuals with visual impairments navigate by vibrating in the direction of obstacles (Lewis 2014). A smart vest developed at the Polytechnic University of Hebron not only vibrates at obstacles but tells the visually impaired individual how to get around the obstacle (blind.tech 2016). A swimming cap was designed by Samsung that vibrates when the swimmer needs to turn (OQuist 2016).

2.2.3 Smart Clothing for Physically Disabled

Smart clothing also provides advantage to individuals with physical disabilities. Lynxio, a sleeve for an injured knee, reminds the wearer to exercise and records their progress (Imagination Catalyst 2014). For individuals who have trouble maintaining their balance, Sensoria developed a smart sock that alerts the wearer that they were falling (McGerry 2015). Celliant has created clothing that increases circulation and blood oxygen levels of diabetics (Schwartz 2011). Clothing is being interwoven with sensors for ECG and respiratory frequency detection and a portable electronic board for motion assessment, signal preprocessing, and Bluetooth connection for data transmission (Sarif Ullah Patwary et al. 2015). Nottingham Trent University researchers (Lugoda et al. 2015) are developing a heated glove liner to reduce the pain of Raynaud's phenomenon. Anderson and Anderson (2017) developed a glove cover for the first author to wear while riding her disability scooter, designed to blink while using bicycle turn signals. Erik deNijs and Tim Smit developed a pair of jeans that include a keyboard and mouse that attach wirelessly to a computer (Slack 2012). Harvard researchers are developing a fabric-based sensor that can eventually become a soft exoskeleton (McDonald 2017). Google and Levi Strauss (Bohn 2017) are weaving clothing with the ability to maintain contact with the user's digital world, thus providing a way for those who may have limited movement to maintain communication. For example, by tapping the cuff of the jacket, the student may be provided with control over communication methods enabled through Bluetooth. This can allow the student to communicate with friends, receive oral and visual directions, and play various media for entertainment (Fig. 3).

2.2.4 Smart Clothing for Learning Disabled

E-clothing shows great potential for individuals with problems in learning. Conductive clothing can store information, so that individuals who cannot remember a code to enter a door can have it stitched into clothing and simply wave the clothing in front of the door (Langston 2017). MiMu gloves help individuals create music, so that those who have problems learning written music or playing an instrument could produce music with this wearable (Shu 2014). Anouk Wipprecht developed a dress

Fig. 3 Glove cover made by Anderson and Anderson (2017)

that reflects emotions of those who wear it that could be incorporated into everyday clothing for problem learners to assess their emotions (Brown 2015). ShiftWear has created high-definition screens in sneakers that could be utilized to project learning videos for individuals with learning issues (Brown 2015). Indeed, the touchpad capability of conductive fabric such as that found in the Levi/Google jacket opens all kinds of aids that can be developed for those with learning problems, including tools for providing travel directions and time telling (Pierce 2017). The inclusion of capacitive thread in fabric, such as the Jacquard smart jacket developed by Google and Levi Strauss that allows the user to interact with digital tools, opens a large future for wearable learning, especially the potential for improving the lives of people with disabilities. Embedded sensors open a new way to communicate for those with hearing impairments, to navigate for those with visual impairments, and to maintain the health of those with physical disabilities.

2.3 Wearables with Microprocessors That Are Attached to the Body

Some wearables are worn as technology attached to the individual with disabilities. These types of wearables offer a wonderful potential for enhancing the lives of people with disabilities. Individuals with visual impairments can be aided by technology-enhanced contact lenses. People with hearing impairments are able to use this technology as hybrid cochlear implants. Individuals with physical disabilities have a wide range of prosthetics to choose from, while the development of computers that attach to the skin can provide an assistance for individuals with learning problems.

2.3.1 Body-Attached Wearables for Visually Impaired

Individuals with visual impairments have a number of attached wearables that assist them in operating within their environment. The Triggerfish is a diagnostic tool that helps measure the user for glaucoma (Duffy 2016). Ecole Polytechnique de Lausanne scientists have developed lenses that compensate for age-related macular degeneration (Senthilingam 2015). Second Sight has developed two prosthetics to aid those with retinitis pigmentosa, one that uses special camera-equipped glasses and one that involves implants in the brain (Mullin 2017).

2.3.2 Body-Attached Wearables for Hearing Impaired

Individuals with hearing impairments have technology that attaches to their body that helps with hearing. Hybrid cochlear implants can provide better hearing for some whose hearing loss can be pinpointed to certain pitches (Gandel n.d.). When the hearing loss is on one side, a bone-anchored device with an external sound processor aids in using bone vibrations to better hear (Gandel n.d.). Tobias Moser of the University of Gottingen is developing a cochlear implant that turns sound signals into light signals that are sent to the brain (Ossola 2017). Apple teamed with Cochlear to develop a cochlear implant that can be managed through the iPad or iPod (Buhr 2017).

2.3.3 Body-Attached Wearables for Physical Disabilities

Those individuals with physical disabilities have a plethora of electronic devices that attach to the body to improve their lives. The Navy has developed new smart prosthetic legs for veterans that integrate with bone and reduce sores that were prevalent in earlier prosthetic legs (Dujmovic 2017). Agrawal, Gailey, Gaunaurd, O'Toole, and Finnieston (2013) compared a smart Proprio prosthetic foot with a conventional one and found the Proprio to be more normal in behavior. Fairley (2014) reported that microprocessor knees resulted in less falls and better health, due to increased mobility. The iLimb prosthetic hand provides a much more normal hand movement that can be controlled from a mobile app (Ossur n.d.). Krishna (2017) created a smart prosthetic arm that is programmed to be controlled by the brain to move and grasp items. Johns Hopkins researchers developed an arm that can be controlled by brain activity (New York Times 2015). Researchers at Johns Hopkins are working on a hand that provides two-way communication to the hand, allowing the user to be able to feel touch as if it were a real hand (Wood 2015). The brain-controlled hand has become available for public use in 2017 (Bump 2017). Even those who have quadriplegic paralysis can be made to walk again. Arke (Bionik Laboratories n.d.) is a wearable exoskeleton with microprocessors, designed for those who use a wheelchair, that allows them to walk. ReWalk is another smart exoskeleton that is used for therapy for those in a wheelchair (Andrews 2017).

2.3.4 Body-Attached Wearables for Cognitively Disabled

Wearables that help students with cognitive impairments have begun tapping into brain activity or electronic pulses to stimulate brain activity. The Emotiv Insight measures brain waves as individuals interact with elements in the environment and claims to improve learning(Charara 2017). FocusBand is a brain training system that reduces stress yet trains the brain (Focusband n.d.; Saternus 2016). Narbis works with the user to focus on information (Gokey 2015).

Smart microprocessors offer a chance for prosthetics to act as natural appendages. Microprocessors can make the prosthetics behave more naturally and are more responsive. Hands, feet, arms, and legs move and perform tasks needed for daily living with the help of the mechanics and sensors that are now available. Continued improvements are being tested to make the prosthetics even respond to brain commands by the user with disabilities.

3 Applying Universal Design Principles to Wearables for Those with Disabilities

3.1 Universal Design and Universal Design for Learning

Wearables as accessories can be used to make the environment of the person with disabilities into a universally accessible environment. Story, Mueller, and Mace (1998) identified principles of universal design as "the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities (Story et al. 1998, p. 2)". Mace (1990) further identifies seven principles in universal design: equitable use or a design that is useful and marketable to people with diverse abilities; flexibility in use or a design that accommodates a wide range of individual preferences and abilities; simple and intuitive use or a design that is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level; perceptible information or a design that communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities; tolerance for error or a design that minimizes hazards and the adverse consequences of accidental or unintended actions; low physical effort or a design that can be used efficiently and comfortably and with a minimum of fatigue; and size and space for approach and use or a design that has appropriate size and space for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Researchers at the Center for Applied Special Technology used the principles of universal design and applied them to education, calling it universal design for learning or UDL (Center for Applied Specialized Technology [CAST] 2018). They defined UDL as "a framework to improve and optimize teaching and learning for all people based on scientific insights into how humans learn" (CAST 2018, "About Universal Design for Learning," para. 1). UDL contains the principles that to maintain access to quality education by all individuals, curriculum must provide the following: multiple means of engagement, multiple means of representation, and multiple means of action and expression. Multiple means of engagement refer to using a variety of curriculum means, such as books, presentations, or videos, to keep learner interested and engaged. Multiple means of representation suggest the curriculum include many different ways to provide information to learners, i.e., books, audio, pictures, etc. Multiple means of action and expression means that learners have varied ways of proving what they know, i.e., presentations, videos, book reports, etc.

Universal design for learning will utilize not only standard curricular tools but also assistive technology. Wearable technology can be recommended by special education assistive technology assessment teams for students with disabilities. Thus, wearable technology can become part of the myriad of tools that can be used to meet UDL principles.

3.2 UDL and Wearables Used as Accessories

Wearables that are designed for people with disabilities play a role within a UDL classroom. Those wearables that work as clothing accessories allow for a discreet presence and use in a UDL classroom. They are part of the tools for meeting multiple means of engagement, representation, and action and expression for multiple types of disabilities.

3.2.1 UDL, Wearables as Accessories, and Hearing Impaired

Individuals with hearing impairments have several wearable options that meet UDL guidelines. The Q band which wraps around the palm of the hand translates speech to text that appears on a band on the hand, allowing the teacher's remarks to appear on the palm of the student with hearing disabilities, allowing them to participate in classroom discussion (Core77 n.d.). This represents the UDL principle of multiple means of representation for students with hearing impairments. The vibrating watch such as that made by Apple (DHN 2015) will help the student keep track of time within the classroom as he/she does their work. Wavio will help the student to tune into sounds that it translates to a phone, allowing the student to identify sounds, meeting the requirement under UDL for multiple means of representation. With proper programming, Wavio can assist classrooms that need the student to identify sounds that might be produced on devices within the classroom as Wavio captures classroom sounds that have been previously programmed into the device, thus meeting the requirement of multiple means of representation (Watkins 2017).

3.2.2 UDL, Wearables as Accessories, and Visually Impaired

Wearables for blind or visually impaired focus primarily on communication and navigation. The Braille dot smartwatch (Pulvirent 2017) helps the blind in the UDL classroom to identify times for activities or using the Omate smartwatch with built-in Alexa (Lai 2016) can use programmed Alexa commands to control the classroom environment for the student with visual impairments. OrCam's MyEye 2.0 (Holton 2017) and like devices communicate with the visually impaired student to identify elements in the classroom environment and to communicate with classmates.

3.2.3 UDL, Wearables as Accessories, and Physically Disabled

Students with physical disabilities can benefit within a universal design for learning classroom, thanks to wearables. The Myo armband (Eadicicco 2016) or a headmouse can be used as mice for students with physical disabilities who cannot use a traditional mouse. These devices allow the physically disabled to utilize the principles of multiple means of engagement, action, and expression. Both the Myo armband and headmouse provide a way to interact with a computer or tablet. A Sesame phone allows for all three principles of UDL. With a Sesame phone, the student with significant physical disabilities can communicate with others, type, and play games, all three of the principles of UDL. An exoskeleton allows students with physical disabilities to move to activities or with activities.

3.2.4 UDL, Wearables as Accessories, and Emotional Behavioral Disabled

Students with emotional behavioral disabilities benefit from wearables within a UDL classroom. The definition of EBD is that emotional difficulties are the source of learning problems within the classroom, both academic and behavioral. Wearables can determine when students or teachers need to allow EBD students to destress, to renew their ability to benefit from the classroom instruction. These wearables, like the Feel armband (Beck 2016), show users when the user is becoming stressed. The Thync (Brinson 2017) will actually modify the brain electromagnetic pulses to make the EBD student feel less stress to benefit from the classroom.

3.2.5 UDL, Wearables as Accessories, Learning Disabilities, and Cognitive Disabilities

Wearables play a role in the UDL classroom for students with learning disabilities. Typically, academic issues with students with learning disabilities and cognitive disabilities include reading and writing issues. Special education professionals have several wearable options to select from to facilitate the successful involvement in the UDL classroom. The Instapaper connected to an Apple Watch (Freeman 2016) will also read articles to them. Even the Levi/Google jacket will read phone messages to the student through their phone (Pierce 2017). Difficult concept mastery can be enhanced through the use of virtual reality glasses such as the Hololens (Fearn 2016). These wearable devices answer the UDL principles of multiple means of representation and engagement. To address the principle of multiple means of expression, the GoPro offers a way to record assignments, rather than write them (Kearns 2016). The GoPro is a small portable camera that can be worn by the user and used to record still pictures or video of directions or assignments being given, as well as of items for completing assignments. For a student with writing problems, the camera can provide a visual record of key elements needed for completion of the assignment or project.

4 How Wearables Aid Universal Design for Learning in the Classroom: Two Selected Case Studies

Wearable technology devices can become tools for developing a successful classroom that uses universal design for learning principles, incorporating multiple means of engagement, representation, and action and expression. Another tool in the UDL classroom is an assessment tool called the SETT framework: students, environments, tasks, and tools (Zabala n.d.). Essentially, using this assessment, the special education assistive technology assessment team asks questions about the strengths and weaknesses of students with disabilities, the environments that they must operate in, and the tasks that they need to do and then recommends tools that can be piloted with the student with disabilities within the classroom. In this part of the chapter, two case studies of students will be described. The students undergo the SETT assessment and then are recommended for wearable technology to ensure successful involvement in the classroom that follows the principles of the UDL classroom. The following case studies describe students who were the students of one of the authors in the special education setting.

4.1 Traumatic Brain Injury

James is a student with a traumatic head injury as a result of a car accident. He was in a coma for 6 weeks, and when he emerged from the coma, he had to use the services of the rehabilitation facility to regain lost cognitive and physical skills, so that he could return to school. He had major head trauma that resulted in cognitive issues and a weakness in his dominant hand. As a result of his head injury, he has difficulty with his memory and cognition. He has trouble remembering the steps to tasks, was behind in grade-level work, and frequently did not know the time of day or events around him. He has difficulty paying attention and is often distracted. He experiences stress frequently, with uncontrolled feelings leading to inaccurate assessments of situations.

The district uses the students, environments, tasks, and tools, i.e., SETT (Zabala n.d.) framework, for assessment of assistive technology needs to determine tools needed in a classroom following universal design for learning principles. This framework looks at the strengths and weaknesses of the students, the environments that they live in, and the tasks that they need to accomplish. Then it offers tool recommendations for a test period.

James' head injury needs have been described, but he was also a student who hated to be viewed as different, so the special education decision-making team felt that he needed the most unobtrusive technology for him to be willing to use them to help him be successful in his classroom.

The SETT process required that the strengths and weaknesses of the students be listed first. James had a brain injury whose deficits were listed earlier. His strengths included a willingness to work with professionals if they met his desire to have his assistive technology be unobtrusive. His environmental needs included compensation for the weakness of his writing hand and his academic needs.

The third step was to outline tasks required by the classroom. The special education team listed these as a step in the SETT process. They included a way to keep track of James' schedule, a way to read or learn the material, and a way to do the assignments. They also worked with the rehabilitation team to suggest the most lifelike prosthetic foot for James to get around the school.

The team looked to wearable technology first for its unobtrusiveness to help James feel comfortable wearing it and using it. James was offered an iPad to use to type and turn in assignments. To help James with his reading issues, the special education team recommended Instapaper with an iPhone to read text sources assigned by the teacher, thus meeting the UDL principle of alternate means of representation. Vue glasses were suggested to help James keep track of a schedule and to use its microphone to record assignments to turn in, thus meeting the UDL principle of multiple means of expression. To help write his assignments, they recommended a headmouse to work with his iPad to aid with navigation and selection, meeting the UDL principle of multiple means of engagement. The team also recommended that he wear the Levi/Google jacket to communicate with the teacher to keep him on task. To deal with his emotional needs, the special education team recommended a Reveal to measure James' stress level, to offer some alone time to destress.

4.2 Blind

Mary was born blind. After several years in the state school for the blind, Mary and her parents advocated for her to attend the local public school for her middle school years, so the special education team used the SETT model of assistive technology assessment to help ease her transition into the public classroom.

Using the SETT model, the special education team looked at the tasks that Mary would need in her new school. They determined that they needed to look at navigation tools for her to get around the school and read time to get to classes. She needed a way to see the whiteboard. She needed a way to show her mastery of concepts. Looking at these needs, the special education team began to make recommendations for devices. Since Mary read Braille, the team recommended a Braille dot smartwatch that would allow Mary to not only tell time but be in contact with her teacher. At the same time, they recommended an Omate watch for the other wrist so that the classroom could be programmed for Alexa commands, allowing Mary to use voice commands to print her work. To supplement Mary's blind cane skills, the special education team recommended that Mary acquire Maptic jewelry. This jewelry provided assistance for Mary to navigate around objects in her vicinity. The vibrations provided by the jewelry warned her of objects above her knee level that might provide an obstacle to walking in the classroom and other locations.

Looking at these two case studies, we can see that wearables can play a role in enhancing the learning of students with disabilities within the framework of universal design for learning. Students can use these wearable devices to meet their individual needs, whether it be a change in how information is provided to the student, how they remain engaged in the learning, or how they demonstrate their mastery of the information.

5 Conclusions

Wearable technologies area develops field that helps individuals with disabilities to improve their lives. With access to wearable accessories such as watches that vibrate or take Alexa commands, jewelry that navigates, or palm bands that translate speech to text, daily living and learning become easier for students with disabilities. Embedding sensors into clothing will make access to the digital world ubiquitous for people with disabilities. Prosthetics that include microprocessors are becoming more and more natural in their behavior and uses and show promise of eventually being controlled directly by the brain, thus increasing access to the classroom for students with disabilities. The world of wearables is definitely bright for improving the world for students with disabilities.

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Toward Wearable Devices for Multiteam Systems Learning

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1 Introduction

Multiteam systems (MTSs) are "tightly coupled constellations of teams offering specialized skills, capabilities, and functions aimed at attaining goals too large to be performed by a single team" that are interdependent (DeChurch and Marks 2006, p. 311). Although most fire and emergency response contexts in the United States involve multiple teams, existing research and workforce training aimed at fostering effective fire response and patient care have primarily focused on individual and single team preparedness. Effective coordination requires a focus on both within- and between-team interactions as they work to attack the fire and save lives together as a system. The promise and challenge of wearable devices for MTS learning and training are revealed when attempting to instrument a complex, real-world setting with sensor-based devices in an exploratory MTS case context. This case study encompasses two simulation scenarios and a technology system that attempts to automatically and seamlessly capture the proximity of individuals and equipment to designated personnel in real time when situated in live fire rescue simulation contexts with wearable devices to reveal insights related to learning and performance.

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Our team has embarked on an educational design research effort involving iterative cycles of research and development toward this objective over the last several years (Bannan-Ritland 2009). Prior work has reported cycles of data collection and analysis in these live emergency response simulations leveraging wearable sensor devices that generate information about proximity, spatial coordination over time, and biometric analysis in challenging real-world conditions (Bannan et al. 2017; Dubrow et al. 2017). The case study reported in this chapter is part of an ongoing design research cycle to uncover the most meaningful points of data that shed light on how multiteam systems may function and ultimately learn from related data visualizations. The case study and two related simulation scenarios are summarized, along with exploratory results that describe the conceptual framing and challenges of this design research effort. Design research is often employed when little theory or understanding exists of a context exists and consists of an "... interventionist, iterative, process-focused, collaborative, multilevel, utility oriented, and theory driven" approach (Kelly 2006, p. 107). The long-term objective of this exploratory study is to progressively work toward seamless capture, processing, and representation of multiple data sources in complex, real-world multiteam contexts. Exploratory wearable device data collection and near real-time analysis is presented here; however, the ultimate goal is to leverage these findings to richly inform learning and training through real-time visualizations of sensor-based data that build on those illustrated in this chapter. These methods have been implemented across several design research cycles and teams including fire and rescue, emergency medical services, and hospital teams engaged in several live, in situ, simulation scenarios (Bannan et al. 2017; Dubrow et al. 2017). Our exploratory work continues as we begin to more clearly identify both the promise and challenge of human sensing analytics through wearable devices and wireless connectivity when teams are engaged in simulated high-fidelity, high-stakes, multiteam contexts for training.

The teams described in these scenarios must coordinate and work together in order to provide continuous care for patients while simultaneously addressing the emergency (e.g., car accident, house fire) to ensure optimal outcomes, often in dangerous, dynamic, and fast-paced situations. The importance of team-based learning and training has been a focus of organizational psychologists and learning scientists for the last several decades. However, more complete understanding of the science of team science, especially from an MTS view, still remains a challenge, especially for sensor-based empirical investigation when attempting to address behavior and learning both within and across teams as described below.

2 Learning and Training in Teams

While individual team training and team learning have been continually investigated and improved since the early 1990s (e.g., Abrahamson and Fairchild 1999; Edmondson et al. 2001; Salas and Cannon-Bowers 2001), training component teams in MTSs have received little attention. As a case in point, Firth and colleagues (2015) represent one of the only reports to address MTS training in an empirical study. Many additional theories related to individual team training exist, such as crew resource management (CRM) training in aviation teams (Salas et al. 2001). Aviation team researchers found that many of the problems that led to fatalities in aviation were due to a lack of teamwork skills, as opposed to a lack of ability to complete individual tasks. The purpose of crew resource management is to leverage both taskwork and teamwork skills training. Over time, single teams are able to learn as a collective unit and improve team performance. Four common team training strategies include cross-training, team coordination, and adaptation training, and guided team self-correction training (Salas et al. 2007). Cross-training, where individuals learn the jobs of their other team members (or, at the MTS level, teams learn the roles of other teams), can be used to build shared understandings of each player's role in the system (Firth et al. 2015). The purpose of cross-training is to develop shared mental models and a common understanding of each individual's role on the team, to later promote team coordination and backup behaviors from teammates when appropriate (Marks et al. 2002). Team coordination and adaptation training, which was found to be one of the most useful training systems for team effectiveness, allows for reduction in the amount of communication necessary between individuals and teams by preparing teams for unexpected changes before they occur. Finally, guided team self-correction training is focused on teams learning to diagnose and solve problems, thus creating shared expectations and shared mental models across the team or system.

2.1 Wearable Sensors for Team Learning and Training

Wearable sensor-based technology to investigate team learning and performance can include real-time, automated, seamless data collection with technologies such as radio frequency identification (RFID) tags, infrared sensors, video and audio recording devices, and accelerometers (Parlak et al. 2012). Rosen and colleagues suggested an input-mediator-output framework for automated sensor-based measurement of teamwork with the integration of various data sources (Rosen et al. 2014). These data sources deliver a form of activity tracing to provide information collected about team member's interactions with other team members, equipment, and tasks. According to Rosen et al. (2010), team performance evaluation can be operationalized as the establishment of standardized diagnostic measurement tools to assess the behaviors, cognitions, and attitudes enacted by team members in relation to clearly operationalized criteria. As such, evaluation is designed to provide information not only on *what* outcomes the team achieved, but also *how* they reached these outcomes. Rosen et al. (2010) recommend that in order to comprehensively evaluate team performance, training designers must employ multiple measurements which capture the behavioral, cognitive, and attitudinal components of performance at the team level. This also means capturing diagnostic information on individual team member roles, teamwork, and tasks in order to potentially provide targeted corrective feedback. This presents a challenge for wearable sensor-based technology both empirically and technically as obtaining continuous streams of data from multiple devices in real time to measure dynamic phenomena such as team-based and multiteam system behavior in real-world settings requires deep understanding of the context and the constructs of interest (Luciano et al. 2018).

2.2 Toward Sensor-Based MTS Coordination Measurement

Beyond role-based *taskwork*, team players rely on *teamwork* skills to work together effectively. In multiteam systems, however, another layer is added, and *MTS work* (or *system-level work*) needs to be additionally explored, addressed, and trained. While task-based training is focused on the skills one needs to complete a job or reach a goal, team and MTS work are focused on working together by collaborating, coordinating, and communicating within and between teams, to successfully work together as a unit or system.

Very few studies focus on cross-team behaviors and human behavioral analytics to inform learning and training for multiteam systems (Rosen et al. 2014; Zaccaro et al. 2012). Only a few studies were identified leveraging these techniques to capture data under real-world conditions (Olguin et al. 2009; Feese 2014). Assessing the collaboration within and between teams has traditionally been addressed through observations of constructed manipulation of team-based tasks in experimental scenarios or retrospective self-report (Asencio and DeChurch 2017; Davison et al. 2012). These studies do not access the authentic environment and provide the ecological validity that a live simulation context supports. In addition, sensor-based data collection provides a new layer of information to investigate both within- and between-team behaviors simultaneously and in detail through unobtrusive fine-grain mobile behavioral analytics that go beyond what is possible by human observation. The case study reported in this chapter captured and visualized the proximity of individuals to equipment (e.g., fire engine on-scene) or other individuals on different component teams (e.g., the medic on the emergency medical services team), in situ, using various data collection methods to provide some indication of coordination within and between teams in fire and rescue contexts. Similarly, Feese and colleagues leveraged smartphone sensor data to determine how long team members were together in subgroups and how and when synchronized movement occurred among different team members (Feese et al. 2014). Typically, these studies have involved a priori defined patterns of interactions and well-defined behavioral expectations. For example, Vankipuram, Kahol, Cohen, and Patel (2011) studied interaction patterns of trauma resuscitation teams with very clearly identified interactions and sensor-based measurements. Conversely, Isella and colleagues explored patterns of interactions on a pediatric unit with low specificity or spontaneity of interactions in an exploratory or descriptive analysis to prevent infections (Isella et al. 2011). Capturing a priori designated and impromptu individual movement or proximity related to role and task is challenging in real time under real-world conditions but may be fundamental to revealing team-based and multiteam system behaviors. The promise of unobtrusive, automatic measurement for individual, team, and cross-team well-defined and spontaneous behaviors to inform learning and training is great; however, as stated previously, this form of measurement presents inherent challenges and a significant need for additional research described below.

2.3 A Pathway for Future Research

Learning and training in MTSs is an unexplored research area. Additionally, there are very few extant studies that address wearable sensor-based measurement of cross-team behaviors. The meaningful linkage of multiteam systems constructs combined with the potential of sensor-based and multiple methods measurement of team behaviors to inform learning remains to be fully explored. Several areas of investigation are promising to explore with wearable sensor-based devices for learning in multiteam systems research, and our work is just beginning to attempt to address these in areas, including leadership.

In multiteam systems, the investigation of leadership is also an established need in the literature as leadership is often executed collectively, rather than by one individual (Davison et al. 2012). Thus, many MTSs have a leadership team that must be specifically trained to lead both their component teams and the entire system (Davison et al. 2012; Lanaj et al. 2013). This is potentially the biggest training need and the most significant area for future research to examine. In order for this to be effective, leaders must know what is required of them in both their roles as team and MTS leaders (Lacerenza et al. 2014; DeChurch and Marks 2006).

Sensor-based measurement and visualization of multiple data sources in near real-time (e.g., in the simulation debrief or after action review) may hold the potential to uncover important interactions and insights about the roles and responsibilities of multiple teams in an MTS goal hierarchy (Rico et al. 2017), as well as to inform leadership within and between MTS component teams to move toward a shared mental model and improved coordination among teams. However, Luciano et al. (2018) caution that these technologies introduce new methodological and validity concerns in measuring dynamic phenomena such as multiteam systems and their change over time with heterogeneous data sources (e.g., proximity sensors, video, audio, etc.). Luciano and colleagues recommend seeking a measurement fit sensitive to the context to identify an appropriate "frame" of measurement (Luciano et al. 2018). We view our work with wearable devices for learning in multiteam systems at a stage that is just beginning to unpack the complexity of the emergency response context and the possibilities of real-time sensor-based measurement. As Luciano and colleagues imply, additional iterative cycles of design research will be needed to achieve the targeted longitudinal data collection and analysis related to determining the *how* and *why* of targeted multiteam systems phenomena and how related constructs emerge and change over time (Luciano et al. 2018).

3 The Wearable Learning Prototyped System

Our designed wearable learning prototype primarily leveraged proximity sensors that permitted designated team members across several teams to continuously and seamlessly record their proximity to strategically placed "listening devices." The wearable sensors fit in each designated team member's pocket emitting a Bluetooth relative strength signal every 3 seconds that is received by the listening device of a smartphone or microprocessor. The physical placement of these listening devices or microprocessors in the simulation scenario is an analytic decision determining what data may be collected in the context. The listening device sends this data to the cloud for processing which then is visualized back to the teams in near real-time during the debrief session immediately concluding the simulation. Each team member's proximity to the listening device is continually recorded providing a human analytic data trail across time and context. In other simulation runs, we have incorporated biometric data from wearable devices as well as proximity but connectivity problems with the Microsoft bands prevented this data collection in the simulation scenarios reported here.

Emergent and ongoing research questions related to multiteam systems include the following questions related to the combination of qualitative and quantitative data in this mixed-method exploratory study:

1. How can human sensing analytics through wearable devices specifically inform within- and between-team interactions in live simulation exercises?
2. How can near real-time data from wearable proximity sensors inform team-based reflection and learning?
3. What can this data tell us about team coordination, leadership, and adaptation within and across teams?

The specific desired learning outcomes are to leverage sensor-based data from wearable devices to provide enhanced information in the debriefing session for reflection to promote team coordination both within and across teams. Reflection-on-action (Schon 1983) by these teams through the visualized sensor-based data and more detailed analysis of selected segments of the video/photo data provided during the debrief may begin to create shared expectations and mental models across the team or system and potentially build these mental models over time across multiple simulation runs. These new forms of feedback through in situ, behavioral analytics could augment and enhance current simulation training scenarios. Video is often leveraged in simulation training to provide audio and contextual information; however, it is very time-intensive when leveraged for behavioral analysis. In this case study consisting of several simulation scenarios testing the technology system, we leveraged video as part of the multi-method approach to further analyze the within- and cross-team behaviors as well as to validate the sensor-based data. The planned use of the biometric data was to incorporate measurement of stress (e.g., heart rate, blood pressure, and galvanic skin response) to then align with the behavioral data as another data stream for reflection on learning. For example, if two individuals on different teams had similar biometric responses at the same point of time and similar proximity to the patient activity patterns, this may indicate some type of coordination between teams. As stated previously, we were unable to incorporate this biometric data during these scenarios due to connectivity issues with the Microsoft bands. The two scenarios incorporating the sensor and video data collection are described in detail below.

3.1 Case Study: First Simulation Scenario

The first live fire and rescue simulation described in this case study involved a simulated fire in a garden apartment in a designated burn building used for training at a Fire and Rescue Academy in the Mid-Atlantic region of the United States. This type of live scenario provided a realistic training environment where field units were able to take part in learning and training scenarios which would not be feasible while engaged in their regular duties or at their firehouse locations. The reality-based training scenario involved several units or crews with both professional and volunteer firefighters and paramedics training together in a real-world condition. The scenario allowed field personnel an opportunity to practice fireground skills under semi-stressful conditions with available resources and expectations that aligned closely with their regular operating environment. This first scenario was created to highlight the importance of apparatus positioning, quick and efficient hose line deployments, hose line management, fire attack, proper laddering, and quick and effective searches as well as to evaluate the command-level and company-level decision-making with tactical skill proficiency. We focused on the intersection of two fire and rescue teams from two different engines in the first simulation and in the second simulation focused on the emergency medical services team personnel interacting with the fire and rescue team. We analyzed how these teams worked together within their component fire and rescue team through their interaction with a standardized patient or victim with third-degree burns (e.g., an individual trained to act as a real patient to simulate a set of symptoms or problems) and then how these teams worked across their component teams (e.g., fire and rescue teams with the emergency medical services team).

The scenario begins with an alert by a *dispatch team* for a fire in a garden apartment situation that has been observed in the kitchen and bedroom of the building. The battalion chief and EMS captain receive calls in their vehicles that display on their mobile computer terminals. The notes for the call indicate that the caller is unsure if the occupants are home or not. The first units arrive on-scene to find a garden apartment building with smoke visible. Crews arriving on-scene need to establish water supply, force entry, advance hose lines into the structure to attack the fires, perform initial rapid intervention functions (e.g., at least two firefighters ready to react if a firefighter is in need of assistance in any immediate dangerous situation), complete searches, locate/remove/assess civilian victims, and extinguish fires. The design of this particular scenario included additional stress and fidelity with the inclusion of a live victim as the standardized patient running out of the building with third-degree burns, clearly in distress, toward the first engine to arrive on-scene. The firefighter teams need to react, care for the patient, and address the fire.

Within this simulation exercise, as the first engine arrives on-scene, the officer directs the crew to interact with the patient who comes running up to the engine. This frontline suppression unit or engine has four personnel on board assigned to specific riding positions and responsibilities. The engine crew is equipped with (1) a driver who is responsible for emergency vehicle response and fireground operation of the apparatus; (2) an officer-in-charge between the rank of lieutenant and captain who is responsible for the entire unit and all personnel on board, directing the team and communicating status updates to the battalion chief once on-scene; (3) the “left bucket” firefighter/paramedic often referred to as the “medic on the engine” sitting behind the driver who is the lead medical provider on the unit; and (4) the “right bucket” sitting behind the officer who is typically a firefighter/EMT. In this fire and rescue department, all personnel are typically trained to the emergency medical technician basic level.

The first simulation scenario focuses on the within-team interactions of the first engine personnel and then between-team interactions of the first and second fire and rescue engine teams. The second simulation scenario setup was similar with the exception of incorporating a house fire rather than an apartment fire but also included the live burn patient in distress. The second simulation scenario incorporates only an analysis of the between-team interaction.

3.1.1 Simulation Scenario 1: Within-Team Interaction

In this scenario, we were able to capture data in near real time, with the wearable sensor devices detecting the varying proximity (e.g., near and far position) of several members of the crew from the first fire engine across time (see Fig. 1).

This representation of the proximity of the officer and the left bucket firefighter/paramedic to the fire engine over time in the scenario was captured in near real-time in a continuously progressing and dynamic scene as the burned patient is being addressed by the first engine crew. This pilot data suggests some synchronicity of within-team interactions. For example, the data imply that the officer and the left bucket firefighter are moving between the engine and the patient to address his needs changing their proximity to the engine over time. Their movements seem to align and are further supported by video and photos presenting the inference that these two roles may be addressing the stressed patient while obtaining and working with the necessary medical equipment.

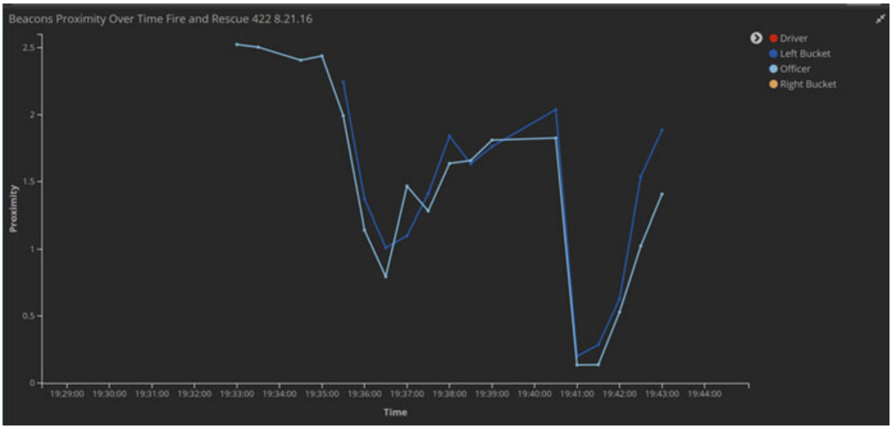

Fig. 1 Proximity sensor data from officer and left bucket firefighter/paramedic with their proximity to fire engine over time during simulation

3.1.2 Simulation Scenario 1: Between-Team Interaction

A few minutes later, the second fire engine and emergency medical services medic unit vehicle arrives and the personnel from this MTS begin to collaborate, coordinate, and communicate to address both patient care and firefighting responsibilities. The first engine driver at one point during the action left her primary responsibility in securing the water supply and assisted the fighter/paramedic with the patient attempting to help him to the ground, and then she returned to the fire hydrant. The first engine firefighter/paramedic or "the medic on the engine" attempted to cover the patient/victim with a blanket, while the driver on that team worked toward establishing the water supply by opening the fire hydrant and positions a backup line ensuring access to a fire department connection. Soon after, the emergency medical services (EMS) team arrived with the senior paramedic, who has the most medical training, who then assumes leadership and direction of patient care from the firefighter paramedics (see Fig. 3). The EMS senior paramedic will indicate when the first and second engine personnel can return to their other assigned duties and assume responsibility and treatment of patients as well as identify egress or a way to exit to transport the patient to the hospital.

3.1.3 Simulation Scenario 1: Analysis of Observational and Sensor-Based Data

There are a total of five teams typically involved in a fire and rescue incident of this magnitude with a battalion chief (see Fig. 2). The overall fire and rescue scenario provides an illustration of a multiteam system with our analysis focusing on three component teams (first engine, second engine, and EMS) and collected sensor data

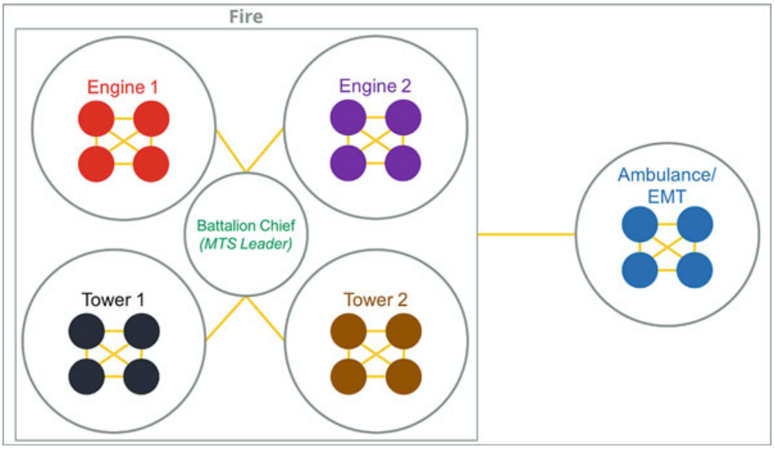

Fig. 2 Fire and rescue MTS structure. (Figure from Dubrow et al. 2017)

only from the first engine and emergency medical services teams. Each of these teams with their specialized skills and functions on-scene works together to attack the fire and provide an optimal continuum of care for patients.

Within- and between-team interaction and coordination were identified in the sensor, observation, and video/photo data from on-scene initially when the officer and first engine firefighter/paramedic first addressed the patient and then as the first engine officer, firefighter/paramedic, and second engine firefighter cared for the patient prior to the handoff of the patient to the EMS paramedic. The teams seemed to focus both on within-team tasks (e.g., initial treatment of the patient and establishing water supply/backup line) and the interaction between the first engine and second engine teams to transfer of command and control and patient from the first engine firefighter paramedic to the senior paramedic from the medic unit.

We identified a unique segment of action when the captain and the "left bucket" firefighter especially demonstrated some aligned coordination of proximity to and from the fire engine captured in real time through wearable proximity sensors as they began to deal with the burn victim (see Fig. 1). This processing and visualization of the proximity data (see Fig. 1) seems to indicate some within-team coordination through synchronization of movement by the two individuals (Feese et al. 2014). Ultimately, we hope to be able to visualize the within-team and cross-team behaviors over time and multiple simulation runs in order to detect any major changes or anomalies in activities on-scene or provide some comparisons of related time event data.

Beyond the individual levels of behavioral tracking, however, Fire and Rescue MTSs take on an incident command structure (e.g., Buck et al. 2006) which includes specific protocols regarding the roles of each team, and how team and individual roles changed based on events, such as the presence of the live victim in this scenario (DeChurch and Mathieu 2009). Several MTS studies speak to this type of leadership structure (e.g., Davison et al. 2012; DeChurch et al. 2011; Lanaj et al. 2013). One example of *leadership switching* occurs at the beginning of a fire event. The officer of the first engine to arrive on-scene becomes the MTS leader until the battalion chief comes in approximately 5–6 minutes later. This is an example of both rank- and function-based leadership switching. We hope to be able to leverage sensor-based data streams triangulated with other digital data sources to begin to track and analyze these points of leadership switching in the fire and rescue context.

The standardized patient who came out of the burn building and approached the first engine team needed immediate attention, so the officer was initially established as the leader on-scene responsible to direct his crew to deal with the patient as well as address the fire and also responsible for a sweep of the outside of the building to look for any other potential victims requiring a high level of situational awareness. The fire paramedic also needs to maintain high situational awareness to identify when the transport unit arrives so that they can make the handoff as fast as possible and then get back to their own team roles and responsibilities.

This case study scenario involves several moments of intense between-team interactions referred to as *inflection points* (Dubrow et al. 2017). For example, there is a point when the second engine may decide that the first fire paramedic needs backup, and send in an additional paramedic to help. The MTS members at work here are the two officers and the two fire paramedics (one of each on each team) and the driver who is outside of the building and assists with the patient until and then finishes her initial task of getting water out of the fire hydrants (see Fig. 2). A second multiteam system inflection point occurs when the medic unit arrives to transport the patient and this crew of a driver, senior paramedic, and junior paramedic interact with the fire engine crews related to the patient. The second scenario demonstrates our iterative data collection and analysis of this multiteam system interaction.

3.2 Case Study: Second Simulation Scenario

The second simulation scenario involved similar team activities and objectives, however, took place in a two-story, single family home burn building with real smoke and fire. The scenario involved several simulated patient mannequins and a standardized live patient. In this scenario, a different first fire engine crew with similar roles (e.g., driver, officer, right bucket firefighter, and left bucket firefighter paramedic) arrives on-scene to attack the house fire along with another medic/transport unit with different roles on board (e.g., medic officer, driver, medic, emergency medical technician).

3.2.1 Simulation Scenario 2: Between-Team Interaction and Analysis of Observational and Sensor-Based Data

In the second scenario, we looked to identify the multiteam inflection points in the observational field notes, subsequent video analysis, and near real-time proximity sensor data. A multiteam system inflection point evident in the second scenario was identified as when the medic/transport unit arrives on-scene. At that point, the firefighter personnel intersect with senior medic officer or paramedic, and junior paramedic, emergency medical technician, and driver in the medic/transport unit. This interaction is demonstrated by illustrating the point of medic personnel and fire and rescue personnel interaction surrounding a patient mannequin pulled from the house fire.

The two teams begin to interact together to establish the highest level of care for the patient available, and as the senior paramedic has the most medical training, he or she will assume leadership once on-scene as stated earlier. The two leaders (e.g., the medic officer or senior paramedic and the fire and rescue officer) will typically intersect to direct their team members in this leadership switching. This point at which these two teams began to interact was captured by the sensor data in Fig. 3 with the members of the medic/transport unit in shades of red and the fire and rescue unit members in shades of blue. The medic unit team members (represented in shades of red and orange) stay in close proximity to the medic (who is wearing the listening device or microprocessor) demonstrated by detection of the proximity signals emitted by the wearable sensors on each personnel. The fire and rescue team officer moved in closer proximity to the medic who was wearing the listening device and the EMT medic officer moved farther away from the medic as demonstrated by the red and blue line converging (see Fig. 3).

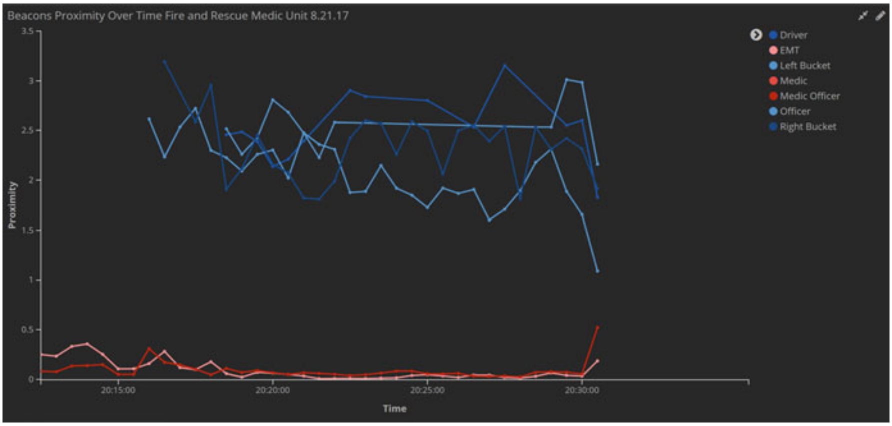

Fig. 3 Firefighter team and emergency medical services team members' proximity to EMS medic (wearable listening devices) on-scene

In this near real-time pilot data, we have begun to visually represent some within- and between-team interaction through proximity to a person or vehicle wearing or subsuming the listening device. The cross-team interaction can be demonstrated at particular inflection points and visualized in near real-time. The cross-team interaction visualized by the sensor data streams is triangulated with and further validated through multiple data sources such as field notes, observational data, and video data.

The leadership switching in this situation is of particular interest as it is both rank- and function-based, such that the senior paramedic takes over patient care from the fire paramedic due to rank (i.e., being more senior) and function (i.e., it is their job to take over). This handoff must be fast, exhibiting a strong shared mental model and transactive memory system (Kozlowski and Ilgen 2006) because the patient needs to be attended to quickly and the fire team members need to get back to their teams and responsibilities. Much more is involved in mapping the MTS related to each team's proximal goals and the MTS distal goals as well as the interdependence between each team to analyze these episodes in an in-depth manner. Our pilot data presented the potential to begin to leverage proximity, observation, and video data to inform within-team and cross-team interaction in real time, on-scene. Collecting relevant data to index interactions between teams and leadership switching to detect patterns or changes in patterns of behavior for learning and training comprises the ultimate goal of our research. These cycles move our research closer to this goal with each iteration of research and development.

4 Informing Learning in the MTS Through Wearable Learning Devices

As we have demonstrated, wearable devices such as proximity sensors have the potential to provide a new window into multiteam systems interactions and participant behavior to also potentially inform learning through visualization of within- and between-team behavior and provide important reflection-on-action on this behavior in the debrief. Our exploratory work demonstrated that continuous sensor-based data can be leveraged for capture, processing, and visualization of human analytics in near real-time in order to provide a more detailed view of within- and between-team interactions to use for participant and team monitoring, reflection, and learning. These sensor-based analytics were shown to the firefighting crew leadership immediately concluding the second simulation scenario for input and improvement of the visualizations and learning. The firefighters input into the implementation, and trial of this system for learning is crucial for identifying the most meaningful points of wearable proximity data capture and analysis in this complex setting to best inform team-based reflection and learning. This iterative design research approach provides cycles of improvement and targeted identification of meaningful points for the detailed data analysis with multiple data sources to uncover and visualize within- and between-team behaviors.

The visualization of this data in near real-time and integration of data sources revealed new insights into important inflection points within and between teams that provided some evidence of coordination as well as revealed some information on leadership behaviors. We continue working toward individual and team-based data capture and meaningful visualization of these collaboratively identified, important inflection points between teams in this dynamic and complex setting to attempt to impact experiential, reflection-on-action learning in near real-time, on-scene, immediately following the live simulation. We are just beginning to uncover the complex contextual details of this multiteam system and component team behaviors over multiple runs of these two scenarios to identify the optimal inflection points for sensor-based data collection, visualization, and analysis.

This mixed method and multi-stream data analysis approach leveraging human sensing analytics and other data sources can provide enhanced information on team-based activity in a live simulation scenario. The importance of triangulating and validating sensor-based data sources with other sources of data to include observation field notes, video, and audio data streams cannot be understated (Dubrow et al. 2017). This new form of triangulation provides validity evidence when dealing with multiple disparate real-time data sources to inform measurement of team-based behaviors (Rosen et al. 2014). Once the MTS inflection points and associated activities have been clearly identified for a given scenario, then the progression toward automated capturing and visualizing patterns of targeted behavior in the debrief over time and simulation run can provide more detailed evidence of team-based learning for multiteam systems. Most importantly, this will then allow for mining for changes in these patterns of behavior within and across teams, for reflection by the teams at a systems level that may provide important insight into MTS learning and training.

5 Future Goals

The ultimate goal for this wearable devices data collection system to address multiteam systems learning is the real-time, seamless, and unobtrusive capture, mining, and visualization of multiple digital data streams representing each team member, each team, and the multiteam system actions in situ across time and multiple simulation runs. Visualizing and reflecting on this information on-scene and in the debrief or after action review may potentially build toward a shared understanding of each player's role in the system and progress these teams toward developing shared mental models to potentially improve team and cross-team coordination, backup behaviors (Marks et al. 2002), and team-based reflection for learning. It may also promote the visualization of cross-team behavior from a system's view to promote individual and team-based learning to better understand how each individual's behavior contributes to the whole of the activity to influence the system. Most importantly, it would allow fire and rescue and emergency medical teams the opportunity to potentially engage in targeted visualizations of near real-time data for team learning to diagnose and solve problems in situ, creating shared expectations and mental models across the team or system to potentially improve patient care and save lives. Current and future studies may consider a multiteam systems view in emergency response contexts (Lazzara et al. 2015) while also considering the important affordances and constraints of wearable sensors for developing theory and assessing validity of the data (Luciano et al. 2018; Kayhan et al. 2018).

6 Conclusion

Illuminating parts of the multiteam system in the fire and rescue emergency context with human sensor analytics (e.g., proximity sensors) may reveal important insights to inform learning and training as well as inform design research data collection and analysis. The MTS itself must be conceptually and descriptively mapped initially to emphasize individual roles, teams, and cross-team leadership behavior in the incident command structure. Sensor-based data can provide an automated, seamless data capture to assist in this mapping; however, important initial contextual analysis of the intricacies and nuances of the dance between teams needs to be addressed, particularly in such complex settings as fire and rescue live simulations.

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Engaging Students in Co-designing Wearable Enhanced Learning Kit for Schools

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1 Introduction

The availability and the price-quality ratio of Internet of Things (IoT) technology have led to a situation where this technology is more and more used in Science, Technology, Engineering, (Art) and Mathematics (STEM or STEAM) to make learning more engaging and authentic. In the last few years, a multitude of studies have expressed concerns on how STEM education does not meet the rapidly growing needs of the society and about methods implemented to improve the situation.

Estonian Lifelong Learning Strategy (ELLS) 2020 follows the global trend by emphasising the need to change learning in classrooms to be more creative, collaborative and self-regulated. The main focus is on "the implementation of an approach to learning that supports each learner's individual and social development, the acquisition of learning skills, creativity and entrepreneurship at all levels, and in all types of education" (Republic of Estonia Ministry of Education and Research 2014a). ELLS emphasises the practical and effective use of modern digital technology in both learning and teaching (the digital revolution in the lifelong learning). Unfortunately, as this strategy brings out, the biggest problem is that almost a third of Estonia's working-age population lacks the expected digital skills; additionally, the students' access to digital infrastructure and teaching materials is inadequate and inconsistent. It is emphasised in the Digital Agenda 2020 for Estonia that modern teaching materials need to support the acquiring of important competences, the independence of the students and feasibility of learning. It is added that innovative teaching material uses modern technological and didactical solutions

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to make learning and teaching more effective and encourages the active usage of Internet resources (Republic of Estonia Ministry of Education and Research 2013).

Schools are expected to explore new ways of using novel technologies (including wearables) to facilitate creative and collaborative learning through interdisciplinary projects (Republic of Estonia Ministry of Education and Research 2016). Even though the learning process has been planned and carried out differently in schools, the basics of the national curricula prepared by the Ministry of Education and Science are followed. In the national curricula for basic and upper secondary schools (Republic of Estonia Ministry of Education and Research 2016), there are requirements such as the following: knowledge and skills need to be used in a real situation, research has to be conducted and the subject matter in different fields integrated with everyday life, possibilities have to be created for studying and coping in different social relationships (pupil-teacher, pupil-pupil) and contemporary and diverse study methods, means and techniques shall have to be used. The Estonian National curriculum for basic schools brings out the importance of technology and innovation as a cross-curricular topic according to which the aim for the pupil is to develop into a person who is well-disposed toward innovation, and who knows how to use contemporary technologies for the designated purpose, who copes with the rapidly changing technological living, learning, and work environment (Republic of Estonia Ministry of Education and Research 2016). A lot of requirements in different regulations are addressed to implement ambitious Digital Turn towards 1:1 computing based on the BYOD approach, practical and effective use of modern digital technology, and contemporary and diverse study methods in schools.

Our goals are based on the current decisions to promote Estonian education (Estonian Lifelong Learning Strategy, Digital Turn (Republic of Estonia Ministry of Education and Research 2014b) towards 1:1 computing based on the BYOD approach, Digital Agenda 2020 for Estonia): (1) to make the natural and exact sciences of general education curricula, as well as technology education, innovative and bring them closer to life; (2) to contribute to effective engineering and lifelong learning; and (3) to create prerequisites for engineer creativity. For this purpose, a project called *Innovatoorium: Smart Schoolhouse by means of IoT* was launched', by aim to implement IoT opportunities in the learning process, to involve learners actively contribute. Among others, these opportunities included wearables such as body sensors and smart clothes.

The aim of the paper is to introduce a project that was started in order to promote STEAM education called *INNOVATOORIUM: Smart Schoolhouse by means of IoT* which, by integrating different subjects with inquiry-based (IBL) and problem-based learning (PBL) methods, will support creating IoT solutions, data collection and analysis. For that purpose, schools were provided with sensor kits. Rosson and Carroll (2009) explain how important it is to take user experience in the design process into consideration when creating a product or service best suited to the users' needs. In this example, the products are the sensor kits that are going to be used in the schools. Hence, it is important to find out who are going to be the actual users of these sensor kits (students, teachers) – user profiles (personas) – and what kind of situations or problems might occur for them (usage scenarios). Taking user experience into account is widespread in software development (Rosson and Carroll 2009; Kazman et al. 1996), and with this in mind, it has transpired from current research that creating user profiles and usage scenarios has also helped to specify the list of equipment that the schools need to acquire. The research indicated that the pupils' readiness and competence of device assembly varies from school to school, so the initial order list of sensor kit components was supplemented with an out-of-the-box solution.

2 Related Work

To get an overview of the possibilities of using IoT in education and composing the suitable IoT kits, different articles from several databases were analysed. Special attention was given to articles with a focus on the solutions of using wearables in the learning process, as they were directly related to the subjects of the pilot project described in the current article. In addition, we included articles that could contribute into creating the necessary framework for integrating the use of IoT in learning processes: Internet of Things in education, IoT for automatic data collection from the surrounding environment, IoT for learning analytics, IoT for learning by doing and IBL and PBL methods in STEAM education.

2.1 Wearables in Education

There is an increasing interest in wearables in education. To gain an insight into the actual usage of wearables in education, we carried out a literature review across topical peer-reviewed articles. Although the preliminary goal was to search from different databases like ISI Web of Science, Social Science Citation Index (SSCI), Scopus (limited to Social Sciences and Humanities) and IEEE (Institute of Electrical and Electronics Engineers) Xplore Digital Library (limited to conference articles), there were a lot of duplicated articles from other databases in Scopus. Thus, the reviewed literature was limited to Scopus only. Another limitation was the language: only articles in English were reviewed. The yearly trends from 2014 to 2018 of the corresponding search terms are depicted in Table 1.

As the terms that were searched for could be used in a variety of different contexts, there was a substantial noise in the search results. We encountered the following restrictions: (1) Although the keywords were different, the search results often contained the same articles; (2) the noise was generated by the alternative

Table 1 Literature review

Search term	Date	Peer-reviewed articles total	2018	2017	2016	2015	2014
IoT or Internet of things	22.01.2018	33,863					
IoT or Internet of things + wearables	22.01.2018	2550	75	1082	456	353	149
IoT or Internet of things + wearables + education	22.01.2018	251	5	126	72	27	12
IoT or Internet of things + wearables + teaching	22.01.2018	757	21	286	175	67	26
IoT or Internet of things + wearables + learning	22.01.2018	67	1	27	17	14	4
IoT or Internet of things + wearables + smart	22.01.2018	15,522	470	5726	3917	2207	1288
IoT or Internet of things + wristband + education	22.01.2018	3067	69	891	674	400	266

use of keywords used for search: “learning-machine learning”, “education-curricula development”, etc. The next step after exclusion of irrelevant articles based on their titles was an overview of the titles and abstracts. The first exclusion criterion applied was based on whether the article discussed any research carried out in the learning process (wearable enhanced learning) or a related issue (learning analytics).

Although the first-glance impression is that there are a lot of articles concentrated on wearables in education, it turned out that the situation is quite the opposite. The most popular IoT wearable is a wristband to collect a student’s vital data (de la Guía et al. 2016; Ueda and Ikeda 2016; de Arriba-Pérez et al. 2017), sleep and stress indicators (de Arriba-Pérez et al. 2017), which was used to predict students’ learning activity (Minor et al. 2017), measure temperature, humidity, light (Pruet et al. 2015), or hand gestures (Wibawa and Sumpeno 2017). Two different articles described their activities with Bluetooth beacons to estimate the location of the students (de la Guía et al. 2016) and according to their position displayed study materials on the screen (He et al. 2016a, b). Examples of wearables for teachers include smart shoes (Donkrajang et al. 2012; Pila and Rawat 2017; Delgado-Gonzalo et al. 2017; Pham et al. 2017; Seesaard et al. 2013; Jeon et al. 2017) or smart clothes (Huang et al. 2017). It can be concluded from the literature review that while there are many articles exploring ready-made wearables in education, only a small proportion of the possibilities has been covered, mainly concerning closed systems. There is a considerable lack of information regarding inclusion of students into creating their own devices, accessing and analysing the data.

2.2 Internet of Things in Education

"The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service" (Whitmore et al. 2015). IoT is used in almost all fields: logistics, agriculture, construction, commerce, marketing, etc. This chapter, however, gives a brief overview of IoT areas and possible solutions of uses in education only.

To analyse the possibilities of using IoT technologies in education, the vision of Smart Schoolhouse (Kusmin et al. 2017) enhanced with IoT technologies was proposed (Fig. 1).

Kusmin et al. (2017) bring out that "The main goal of Smart Schoolhouse is to equip a school to enable automatic data collection from the physical learning environment, and integrate these data with the digital footprints of learners. Then, this data will be used for (1) learning analytics purposes and (2) reinforcing STEM education and inquiry-based learning. For example, students could use the data for project-based learning. In the Smart Schoolhouse, the data coming from the immediate and familiar physical environment will become both an object and instrument of study that engages students in testing various hypotheses, and students will suggest improvements in the design of their learning environment" (Kusmin et al. 2017).

There are three main areas of use of the IoT possibilities in education: (1) the automatic collection of data from the surrounding environment and their usability in the learning process; (2) collecting data for learning analytics (LA) from a physical classroom and from different e-learning environments; (3) a lot of possibilities to stimulate STEM learning – sensors and devices (also wearables) that can be used (Wibawa and Sumpeno 2017) or electronic components of the IoT devices that can

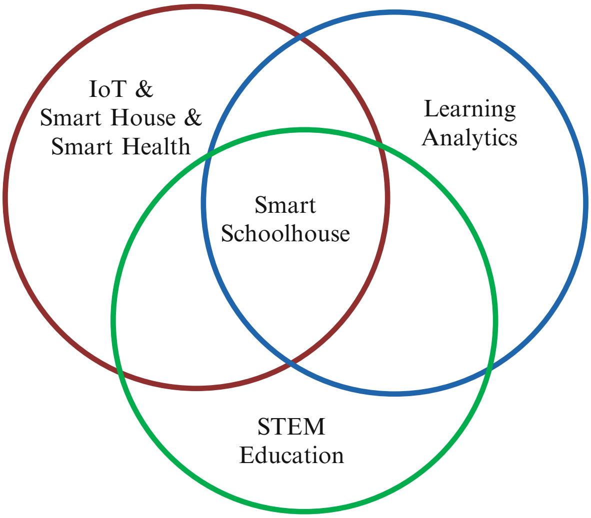

Fig. 1 A Smart Schoolhouse: common core of learning analytics, STEM education and IoT (Kusmin et al. 2017)

be created (Domínguez and Ochoa 2017); analysis of data collected from different IoT devices all around the schoolhouse; analysis of data collected from the students' footprint; etc. (Kusmin et al. 2017).

2.2.1 IoT for Automatic Data Collection from the Surrounding Environment

The mainstream use of IoT in education is designing the learning environment as "smart building" (Johnson 2012) and "smart home" (Lynggaard 2013) solutions. Although the latter approaches are widespread, they are in general closed systems that do not provide opportunities to further use the gathered data, e.g. enliven the learning process (Li et al. 2011). The lessons would be enlivened if learners were able to analyse their surrounding data and draw conclusions or suggestions for fine-tuning or improving the system. By using and analysing these data, together with the data collected for the learning analytics (Andrade and Worsley 2017), they can find the moments when they were successful. Detecting the pattern, they may discriminate the successful learning moments from the unsuccessful ones and eventually discover the attributes that most influence the learning process (Andrade and Worsley 2017).

2.2.2 IoT for Learning Analytics

Collecting data for LA (Giannakos 2016; Domínguez and Ochoa 2017) from a physical classroom and from different e-learning environments is a big challenge in learning process, but it is important for a large number of stakeholders participating in the learning process (learners, teachers, school principals, etc). "The aim is using as much information about learners as possible to understand the meaning of the data in terms of the learners' strengths and weaknesses, abilities, competences and declarative knowledge, attitudes and social networks, as well as the learning progress, with the final goal of providing the best and most appropriate personalised support" (Kickmeier-Rust and Albert 2017). In the earlier days, it was very tedious to collect the information about students' learning and behaviour in physical classroom and identify their learning patterns. The development of e-learning made the collection of information easier, and sophisticated web tracking tools were used to record students' activities (Okubo et al. 2016). These tools gave a visual overview of students' activities in e-learning environment, but unfortunately only through superficial metrics: number of clicks, time spent on a page, etc. However, it was not possible to track the students' behaviour in physical classroom adequately at all. Thanks to IoT, there has been a paradigm shift in LA, and quite soon it will be possible to collect multimodal data from physical classroom activities (Andrade and Worsley 2017), participation, task fulfilment, including BYOD in technology-enhanced learning (TEL) (Giannakos 2016), as well as from activities in e-learning environments, named multimodal learning analytics (MMLA). Using appropriated IoT tools (beacons and stickers, eye-trackers, wearable wristbands (Prieto et al. 2017), Kinect v2 (Echeverria et al. 2017)) or sensors (accelerometer, indoor location/proximity (Prieto et al. 2017)) and combining them with other data tracked from the students' gesture recognition (Junokas et al. 2017), heart rate (Prieto et al. 2017; Di Mitri et al. 2016), step count, galvanic skin response, motions capture (Prieto et al. 2017) and facial action (Andrade and Worsley 2017), it is possible to analyse learning or teaching process in physical classroom, and it allows to support awareness, regulation and reflection processes of the stakeholders involved in the learning process.

2.2.3 IoT for Learning by Doing

The third possibility to use IoT in education is "Learning by doing" (Alletto et al. 2016). "One common alternative proposed to improve engagement and learning about such subjects [STEM], is to involve students in scientific inquiries where students are involved in formulating hypotheses and gathering and analysing real data" (Prieto et al. 2017). Creation (Burd et al. 2017; He et al. 2016a, b) and use of wearables and analysing the collected data will be handed over to the learners themselves. Then they will be able to create various hypotheses, validate them and come to their own conclusions about the learning environment, contributing to a better understanding of their context and to the adoption of inquiry-based methods (Kusmin et al. 2017). This is a quite big challenge for teachers as they have to know the principles of both the problem-based learning (PBL) (Srinivasa and Sowmya 2016) and inquiry-based learning (IBL) (Kipper and Ruutmann 2012).

2.3 STEM and STEAM Education

As expressed by English and King (2015), there is a growing concern for developing STEAM education – a generic label for any event, policy, programme or practice that involves one or more of the STEAM disciplines (Bybee 2010) – to prepare students for a scientifically and technologically advanced society. For some time, there has been more attention paid to STEM education in Europe and elsewhere in the world: it has been studied, different institutions have been set up to improve STEM Education (The Global STEM Alliance[1], The LUMA Centre in Finland[2], The NTNU's resource centre for STEM education in Norway[3], Estonian Centre of

[1] https://www.nyas.org/programs/global-stem-alliance/

[2] https://www.luma.fi/en/centre/

[3] https://www.ntnu.edu/skolelab

Engineering Pedagogy[4], National Science and Technology Council in the USA[5], etc.), several regulations have been adopted (The Royal Society (Charity) 2014; Caprile et al. 2015; Prinsley and Baranyai 2013) and suggestions (National Research Council of USA 2011; English and King 2015) on how to make learning STEM more successful and inclusive were made. The National Research Council of the USA stated in 2011 that "four percent of the nation's workforce is composed of scientists and engineers; [and] this group disproportionately creates jobs for the other 96 percent". The importance of STEM education is also emphasised by different stakeholders, such as policy developers, and business and industry organisations (Caprile et al. 2015; Prinsley and Baranyai 2013; National Research Council 2011; National Science and Technology Council 2013). The former can be summarised by the statement that "improvement and focus on STEM education are a concern of all nations whether they have an emerging economy or one that is long established" (Su et al. 2017). This means that STEM education needs to ensure that the workforce is ready for the challenges of the future. Changes in society and the overload of information and its availability submit demands for digital students to succeed as global knowledgeable workers (National Research Council 2011). The US National Science and Technology Council (Organisation for Economic Co-operation and Development 2013) and OECD (European Schoolnet 2015) argue that in the future, all jobs will be more or less dependent on STEM's skills.

In order to achieve success, it is important to have a profound knowledge in different fields of speciality, giving one the ability to synthesise and put the information into practice in new and innovative methods. Expectations in STEAM education are high, but a much bigger issue in many countries is the lack of interest in learners to continue their studies in the fields of STEAM. Nugroho and Haryani (2016) claim that to involve the z-generation, who form the majority of learners at this moment, it is needed to create life-based learning situations. At the same time, according to the European Schoolnet 2015 report, the teachers' education and their professional development are also big factors in improving the quality of STEM learning, making it more popular and arousing the interest of the youth. They suggest contributing to the reinforcement of STEM teachers, including the ones just starting, and strengthening the community by learning from and supporting others to ensure the fields' development and sustainability.

The same standpoint is presented by (Su et al. 2017) by stressing that the teacher and the chosen teaching methods play a crucial part in arousing interest in learners. Su et al. (2017) were looking for a potential model for the educational reform and compared to the educational systems of the four countries (Canada, Estonia, Singapore, Finland) that are consistently at the top of the list in PISA tests. As a result, they have shown that problem-solving and inquiry-based projects in STEAM education related to other subjects can foster curiosity and creativity of students, and the learning process becomes more personal.

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[4]https://www.ttu.ee/en/?id=150200

[5]https://www.whitehouse.gov/ostp/nstc/

Rüütmann and Saar (2017) recommends to exploit *indirect model* in STEM education: "This approach is very effective because students interact with the content to make meaning". Teaching methods in indirect model (project- and problem-based learning and "just-in-time" teaching) encourage students to predict, apply, create, analyse, compare, evaluate, criticise, implement and gain professional perfection (Rüütmann and Saar 2017). Hoić-Božić et al. recommend Jonassen's problem typology, which describes well- and ill-structured problem types for STEM education (Hoić-Božić et al. 2016). The first one is for simple tasks but the second is for project-based or inquiry-based learning (IBL). The IBL stimulates students to take control of their learning by themselves. Bell et al. (2010) brings out that in order to solve problems using IBL methods, students have to go through several iterative steps (question-predict-experiment-model-apply-reflect). In an ill-structured problem, the solution and the problem-solving process, or both, are unknown, and sometimes there are alternative solutions (Hoić-Božić et al. 2016).

Research by Haaristo et al. (2013) shows that "the deep study of real and natural sciences is very probable to lead into further studies in STEM fields". His claim is that positive experiences play a big role in the learners' choices, for example, active hobby education and other self-fulfilment opportunities in STEAM fields.

2.4 INNOVATOORIUM: Smart Schoolhouse by Means of IoT

The "INNOVATOORIUM: Smart Schoolhouse by means of IoT" project was initiated to raise the popularity of engineering and technology among students and encourage them to put the connected knowledge into use when finding solutions for life-based problems. An additional goal is to innovate the STEM learning processes in general education curricula to make it more life-based, contribute to effective engineering and lifelong learning and create better preconditions for engineering. Inquiry- and problem-based learning methods of STEM learning should become fundamental in the schools involved in the project.

Over the course of the project, students are involved to find solutions to vital problems, create active learning and teamwork teaching materials and analyse, test, present and evaluate them during practical activities. Real and natural sciences will become more interesting and engaging for students, giving them a chance to integrate solutions in different subjects for life-based situations using IBL and PBL methods, e.g. "How does the temperature of the room or changing of the light affect a student's attention and ability to concentrate?" or "What is the student's body position (sitting position) during the different stages of class, and how often does he/she change it?". Teachers could also get feedback on their activities in class using IoT possibilities, e.g. "What is their trajectory during different stages of a class, and where do they stop for longer or more often?" and "How much does he/she gesture during a class, or what is their heartbeat at different times?"

The project helps the development of digital skills in learners and teachers by integrating IoT technology (including wearables) in different subjects and contributes to the following:

1. The fields of natural and exact sciences are popularised.
2. The implementation of IBL and PBL methods in the teaching of natural and exact sciences is contributed to.
3. An innovative teaching material implementing IoT kits in the learning process supporting STEM learning is created, together with guiding learners to create teaching materials supporting new and modern learning opportunities.
4. Learners are being involved to find practical solutions to life-based problems by integrating different subjects and IoT technologies.
5. Learning activities that encourage finding solutions to practical and innovative information society problems by offering equal opportunities are supported.
6. The teamwork, knowledge and experience sharing of real and natural sciences teachers from different regions is supported, meaning a real and natural sciences teachers' workshop will be created.
7. Students' attitudes towards genders and gender roles are influenced and modernised.
8. Learners' knowledge about possibilities of STEM education is expanded to encourage further studies in the field.

The duration of the project is 3 years in total but it is divided into shorter periods of time (preparatory period, pilot period, involving partners, learning in teams, operating in teams, and the end stage of the project) where each period has its own aim and functions. It includes basic and secondary education students ($N = 1833$), from 19 different schools.

In the pilot period, covered by this article, there are 645 basic and secondary education students from five schools from different regions participating. Each school acquires an IoT sensor kit of their choice (room sensors, smart clothes, body sensors, research lab, digital art kit) to be used in subjects specified in national curricula. The purpose of the pilot period is to test the implementation of the mentioned IoT kits in the learning process, to create teaching narratives for their use and to make suggestions to improve the composition of IoT kits for the next periods when students from 14 more schools will join the project.

The main idea of the project is to carry out the idea of Smart Schoolhouse and find the best solutions how to use IoT technology to support STEAM education.

3 Research Methodology

This study is a scenario-based design (Carroll 2000) research that focuses on designing mobile kits for wearable enhanced learning. To better fit the kits in the learning process, it was necessary to take into account that each school and user have different needs and expectations, and thus it was important to involve everyone participating in the project in the research. At the beginning of the analysis stage of the study, a literature overview was carried out, and a primary specification of the sensor kits was created.

As it is important to take user experience in the design process into consideration when creating a product or service best suited to the users' needs (the sensor kits that are going to be used in the schools), we had to find out who are going to be the actual users of these sensor kits (students, teachers), how they look like (user profiles – personas) and what kind of situations or problems might occur for them (usage scenarios). Therefore, we conducted Skype interviews with students and teachers and after a while gathered information through a questionnaire. Following this, personas (two students, teacher and entrepreneur) with user profiles and user scenarios were created and used to make thorough changes to the primary kits. We also conducted a design experiment at university to get confirmation of suitability of these IoT kits.

3.1 Sample

In 2016, there were 316 basic schools with approximately 36,700 students in seventh–ninth form and 165 secondary schools with approximately 21,400 students all over Estonia. Out of them, 19 of the schools are participating in the project, with 1833 students ($M = 1833$) in total. The pilot period (Table 2) involves 645 students from five different schools (249 from basic and 396 from secondary schools). The schools were chosen into the pilot based on volunteering and prior positive partnership. Table 2 depicts the total of pupils in each school, the total of pupils in the participating age groups, the subjects in which the wearable enhanced learning will take place and the total of pupils participating from each school. In addition, the table gives an overview of the sensor sets used in the schools.

3.2 The Instruments

The instruments for the survey were Skype interviews, after which a questionnaire was filled and a tutorial video about IoT possibilities was shown. The purpose was to gather information to construct personas fitting the context of each school in order to create scenarios based on those personas. The scenarios were used to compile a list of needed smart clothes and body sensors, and to order the corresponding sets. It was necessary that the questionnaire was filled out only by the pupils genuinely interested in the topic and for that reason answering it was voluntary and skipping questions was allowed.

Table 2 Schools in the pilot project

Type of school	Pupils in school	Pupils in the set age group	Form participating	Pupils in the project	Sensor set	Subject
Lower secondary school	137	44	7	18	Science Lab	Maths, Life science
Secondary school	1043	255 + 274	6; 10; 11	76 + 186	Smart clothes	Biology, Art
Lower secondary school	125	41	7; 8; 9	41	Smart classroom	Physics, Technology education
Upper secondary school	152	152	10; 11	106	Body sensors	Chemistry, Physical education
Secondary school	1221	311 + 153	8; 9; 10	114 + 104	Digital art	Maths, Art

The Skype interviews were held with the schools that are going to use smart clothes or body sensors. At least two pupils, two teachers and a project manager were present for the interview. The data was collected in the course of a semi-structured interview.

The questionnaire was created using GoogleForms, as it is already known by Estonian pupils, and it is easy to manage and convenient for data collection. The questionnaire consisted of three parts: background information – different sections for both students and teachers; awareness about and attitudes towards IoT possibilities; and readiness to use IoT solutions in learning process. The questionnaire also had control questions, which enabled to analyse whether the questions were read properly and if the respondents had a firm standpoint.

This study was conducted using the survey method, and it involved 174 respondents – 159 students and 15 teachers. There were 17 questions in the questionnaire: (1) background information (different for students and teachers); (2) awareness and attitudes of IoT: seven questions on a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree) and two open-ended questions about the possibilities of IoT implementation; (3) readiness to use IoT solutions: five open-ended and one multi-choice question. The students' and teachers' data were analysed separately.

4 Results

There were 159 replies to the survey by students but only 156 questionnaires were taken into account. It was evident by looking at the control questions that three students had not concentrated on the questions when answering. A descriptive statistics analysis was done using MS Excel (Analysis Toolbok, Realstats, Solver

Table 3 Gender distribution of respondents

Gender	Number of respondents	Percentage (%)
Male	85	54.5
Female	71	45.5
Total	156	100

Table 4 Distribution of respondents according to age

School level	Age	Number of respondents	Percentage (%)
Lower secondary school	12–15	84	53.8
Upper secondary school	16–18	72	46.2
	Total	156	100

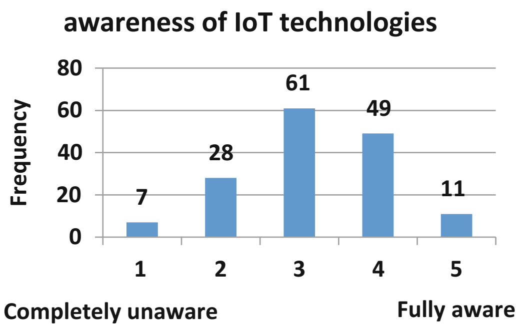

Fig. 2 Students' awareness of IoT technologies

Add-in). Table 3 shows the distribution of respondents by gender. 54.5% (85) of the students were males, while the remaining 45.5% (71) of the students were females.

Meanwhile, Table 4 shows the distribution of respondents by age. 53.8% (84) of the students were aged between 12 and 15, followed by 46.2% (72) who were between 16 and 18.

Awareness – a direct question about the awareness of IoT technologies was used: "What is your degree of awareness regarding IoT possibilities?" (Fig. 2)

A 5-point Likert scale (1 = completely unaware, 5 = fully aware)

Indirect question: "What benefits are there for using smart clothes?"

A selection of answers from pupils: "Smart clothes could signal the person that they are crouching, and to direct the person to fix their sitting position"; "They can be used to measure physiological data"; "Feedback about a person's mental and physical changes, their habits"; and "Athletes could keep track of the effectiveness of their training".

Security – direct question about security: When talking about IoT possibilities, mark the strength of the connection you get with the word "security" (Fig. 3).

A 5-point Likert scale (1 = connection is small, 5 = connection is strong)

To the indirect question "What kind of problems might occur when using IoT possibilities/technology?", we received a variety of pupils' answers: "The disappearance of privacy, which in a changing world is self-explanatory" and "Lack of privacy, misuse of data".

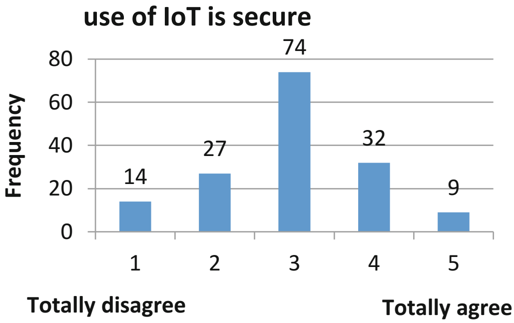

Fig. 3 Students' beliefs with security of IoT technologies

Readiness – indirect question: "What are the options for using wearables in the learning process?"

A selection of answers from the pupils: "All kinds of different tasks done in school to see how the body reacts to them", "Something that is exciting and would not be uncomfortable", "Could be used to analyse a person's emotions and psyche so the person could get to know their self-image" and "To create a new subject for pupils interested in continuing their studies in technology and others of the kind".

As a result of the survey, it can be confirmed that students are aware of the risks associated with IoT technology. Also, it turned out that they are ready to use new opportunities in the learning process.

5 Design Experiment in University

Before designing the wearable kits in context of the schools, a design experiment was conducted with an interdisciplinary group of five university students: two bachelor ICT students together with two master students from medical school and one master student from Communication Management programme. They have spent five 3-hour sessions in the lab by exploring the possibilities, ideating, designing, developing and testing wearables.

As a theme of the trial designing wearables for health and well-being was chosen, the students had an introductory lecture on main problems related to physical activities and motor functions. After that, the team selected a problem of correct movement when implementing a plank exercise. The problem is that if there is no symmetry in doing a plank, the exercise may damage a person's health instead of making benefits to it.

After selecting the problem, the kits with selected health-related wearable sensors were introduced to the team by an expert in software and hardware engineering.

The students started to sketch different possible solutions and play possible scenarios with those low-fidelity paper prototypes. During that period, students have discussed with the expert possibilities to use one or another specific sensor by having in mind their features and limitations.


Fig. 4 The prototype for posture measurement for the planking position

After the final agreeing on the idea, students started the implementation process. They have implemented into a sports shirt several electronic components, including Adafruit FLORA board (15$), Adafruit LSM90DS1 gyro/accelerometer (15$), Adafruit Long Flex (13$), vibrating mini motor disc (2$) and a power source (Fig. 4).

The high-fidelity electronic prototype has represented a set of clothes which are able to detect if yoga posture is correct or not and notify the user with a gentle vibration if she is making a mistake.

The gyroscope is used to measure when the balance of the body is lost, and an accelerometer is used to measure how fast the body is moving from the centre of gravity. The bending sensors are fixed to the lower centre of the spine and are intended to make certain that the spine is straight. If the spine is caving inside, a vibrating mini motor disc starts vibrating to inform the user about the issue (Fig. 5).

The design experiment has resulted in two important concerns. Firstly, there is a big variety of sensors in the market with a high range of prices and quality. The quality is represented from one side by measuring accuracy and reliability of the hardware. The cheap sensors may be very inaccurate in providing data. Some of them stop to send the signal just after several seconds of work. That raises up an issue of choice and inventory of sensors. Considering the school context, there should be good price/accuracy/reliability ratio.

Fig. 5 Testing the prototype by implementing plank exercise in the controlled environment

Secondly, during the workshop, the students need the continuous scaffolding from the relevant experts. In our case, we have used separate experts on physical health, design, engineering and textile works. In the context of schools, a trainer sometimes has to implement all these roles alone. If that is the case, a smaller amount of simultaneously working groups should be considered.

Based on the results of the survey in schools, and design experiment with university students, we launched the next phase of our design-based research: creating personas and scenarios for defining the topology of the wearables kits to be used in schools.

5.1 Personas

In order to create the learners' personas, the students' answers were analysed, yet the responses where it was evident that the pupils had not concentrated enough were not taken into account. Hundred and fifty six replies by the students were taken into account when creating the personas. At the time of the survey, it was clear that the pupils know rather well about the dangers of the Internet, they have a vision about IoT solutions, and most of them believe that smart clothes and body sensors can only be used to measure the wearers' physiology and results in Physical Education.

Having a Robotics class in school's curriculum made the biggest difference in the choices of each pupil. It also became the biggest factor in creating the personas. This was concluded when the data showed that the pupils who have Robotics class in school prefer to create their own IoT solutions not use the kits already available.

Persona 1 *Liisi (F)* is 13 years old and studies in the 7th form of a small lower secondary school. Her favourite subjects are Chemistry and Physical Education. She believes to be acquainted with IoT solutions as she has a smartwatch and a Roomba, yet she is not certain how much a person can trust technology that collects information and stores it on the Internet. Liisi believes that using IoT solutions is an exciting opportunity to combine subjects in school with solutions to problems one might face in real life. In her opinion, IoT solutions can be used for physiology and in Physical Education. She would gladly use smart clothes to get a better overview of her health, and to have them send information to her close ones in case of emergency. She prefers to use ready-made solutions as she does not know what it would be like to, for example, create a necklace that reads the wearer's heartbeat and other vitalities.

Persona 2 *Jaan (M)* is 17 years old and studies in a small town secondary school, in the 11th form. In his school's curriculum, they have a Robotics course which he enjoys immensely, yet his favourite subjects are Math and English. Thanks to the Robotics course, he knows a lot about IoT solutions, yet he believes his knowledge is still rather poor. If possible, Jaan would use all kinds of smart gadgets – a smartwatch, smart clothes, smart shoes and even smart socks – as he believes it opens up the whole world. It is possible to measure phenomena that could help with both training and improving one's posture, they give feedback on how the surrounding noise affects one's organism, and they notify the wearer about a lack of vitamins or other health issues (e.g. high blood pressure, blood sugar levels, body temperature, etc.). Additionally, the data collected using smart clothes could be used to do research and analyse different vitals that would give one a better knowledge about how their body reacts in different situations. If he had the opportunity to create his own IoT solutions, he would first create a gadget to automatically calculate angles for drifting with his car. He is also interested in creating a device that observes how a person thinks by analysing their brain. Jaan is very optimistic about the future, and he hopes that IoT solutions will help solve a lot of problems in many different fields.

Persona 3 *Sirje (F)* is a 53-year-old primary and secondary school biology-anatomy teacher. She considers her computer literacy moderate, but at the same time she is fond of innovative ideas, even if it involves using new and unknown technologies. She likes the subject she teaches and would like to share her enthusiasm with her pupils so that they would be able to autonomously find ways to apply their factual knowledge in real life. Sirje believes that incorporating novel technologies such as IoT devices into her class activities would make studying biology and anatomy more exciting for the students and encourage them to participate more actively. She is slightly insecure in using these novel technologies, but her eagerness motivates the students who, in turn, are glad to assist her in lessons. Thanks to this encouragement, Sirje is continuously looking for new interesting methods for engaging students.

Persona 4 *Getter (F)* is a 32-year-old software developer in an ICT company. Besides working on client projects, she is interested in motivating young people to start higher education in engineering areas and making ICT professions more appealing for students. This is why she works part-time as a guest lecturer of Software Development in a university. Getter is enthusiastic about novel technological trends and a firm believer that the ultimate purpose of technology is to improve human life. Lately she has turned her attention also to primary and secondary education by giving programming lessons, organising work-shadowing events at her company and participating in internship programmes as a mentor.

5.2 Scenarios

Based on these personas, different scenarios have been compiled to understand the different situations of using these IoT kits.

Scenario 1 One of the topics during the first semester of the 9th grade is the effect of training on the skeletal muscles. Sirje believes that providing more practical connections with real life would make the lesson more engaging for the students. She discusses the topic with the school's computer and robotics teacher Raul who suggests using wearable IoT devices. Sirje asks for the pupils' opinions and preferences regarding the devices to decide which ones to use in the lesson. Together with Raul she composes the list of needed IoT wearables and orders it from an e-commerce shop. The kit arrives 2 weeks before the anticipated lesson in a cardboard box. She is surprised that some of the devices are very small and decides that if the practical class proves to be a success, she needs to organise the devices in a more secure container to sustain them for the future years. Furthermore, some of the devices are disposable, which means that a lot have to be ordered for each lesson. She decides to use pressure sensors to provide examples in the lesson: pupils would use the sensors in their footwear to observe different styles of walking, and how the load is distributed on the foot soles when walking. Based on the gathered data, the students can analyse the movement-related processes of different skeletal muscles, bones and joints. In addition to the lesson plan, she hopes to gather additional input from students to put the IoT devices into further use. For collecting ideas from students based on their hobbies and interests in IoT, she includes an innovation board game into the kit designed to promote generation of new ideas on using IoT wearable devices. It is a novel approach and Sirje plans to co-create teaching materials and manuals collaboratively with her pupils to promote employing these practices again in the upcoming years.

Scenario 2 A collaboration day has been initiated at the school with the objective of encouraging the cooperation of pupils from different schools through participation in various projects. Four pupils, including Jaan, are planning to take part in it and use the knowledge and input they received from anatomy and robotics lessons. They wish to explore and introduce the possibilities of using and creating smart clothes and provide other pupils with the opportunity to create them on their own. The group starts their preparations a month before the collaboration day. To specify their ideas, they ask the opinion of several teachers. Sirje, the teacher of anatomy and biology, helps them decide between several product ideas, and in the end they decide on two: (1) headband for measuring neurofeedback, relaxation and concentration and (2) bicycle gloves that measure speed and pulse and when pinching two fingers indicate direction by flashing integrated LED turn signals. For instructing their co-learners, they collaborate with Arts and Robotics teachers to compile worksheets where the required IoT devices are described with explanations on how to use them. Robotics teacher Raul helps to select the necessary sensors and accessories for creating smart clothes. Arts teacher gives suggestions on how to design the clothes so that the sensors would be unnoticeable to the wearer and not cause discomfort. Before the collaboration day, the team obtains cheap gloves and fabric for headbands. Jaan and his friends have a fun and educating time at the collaboration day. They experience teamwork and have an opportunity to use the knowledge and facts that they have learned in various subjects and classes by applying them in real-life problem-solving situations. They are contemplating in continuing their further studies in STE(A)M education so that they could work in engineering professions.

Scenario 3 A summer-school initiative for primary school students was started in Getter's company to increase young people's interest in engineering and expand potential new ICT workforce. At the summer school, each pupil group has to come up with a product idea and develop a prototype. Getter has met Liisi and her classmates at a school collaboration day when they were learning from Jaan how to create smart clothes. Liisi and her friends were planning to create a fashion line of smart clothes that gather data about the wearer's ergonomics, so she invites them to participate as her mentees. The group accepts the invitation and informs her that they were still interested in their project but had had some issues with product development processes. During the summer-school project, the many sides of ICT and engineering are introduced to the pupils, to show them that ICT is a much broader area than just programming. Pupils learn about product research and development, project management, robotics and programming, user interface and user experience design. Liisi and her group create prototypes of clothing items that identify bad posture and notify the user by blinking LED lights. In addition, the clothes gather data about the wearer's posture behaviour and send a weekly report to the user's phone over Bluetooth. There are three prototypes: a dress, trousers and a blouse. Liisi and her friends inform Getter at the end of the summer school that after graduating from secondary school they are intending to continue their STE(A)M studies in university. They agree to stay in touch and hopefully meet again during internship or another summer school.

The scenarios described above served as design artefacts in building an initial concept of wearables learning kits that address the key challenges of STEAM education in the light of expectations defined by the national strategy of education.

6 Conclusions

On the basis of the analysis of the literature, lists of primary IoT technology kits meant to obtain for the schools were created. To verify the suitability of the kits and the readiness of their use in the schools, a scenario-based study was conducted in the schools participating in the pilot period. For the study, several Skype interviews were held, after which a questionnaire was filled out, and the data collected was used to create personas and user scenarios. Based on these scenarios, the list of sensors and other gadgets in a set for wearable enhanced learning was put in order. Also a design experiment at university was conducted to get confirmation of suitability of these IoT kits. The last step was to update the lists of IoT wearables technology kits to be obtained for the learning processes. The study showed that the willingness of students and teachers to use IoT wearables technology kits varied between schools. It turned out that the biggest differences did not depend on the age, favourite subjects or hobbies of students but more on the pupils' prior contact to Robotics, whether as a subject in school or an after-school hobby. Based on that, many radical changes were made to the order list of the sensor kits.

Body sensor set In the body sensor kit, there were both neuro- and biofeedback sensors like Mindwaves, Fingerprint and Eyetracker and devices that measure a person's activeness (Kinect, wearable wristband). Based on the users' preferences, independent devices were swapped for a full kit, which allowed to measure more than 20 biometric parameters including pulse, breath rate, oxygen in blood, electrocardiogram signals, blood pressure, muscle electromyography signals, glucose levels, galvanic skin response, etc.

Smart clothes kit At first the smart clothes kit consisted of smaller kits of sensors and gadgets. However, based on the preferences of the pupils as well as their and their teachers' interests, the kits were removed and replaced with independent devices. Instead of the 5–6 there were now 29 different types. The biggest change was leaving out Arduino sensors and replacing them with Adafruit solutions. The sewing kit was replaced with independent gadgets. The pupils also wished to add more bending and pressure sensors to the smart clothes kits to create smart shoes and other wearables.

6.1 Next Steps

The purpose of the project's pilot period is to test the implementation of said IoT kits in the learning process, to create teaching narratives for their use and to make suggestions to improve the IoT kits for next periods.

After the first step, obtaining the suitable IoT technology kits, the next step in the pilot period is to test the IoT wearables technology kits in learning process. The outcomes are used to create teaching narratives, instructions on how to use the kits in different subjects and suggestions to improve the kits. Students are going to record the design sessions and collect the usage data through observations, interview and data logging, with the researchers assisting the students and teachers in data analysis.

The initial plan is to acquire all the necessary information for the IoT wearables technology kits needed for the next phases of the project from suggestions made by the schools in the pilot period. However, based on the scenario-based studies, it was found that in addition to the suggestions of the pilot schools, it would be pertinent to repeat the study amongst the schools joining in the next period. The goal is to take into account the peculiarities of different schools and the readiness of students and teachers to implement IoT technologies in STEAM education. As the next study will involve 14 more schools in addition to the original 5 participating in the pilot period, a better pattern, which could be used in future projects similar in enriching STEAM education, will emerge.

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Part III
Technological Frameworks, Development and Implementation

Toward Deployment of Architecture Incorporated with IoT for Supporting Work-Based Learning and Training: On the Threshold of a Revolution

Dan Kohen-Vacs, Gila Kurtz, and Yanay Zaguri

1 Introduction

Since the early days of the industrial revolution, entrepreneurs dream and put in their efforts while seeking to improve governmental, industrial, and commercial processes through technological innovations. These efforts focused on integration aimed at improving aspects of daily routines, including those exercised for labor, commerce, and learning purposes (Liotta 2012, Perez 2010). For several decades, these intents to integrate technologies for supporting casual processes have been prominently emphasized in Information and Communication Technologies (ICT) (Misuraca and Colombo 2016). Specifically, in many cases, ICT implementation is practiced to improve and find new ways to manage and provide services that are precise, adaptive, seamless, and user-friendly (Wang et al. 2014).

During the last several years, ICT advanced while introducing a revolutionary concept known as the Internet of Things (IoT). This concept relies on devices constantly connected to the Internet in order to report their various statuses. Such devices could be organized and interconnected in ecology as a set of sensors embedded and reporting conditions from casual situations occurring across spaces. Additionally, IoT capabilities could be embedded in personal or public devices carried or wearable. Consequently, IoT could be exploited to enhance daily routines associated with various sectors including those ones related to administration, commerce, leisure, learning, and training (Brown and Green 2016, Gianni et al. 2019).

A recent Horizon Report (2017) acknowledges the notion that IoT is also expected to impact additional fields beyond traditional educational systems, includ-

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ing fields requiring work-based learning and training. For example, the ways people work, learn, and do leisure were traditionally considered as separated contexts of casual and daily routines. Nowadays, one can apply for a position requiring job capacitation that could be accomplished in flexible geotemporal boundaries associated with the training process (Karmakar and Nath 2014). Specifically, during such training experience, job capacitation could be achieved through a controllable, traceable, and responsive process that is technologically supported (Sowa and Marchlewska 2016). Practically, such properties of work-based learning and training could be supported by IoT offering convenient means of encompassing, tracing, and improving capacitation activities exercised during work-based learning and training (Swan 2012, Zezschwitz et al. 2015).

As implied, IoT devices offer opportunities to enhance processes related to learning and training sessions that may be practiced ubiquitously. In this sense, IoT could be examined and explored for potentially enabling transitions in the studies of an educational approach known as mobile learning. IoT could be addressed as an additional mean that could be used during mobile learning in the light of its capabilities to support enhanced interactions practicable across contexts and settings. Furthermore, this approach could be considered as aligned to mobile learning in the sense that it addresses exploration efforts focused on how the mobility of learners could be augmented by personal and public technology to contribute to the process of gaining new knowledge (Sharples et al. 2014). It should be mentioned that we acknowledge the ongoing debate dealing with mobiles and ownership of data possibly collected by mobile devices during work-based learning and training efforts (Wishart 2017). Accordingly, we assume that the resolution of these topics corresponds to legal aspects dependents and may change according to the environment in which organizations practice their efforts.

Devices enabled with IoT capabilities could be used to enhance work-based learning and training conducted across contexts and settings, as they could be distributed among trainers, trainees, as well as conveniently embedded in all types of training environments. Practically, deployment of IoT sensors at indoor and outdoor spaces is becoming simple and inexpensive. Additionally, smartphones and other personal and public computing devices are enabled with IoT capabilities that could be used by trainers and trainees to proactively exercise and interact along job capacitation (Zezschwitz et al. 2015). Such devices embedded in public spaces and enabled in personal and public appliances may assist in fulfilling the requirement of tracking the proceedings of trainers and trainees anywhere and anytime during work-based learning and training (Cheng and Liao 2012).

Although IoT as a concept has been present for the past decade, its potentials and challenges related to these technological and practical implementations are still being explored (Gubbi et al. 2013). These innovations are being studied and examined in terms of their possible integration into existing architectures used in daily routines including those exploited for learning and training purposes.

In this chapter, we aim to address requirement analysis toward deployment of IoT-enabled architecture for supporting work-based learning and training. We emphasize these aspects while implying that conceptual and technological advancements may seed and provoke a possible threshold of a revolution in the field of work-based learning and training. Accordingly, we begin and introduce the field of IoT as an evolution of ICT used to support work-based learning and training. In the following section, we propose the contextualization of IoT, including its potentials, for mobile learning. We do so as we aim to explore how IoT may impact known concepts in this field. To enable such examination, we continue with an additional section describing various use-cases envisioning scenarios related to work-based learning and training that are supported by IoT. These use-cases are later examined in terms of aspects related to learning and training as well as to those related to the administration of such activities. In addition, we examine technological aspects for supporting these scenarios. In the following sections, we revisit the described use-cases to identify learning, training, administrative, and technological requirements toward the suggestion of an architecture embedded with IoT that is aimed to support work-based learning and training. Finally, we conclude and summarize with a discussion also addressing future directions of exploration.

2 Evolutions in Mobile Learning Augmented by IoT

The origins of work-based learning and training that practiced ubiquity could be partly traced back to efforts made by Xerox company more than four decades ago. These efforts included the deployment of a basic device enabling retrieval of information from across locations (Goldberg 1979). Research efforts focused on methodologies as well as technologies to develop mobile learning were constantly exercised and were encompassed by technological developments in mobile devices (Sharples et al. 2014). A few years ago, the MOBILearn project was introduced, while aiming to facilitate ubiquitous access to information and content management for knowledge workers (Kukulska-Hulme et al. 2009). These development efforts aimed to support mobile interactions related to registration, messaging, and management of content required by workers.

As implied, the assimilation process of mobile technologies within learning training for work-based purposes is tightly dependent on technological evolutions and their adoption among the target population. This process could be examined through an approach known as the Hype Cycle diagram (Fenn 2007). The Gartner group developed this general approach aimed at examining different phases related to the assimilation of emerging technologies used for various purposes. This approach can also be used to analyze and understand technology's relevance and its roles in different domains, including such related to work-based learning and training.

Research carried out by Laru (2012) and later elaborated by Kohen-Vacs (2016) provides an analysis of mobile learning relying on the different phases presented in the Hype Cycle diagram. Figure 1 illustrates Laru's (2012) approach for categorizing and analyzing research dealing with topics related to the evolution of mobile technologies used for supporting education.

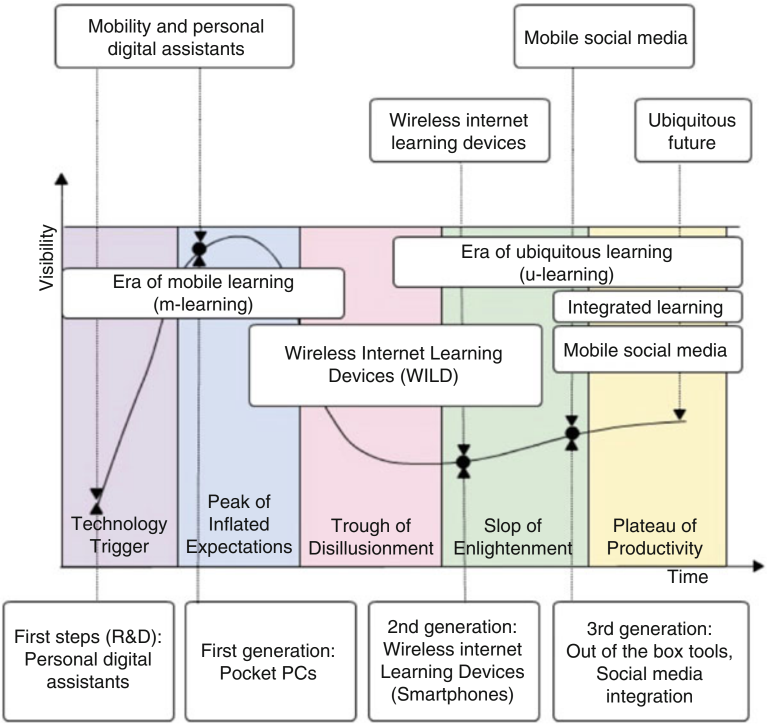

Fig. 1 Gartner's Hype Cycle adapted to examine cases related to mobile learning. (Adapted from Laru 2012)

The figure above illustrates Laru's approach to several cases associated with the different phases of mobile learning, starting with two cases, one located in the technology trigger and the other in the peak of inflated expectations. These cases were described by Laru (2012) and later elaborated while addressing an ongoing process starting from initial R&D efforts to create and support the first generation of Personal Digital Assistants (PDAs). The next two cases (third and fourth cases) are associated with the phase called slope of enlightenment. The third case addresses the implementation of mobile computing and wireless Internet exploited for educational purposes. The fourth case reflects the actual age of mobile learning, enabling better computational and communication services exploited for learning purposes.

Laru's diagram addresses learning in the light of teachers and students practicing mobile learning in organizations like schools and universities. As implied at the beginning of this section, mobile learning and its affordances for work-based training are discovered in the past several years. Consequently, it is assumed that this phase could be associated with the middle period of the third generation known as the Plateau of Productivity. In this respect, we propose to examine this phase also in the light of IoT, including its potentials and challenges related to work-based learning and training which is augmented by IoT. We accordingly would consider and evolution of this phase representing a new educational situation in which a major part of the generated data is not necessarily generated as a result of human interaction. In this phase, a major part of the data is created by IoT devices not necessarily depending on any human actions.

As mentioned in the introductory section, in such an examination we propose to consider didactical aspects of work-based learning and training as well as its administrative aspects. Finally, we also consider the role of technology used to support such processes. Accordingly, and to initiate such analysis, we suggest using Mobile Seamless Learning (MSL) dimensions as proposed by Wong and Looi (2011), which addressed challenges related to seamless and mobile learning. We bring a description of MSL dimensions while re-examining possible implications following the introduction of IoT as a concept embedded in casual spaces as well as in personal and public appliances.

Additionally, in Table 1, we examine the affordances and challenges of such implications for supporting work-based learning and training.

As noted above, we assume that modern work-based learning and training is aligned with the known affordances associated with mobile learning. In Table 1, we revisit this assumption while elaborating on different dimensions as conceptualized by Wong and Looi (2011). Accordingly, we notice that mobile learning as a

Table 1 MSLs proposed by Wong and Looi (2011) re-examined in terms of work-based learning training augmented by IoT

MSL	Description as proposed by Wong and Looi (2011)	IoT affordances for learning and training
1	Encompassing formal and informal learning	IoT is capable of tracking daily routines including those occurring in formal as well as informal situations
2	Encompassing personalized and social learning	Information originating from IoT devices embedded in personal appliances could be shared
3	Learning across time	Information retrieved from IoT devices could be reused along any phase of a learning scenario
4	Learning across locations	IoT could be embedded everywhere
5	Ubiquitous access to learning resources	Things attached and embedded with IoT may become ubiquitous objects serving resources for learning
6	Encompassing physical and digital worlds	IoT could be embedded everywhere
7	Combined use of multiple types of devices	IoT could be embedded across various types of devices or objects that originally were not intended to be enabled with such technological capability
8	Seamless switching between multiple learning tasks	IoT embedded and scattered anywhere could support learning across interrelated and switchable learning tasks
9	Knowledge synthesis	IoT generates mass amount of information and therefore can serve in processes of synthesizing new knowledge
10	Encompassing multiple pedagogical models	IoT is a resource of information applicable across different didactical practices

didactical approach aligns with professional requirements as needed during work-based learning and training. This includes formal and informal experiences in these practices occurring in organized sessions as well as in casual moments along daily routines. In addition, such alignment covers sessions experienced by individuals or groups of workers. Furthermore, such sessions could be conducted according to adapted and adopted pedagogical models requiring workers to be trained ubiquitously while exercising various learning and training tasks.

MSL dimensions and mobile learning also consist of administrative tasks required to be practiced as part of the organization of learning and training activities. Such organizational practices consist of designing training and learning sessions consisting of various types of tasks designed along a predefined learning path. Accordingly, workers could interact with these learning tasks preplanned in a sequence and used by users organized in various social settings (individually or in groups) present across locations.

Finally, these types of activities may result in an additional level of data revealing environmental information like data about the location, time, and temperature. This type of information could be later reused for conducting additional phases in the activity as well as for reasoning and refinement purposes aimed at improvement of future cycles of such type of activities (Kohen-Vacs 2016).

In this section, we proposed to consider and incorporate IoT during activities focused on work-based learning and training. We demonstrated how this technological concept is aligned and provides further opportunities for advancements for mobile learning and training aimed at work-based purposes. In the next section, we present a number of use-case scenarios focused on work-based learning and training that are IoT-supported.

3 Use-Cases Supported by IoT

In this section, we describe various deployable efforts concerning learning and training activities that could be practiced in work-based learning and training. We describe a case aiming to facilitate the integration of new workers into their new environment. We continue with another case focusing on alleviation of typical challenges concerning management, growth, and development of organizations. Next, we present a case focusing on learning and training toward optimization of work processes. We bring a case describing a medical procedure including the exploitation of IoT during surgical interventions. The described use-cases are summarized in an additional subsection summarizing the envisioned scenarios while emphasizing their major aims and their operative goals. In addition, we indicate the sources of data to be extracted for each of the scenarios. Finally, we address data analysis based on extracted data as well as the reasoning process practicable based on it.

The activities proposed in this section are presented while acknowledging a Design-Based Research (DBR) methodology use to deploy them (Brown 1992, Collins 1992, Collins et al. 2004, Hoadley 2002). In the following subsections, we present our suggestions for work-based learning and training oriented to mobile learning supported by IoT. We propose a DBR process for these activities while relying on various investigation efforts inspiring research conducted by one of the authors (Kohen-Vacs 2016).

3.1 Use-Case # 1: New Employees' Onboarding

This example is aimed at shortening the process of integrating new employees into a company and its culture as well as getting new hires the tools and information needed to become productive members of the team. Onboarding plans take place within the organization's workplace (physically or virtually). They are intended to make new employees familiar with the overall goals of a company, information on the products, services, and processes of the company to support them as they embark on early projects all to achieve quickly time for proficiency.

During the onboarding process, a group of students, new employees, who have joined the organization, is required to learn a huge amount of information in a short time. This study material is designed to facilitate the absorption process of employees, to make them as quickly as possible and to speed up the process of socialization of new employees.

To date, much of the new employees' onboarding are held through traditional learning methods and means like face-to-face meetings, instructor-led training (ILT), and e-learning authoring tools. In a work area saturated with IoT devices connected to one central network, learning will be based on the real-time experience of new employees.

A network of cameras, mobile devices, and IoT network traffic will record and analyze the activity of the new learners: What are their recurring questions? Who do they meet? What physical structures are they in? What content do they read? And even data about their orientation in the physical space like, What physical structures are they in? Where are they parking their car? Where do they have their lunch/dinner? To whom do they refer for office supplies? This data will be analyzed according to parameters of frequency, location, context, people, and course content. The accumulated information will be available to the new employees as self-assessment of the onboarding training so far and suggestions for the continuation of the learning process.

In an example of a hypothetical process, a new employee who is looking for information about an organizational process, for example, regarding the approval of vacation days, will receive a rating of the articles, forms, and publications which his colleagues searched for, what was absorbed, subject and relevant content. In addition, this information will be distributed among the new group of employees to maximize learning and to maintain socialization processes.

3.2 Use-Case # 2: Adaptive Personal Learning

This example is aimed at overcoming one of the main challenges facing today's management, growth, and development of organizations: how to grant employees the right knowledge and competencies in the right context while taking into account the different learning styles. The stakeholders are organization officials who are challenged to cope with the knowledge that is frequently updated. Adaptive personal learning can take place any place any time while prioritizing the employee's learning style. Knowing what content and resources to provide an employee at precisely the right time, place, and style will help that employee get better at his/her job, while they are doing it.

For example, a manager of a purchasing department in a large organization is invited to a kickoff meeting on a new large project that he will lead. The project involves conducting contract processes with equipment suppliers that are unknown to the procurement manager. These processes require the purchasing manager to understand the concepts of the content domain and the differences between the equipment types. The purchasing manager identifies the knowledge gap and initiates a process which will design an ongoing customized learning process.

The process will include the following steps: (1) identifying the knowledge gap, (2) converting the required information into a learning unit that fits the purchasing manager's learning style, and (3) identifying optimal learning opportunities. Each of these steps is specified as follows.

1. Identifying the knowledge gap—The manager's smartwatch will monitor the terms and concepts used in the meeting. Whether by a purchasing manager mark on the smartwatch or automatically. This information will be processed and transferred to the purchasing manager's mobile device.
2. Converting the information into a learning unit—The purchasing manager's mobile device will find the information and concepts on the organizational network, supplier sites, and organization documents. The multiple-source content will be customized to the preferred delivery method and in accordance with his/her learning style.
3. Learning opportunity—The purchasing manager's calendar will identify the best learning opportunities, considering the learning time required, and the time availability of the within the daily tasks as appeared in the calendar. For example, the calendar events might allocate that the duration of the drive from work to home is the best learning opportunity for a specific learning unit. When the purchasing manager enters the car, the car's computer will send a reminder that a learning unit is waiting, and will play it during the trip.

3.3 Use-Case # 3: Central Organizational Learning Machine

This example is aimed to optimize work processes and minimize human errors to the lowest level possible via a central learning machine. Reducing human errors and improving efficiency become an absolute necessity for organizational survival. The direct stakeholders are employees whose performance metrics are calculated according to the number of errors. Indirect stakeholders are managers whose productivity and efficiency are based on their work subordinates' quality of work. The diagnostic system operates within the organization's workspace (physically or virtually).

A central system that monitors all the organizational machines can detect repeated mistakes of employees. This system can record each individual case: who is the employee, the time, the result, and the physical condition of the employee by monitoring the employee's measurements, such as skin volley, pulse, motility, and salinity level, at the time of the error and the availability of the employee to learn.

This analysis will be translated into two types of insights: (1) evaluation of reasons for the error (when it is possible to analyze it) and (2) evaluation of the conditions which occur just before the mistake. This information will accumulate over time and will be analyzed by the same central system. The system will continue to analyze the accumulated information and select the point where there is enough information to intervene.

In situations where the system will identify with high certainty the cause of the error(s), an automatic change will be made to the processes or interfaces to prevent the error. In most cases, these changes will not require a learning intervention, considering the likelihood the solution will include automation of processes and not human performance. In situations where the system cannot isolate the specific cause(s) of the error, it will run a correlation analysis between the relevant predictive variable(s). Identifying the main predictive variable(s) will allow the employee to be alerted and in real time to be aware that a certain type of error may occur. This alert increases employee awareness of her work paths and, hopefully, leads to a behavioral change among employees without a human learning intervention. The central organizational system will moderate the employee without delivery of learning interventions to improve interfaces and reduce user error constantly.

3.4 Use-Case # 4: Learning and Training Focused on Medical Procedures

In this scenario, we describe a process aimed at the training and learning of medical procedures while focusing on chirurgical interventions. Furthermore, we propose this scenario as we aim to suggest short-time, effective, and educational opportunities supported by wearable technology enabling the transition of knowledge related to the medical procedures to be improved.

We acknowledge that the distribution of medical procedure among practitioners requires investment in human resources as well as in medical infrastructure. Most often, in these kinds of processes, the involvement of an expert physician is required during learning and training activities. Accordingly, such expert aspires to train and provide his trainees with motor skills related to the targeted procedure. His learning and training efforts could be supported while wearing a smart bracelet capable of tracking and transmitting his hand movements.

The training physician wears the bracelet while demonstrating a medical procedure. The bracelet is enabled with features capable of providing feedback in real time. Specifically, real-time vibration and instructions (voice) would encompass the learning and training process while focusing on how to perform the exact steps. During this process, data is transmitted and collected from the bracelet and analyzed to be used later for learning and training purposes. This data is stored in a global database that accumulates raw data and analyzed information focused on best practices offered for improving medical skills. We emphasize that this database will include data and information about successful processes as well as those representing failures usable as learning and training opportunities.

We foresee that the information on practitioners' movements could be used as a fertile ground for analysis and reasoning based on recognition of typical patterns of motor movement exercised during a state-of-the-art procedure.

4 Overview of Aspects for Described Scenarios

In the previous sections, we described four scenarios dealing with various learning and training processes potentially supported by IoT devices. In Table 2, we describe major aspects for each of the scenarios.

As mentioned, the table above presents major concerns that need to be addressed during the design, development, and deployment of such activities. We present these concerns toward the following section dealing with requirements for use-case scenarios. Specifically, we bring these concerns as we propose to use them as starting points for ongoing and iterative design for such activities as described in the next section.

5 Discovering Requirements for Use-Cases Supported by IoT

In the previous sections, we presented IoT and its potential affordances while implemented in use-cases practiced across domains. Accordingly, we envisioned possible deployment efforts illustrating how data could be generated from learning and training interactions supported by IoT. In addition, we showed how this data could be analyzed in order to serve as a means to generate new insights valuable for the trainers and trainees. Finally, we pointed out the potentials to further adapt

Table 2 An overview of major aspects as described in the mentioned scenarios

Case #	Major aims	Operative goals	Sources of data	Data analysis	Reasoning
1	Track if new employees respond to their learning needs and continually improve the onboarding process	Providing these learning units for new employees in real time and in context	Track places, moments, queries, structured data (calendars, appointments, logs, etc.) and unstructured data (calls, information from materials viewed by the user) of all new employees	Identify repeated patterns of queries and information	Design and produce learning units adapted to needs of new employees based on collected data and common patterns that were identified
2	Track that the learner uses terms in the right context	Create customized learning slot offered in appropriate contexts	Collect terms and their context of use that are implicitly or explicitly required by learners during their practices	Seek and track for appropriate definitions for terms and their corresponding context of use	Design and produce learning units according to unfamiliar terms and their context while emphasizing adaptation for learning style
3	Measure error for enabling continuous improvement of processes and work interfaces	Alert in cases that are independent of the human factor and merely relate to the working environment. Provide alerts in cases in which human indices may imply human mistakes that are going to occur	Collect information about human or environmental conditions measured prior to the occurrence of errors. Collect data focused directly on errors and their causes	Analyze the cause of errors and the environmental or human factors causing them (if any)	Detect cause factors for errors and their effects. Plan to extract critical points in the occurrence prior to the making of an error
4	Identify practices and mistakes for optimizing learning and training process	Provide sonic and haptic feedback while training or performing the medical procedure	Collect metrics focused on movements during the procedure	Identify successful and unsuccessful movements	Generate a sequence of actions based on previous and successful experience and vibration feedback

and refine this activity based on the retrieval of the data and its corresponding analysis. In this section, we acknowledge these potentials and accordingly propose a design approach practicable along a process offering to facilitate various challenges focused on:

- Learning and training opportunities supportable by IoT.
- Practicing interactions supported by IoT across contexts including those addressing social, temporal, and location settings.
- Offering means to extract new insights based on data generated resulting from interacting with various tasks.
- Suggesting means to evaluate tasks consolidated into entire activities supported by IoT.

As implied, in Table 1, all these opportunities and challenges could be contextualized and aligned with MSL dimensions. Specifically, the first and the third points relate to elicitation of requirements addressing educational and training tasks (mainly MSL-1, 8, 9, and 10). The second point is related to organizational aspects required to be set for the educational and training tasks as reflected mainly in MSL-2, 3, and 4. The last point targets aspects related to the evaluation of such activities. All the mentioned points address enactments that rely on IoT support (mainly reflected in MSL- 5, 6, and 7). As mentioned in the introduction, these challenges in the light of educational design were addressed by different researchers (Looi and Wong 2011, Milrad et al. 2013). Accordingly, Kohen-Vacs (2016) proposes a design approach adopted and adapted from research efforts carried out by Ravenscroft et al. (2012). These ideas are illustrated in Fig. 2.

In Fig. 2, we illustrate our proposal for a design process spanned along three iterations. In the first iteration, we suggest considering and practicing various design tasks including:

- Prioritization of aspects as reflected in the different MSL dimensions, addressing the activities' goals and challenges. This prioritization aims to enable design of activities for multiple purposes while conceptualizing its educational, organizational, and technological aspects.
- An exploratory phase examining the experiences and constraints related to different aspects of activities focused on learning and training for work.
- A practical design process aimed at providing potential solutions linked to implementations of such activities.
- An evaluation phase addressing the ongoing design process and targeting how diverse MSL dimensions were conceptualized in the previous design process.

In the following iteration, these tasks are repeated while conceptualizing MSLs in the same continua (Milrad et al. 2013). The last iteration includes a final session aiming to assess challenges from previous iterations that need additional adjustments. In the next phase, the final design is evaluated and proposed as a mature concept for activities aimed at work-based learning and training to be offered for adaptation and reuse in the future. In this section, we proposed a process enabling researchers and trainers with opportunities to conceptualize and design activities

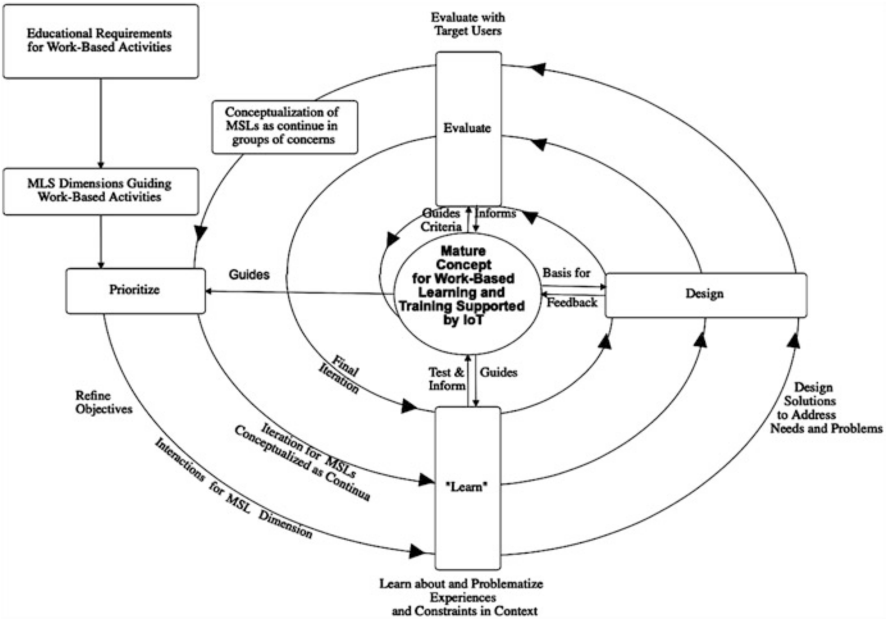

Fig. 2 Spiral iterations included for the Mature Design process. (Adapted from Ravenscroft et al. 2012)

while considering their educational, training, and administrative requirements. In addition, this design process offers an opportunity to identify technological aspects that needed to be developed and deployed to provide support for such activities. In the following section, we present our proposal for an architecture aiming to offer support for work-based activities practiced for learning and training purposes.

6 From Design to Technological Deployment

In the previous sections, we illustrated four scenarios emphasizing dimensions addressing work-based learning and training. In these descriptions, we described proceedings including various aspects that require technological support. Specifically, we emphasized several MSL dimensions associated with technological aspects of these scenarios. For example, MSL-5 deals with ubiquitous access to learning and training materials from across contexts of the work-based setting. Additionally, MSL-6 directly addresses encompassment between the physical and the digital. MSL-7 deals directly with interactions exercised with multiple devices. In this respect, it should be mentioned that the cases we deal with here involve with devices (mobiles, tablets, and other types of computers) as well as IoT devices that were not originally mentioned in respect of research efforts addressing MSLs. Other

MSLs are indirectly related to technological aspects in the sense that some of them deal with learning interactions, while others deal with the administration of learning and training aspects. In these two cases, technology also could be used to facilitate the educational aspects as well as administration. Consequently, we identify that these series of challenges could be supported by a series of interrelated services included in a service-oriented architecture.

In the previous subsection, we elaborated on a spiral process aimed at enabling design aspiring toward matured activities focused on work-based learning and training. In this respect, we suggest examining various aspects related to these kinds of activities toward the establishment of an architecture capable of addressing insights associated with MSLs. In the described scenarios, we mentioned a variety of user interactions that may require the employment of services for supporting the different types of practices, e.g., synchronous or asynchronous interactions (Mayer et al. 2008). In addition, we employ other services to handle data related to interactions communicated from IoT devices at all times. Data originating from IoT devices could be used as a complementary picture describing the context in which learning and training were practiced. For example, data transmitted from wearable devices could provide information about body temperature during the performance of a practice exercised by a trainee. In other cases, information communicated from IoT device embedded in a machine employed during a production process could be used to constantly inform data dealing with the capacity of a worker.

In Fig. 3, we present our proposal for a general architecture offered for learning and training activities incorporated with IoT devices and aimed at work-based settings.

As mentioned, the presented architecture aims to address each of the presented scenarios while offering technological support for the required services interacted by various types of IoT devices. Furthermore, this architecture offers a comprehensive support also possible for other scenarios beyond the described in the previous subsection.

Accordingly, in Table 3, we summarize the involved aspects in each scenario and the way they are being supported in the presented architecture.

In this table, we emphasize how the proposed architecture addresses the four different scenarios we illustrated both in terms of the methodological aspects of the learning and how these are later supported by the different devices and components included in the illustrated architecture.

Specifically, the presented architecture includes an enactment engine communicating with a database containing work-based learning and training scenarios. The enactment engine communicates specific instructions (call for interactions) for trainees using mobile devices as well as stationary or laptop computers. In response, trainees interact with the enactment engine through dedicated web services. The result of these interactions is stored in a cloud database providing affordances to store data from a work-based environment whose boundaries are flexible and expanded across various sites. As mentioned, the training sessions we described are encompassed by IoT in the sense that trainees may wear devices enabled with IoT. In addition, trainees could use equipment enabled with IoT to interact in spaces

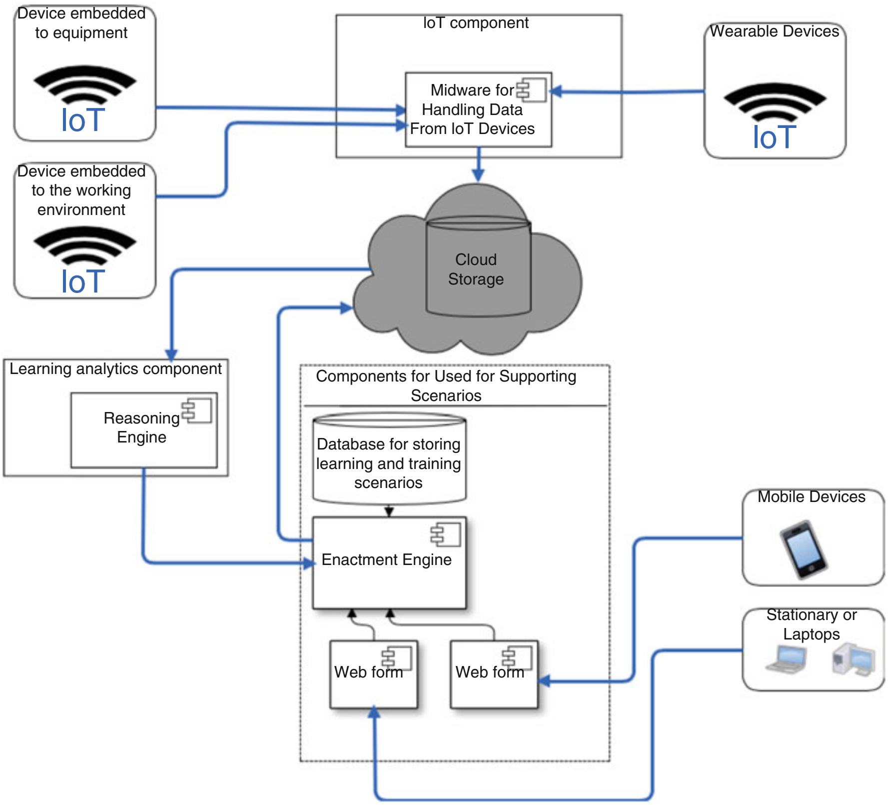

Fig. 3 Suggested architecture incorporated with IoT devices aimed at supporting learning and training in work-based settings

(e.g., production rooms) embedded with this technology. Data communicated from IoT devices could constantly be transmitted and stored in cloud data storage. Later, this data could be related and analyzed along with other pieces of information that explicitly interacted. As illustrated in Fig. 3, a reasoning engine is connected to the cloud data, enabling rely future proceedings of the learning and training scenario upon previous occasions deliberately interacted by users or/and data communicated from IoT devices.

We suggest this architectural approach while aiming to offer encompassment and insights originating from data communicated from IoT devices. In addition and as mentioned, data from IoT devices could be interrelated with other data that explicitly interacted. In this sense, we acknowledge that these pieces of data enabled by such architecture may provide fertile conditions for conducting reasoning process oriented on improving such scenarios and making it possible to mature them along a process that is technologically supported.

Table 3 Description of common aspects for suggested scenarios

	Stakeholders and goals	Involved services	Nature of generated data	Purpose of exploitation for reasoning service
Common aspects for scenarios 1–4	Trainers and trainers practicing a work-based learning and training across contexts and settings	Trainees could be tracked as they use wearable devices (like clothes or bracelets) as well as from computers or mobiles used by them along the process. In addition, other ambient conditions experienced by trainees could be tracked from devices embedded to the physical environment in which learning and training is conducted from	Personal and environmental data addressing individual as well as global conditions experienced along the training and learning process	Individual as well as global data could be exploited in order to refine the methodological aspects of the training and learning scenario (aligned to DBR) Technological aspects of the activity could be also refined while practicing discovery of requirements as part of a system analysis

7 Summary and Discussion

In this chapter, we present our efforts to analyze, design, develop, and deploy optimized scenarios focused on training and learning for work-based settings that are IoT-supported. Accordingly, we emphasize our efforts to identify requirements toward deployment of an architecture addressing these scenarios supported by ICT devices, including those that are IoT-enabled. Our investigation relies upon a multidisciplinary view focused on work-based learning and training, ICT, and the requirements needed to be addressed to consolidate these fields. We suggest that the result of our exploration efforts may serve as potential game changers, breaking ground and offering new and appealing opportunities for learning and training.

We acknowledge existing research on mobile learning and an intent to adopt and adapt it for the sake of exploration focusing on activities practiced in real-life settings during work-based learning and training. Specifically, we examined the evolution of mobile learning in the light of the new generation, also including IoT as part of this line of research. Accordingly, we propose to examine work-based learning in the light of MSLs as suggested by Wong and Looi (2014). In addition, we propose to consider an additional dimension specifically addressing learning and training in the light of IoT that is focused on learning from objects rather than from human origins.

As part of our research efforts, we envision several use-cases, including one focused on training of new employees and the other one addressing adaptive personal learning. In addition, we also brought another use-case about the central organization focused machine. Finally, we described a scenario focused on acquiring new skill during a medical intervention. We follow these use-cases with an additional subsection addressing various concerns required to be addressed during the design, development, and deployment of these scenarios. In the next steps, we analyze the mentioned interactions with users that eventually provide feedback and further processing for a possible iterative process. We use the outcomes of this analysis to identify requirements for designing, enacting, and administering aspects of the presented scenarios.

Having in mind the mentioned analysis, we proceeded and proposed an architecture offered for supporting activities empowered by IoT as described in the scenarios. We propose this architecture based on analysis practiced and aligned to the steps as proposed in the spiral process. In this respect, we suggest that this analysis could provide opportunities to gain new insights enabling refinements during the design, development, and deployment process. Specifically, we bring and propose this spiral process as it aligns interdisciplinary to the exploration and refinement processes practiced for design and deployment of new technologies (Alexander and Beus-Dukic 2009). In addition, this process also aligns with design-based research applicable to deployment of activities focused on technology-enhanced learning (Barab and Squire 2004).

In future exploration efforts, we aim to continue and deploy the proposed architecture in real settings. In this sense, we will dedicate our future efforts to continue and deepen our understanding related to requirements associated with the implementation of IoT devices for work-based settings. Furthermore, we will explore future opportunities to extensively exploit big-data resulting from such devices in the light of reasoning systems aimed at improving learning and training. Finally, we aim to consolidate our efforts toward offering a methodological approach that is technologically supported and align our efforts to mature work-based learning and training empowered by IoT.

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Using the Internet of Things for Enhanced Support of Workers in Manufacturing

Carsten Ullrich, Cédric Donati, David C. Pugh, Alex Gluhak, Anthony Garcia-Labiad, and Xia Wang

1 Introduction

Blue collars on the shop floor (the area of a factory where operatives assemble products) work in highly demanding environments: Their foremost objective is to maintain productivity in order to fulfill customer orders by producing the required number of products. At the same time, they have to adapt to the permanent technological innovation that leads to new materials and new technologies used in production and assembly. Additionally, a decreasing workforce requires employees to become more flexible and master a larger number of skills, for instance, to be able to stand in when colleagues are not available and to use machines that are not their primary area of expertise. As a consequence, the employee is under constant pressure to solve problems occurring on the shop floor as fast as possible, and simultaneously to improve his work-related knowledge, skills, and capabilities. This makes the shop floor an area where the usage of technology to support problem-solving and learning of the employee can result in significant benefits (Mavrikios et al. 2013).

Previously (Ullrich et al. 2015), we have shown that adaptive systems using artificial intelligence methods can provide services, which are context-depend (based on the affected machine, its state, the current product) and personalized (adapted to the individual employee, i.e., capabilities, work history, development goals). We

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distinguish between assistance and knowledge services: assistance services assist in solving a current problem, while knowledge services support the transfer of knowledge and the achievement of individual medium- and long-term development goals (Ullrich 2016). Assistance may take the form of step-by-step instructions or superimposition of information in the field of vision through augmented reality (AR). Knowledge support is given by contextual recommendations that include suitable work activities, but also information relevant in the current context, e.g., from manuals.

Such systems require knowledge about what is happening on the shop floor, specifically about the current state of assembly and the actions of the workers. In highly automated environments, such data is available, albeit used for a different purpose, namely, the control of the production process: what action a machine should take, when to perform the action, etc. This sensor data can also be used by assistance and knowledge services to understand the interactions between blue collars and machines. Examples are whether a worker refilled a consumable, reset a machine, etc. All such states can be deduced by analyzing sensor data. However, not all production or manufacturing environments are highly automated or "sensorized." On such "analog" shop floors, only limited or no sensor data is available, and support systems become "blind." They do not know about the current state on the shop floor and in consequence, the quality of the given support decreases.

In this chapter, we describe an approach to handle the digitization of working environments. Based on a use case in which we employ off-the-shelf sensors to enhance assembly environments in aviation (at Airbus) such that assistance and knowledge services collect sufficient information to provide personalized support, we start by summarizing current work on worker support in production and manufacturing (Sect. 2). We then give an overview of the technologies of the Internet of Things (Sect. 3), followed by a description of how we analyzed and managed the use case (Sect. 4). Section 5 described the final setup and presents a detailed example. We conclude the chapter with a summary of lessons learned and an outlook on future work in Sect. 6.

2 Related Work

Educational technology and adaptive environments are clearly relevant for supporting employees in workplace-based learning (Koper 2014) and in manufacturing (Mavrikios et al. 2013) in particular. Existing work investigating support on the shop floor has focused on very specific areas, such as assembly, in order to increase process quality (Stoessel et al. 2008; Stork et al. 2012), collaboration between machine and operator (Sebanz et al. 2006; Lenz et al. 2008), control and monitoring (Wersborg et al. 2009; Bannat et al. 2009), but always focusing on specific machines. Approaches that look at the shop floor more broadly investigated how to use data from factory-wide sensor networks to control information flow so that cognitive overload of employees can be avoided (Lindblom and Thorvald 2014) or how to display the data in a way that employees' satisfaction is increased (Arena and Perdikakis 2015).

Limited research focused on using methods of artificial intelligence to realize adaptive learning environments for the workplace. The potential of such methods has been shown for generating assembling instructions automatically from product lifecycle data (Stork et al. 2012), for supporting the transfer of practical knowledge (Blümling and Reithinger 2015), as well as for providing manufacturing assembly assistance (Alm et al. 2015). The APPsist system is a service-oriented architecture for learning and work support on the shop floor (Ullrich et al. 2015). There, a set of basic services covers basic functionality, with respect to the user (authentication, authorization, session management), to integrated (Internet of Things) devices (device sensor information, sensor data visualization) and software (such as learning management systems in university and schedule software in industry), and to user interaction (services that implement user interface depending on the specific output device). Advanced services use the basic services' functionality combined with an expert system to provide adaptive functionality to the user. The expert system models part of the knowledge of a human mentor or trainer: It decides which materials (work procedures, blueprints, manuals, etc.) are relevant for an individual learner in a particular situation and presents these materials on a mobile device. The modeled knowledge is abstracted from the specific shop floor configuration and was applied in several different workplaces, ranging from a small, regional enterprise to a market leader in automation. The system relies on sensor data from the machines on the shop floor to model the current situation on the shop floor, and to react to it. However, not all training and working environments contain sufficient sensors to make such decisions. In such situations, sensors that are brought in, either in wearables or explicitly installed, might come to the rescue.

Research in the field of vocational training mainly uses sensors of AR devices and smart helmets, watches, and glasses, as well as the camera of tablets or smartphones. An example of these uses with the goal of capturing and re-enacting expert performance using wearables is WEKIT (Guest et al. 2017), which uses Microsoft's HoloLens, among others, to support aircraft maintenance training. First studies have shown that AR training can profit from adaptivity provided by intelligent tutoring systems (Westerfield et al. 2013).

Simpler devices than AR can also bring benefits. The built-in sensors of smartphones are used, for example, support the learning of manual tasks (Ando et al. 2014). There, a smartphone is attached to a saw used by students for practicing the technique of sawing. The students inspect their performance in different graphs so that they can improve without the help of a teacher. Also, sensors attached to equipment and tools in industrial environments allow to support training in stonemasonry (Sivanathan et al. 2017) and also in assembly (Aehnelt and Wegner 2015). There, an assembly trolley is equipped with force sensors, infrared sensors, and inertial measuring devices, which enables the detection of the currently performed work step and the display of instructions and notes on a touch display.

The use case presented in this chapter focuses on the use of inexpensive, off-the-shelf sensors to digitize existing work and training environments, in order to provide sufficient information to an AI-based system to support the workers.

3 Overview of the Internet of Things

3.1 IoT Service Patterns

From a technical perspective, the Internet of Things (IoT) consists of objects that are identifiable, able to communicate and to interact (Miorandi et al. 2012). Identifiable means that objects have a unique digital identifier, the Electronic Product Code (EPC), which is typically broadcast using Radio-Frequency Identification (RFID) technology, a very basic way of communication. Further communication, i.e., sending and receiving data to other objects, is enabled by various wireless technologies, realizing the step from single things to a network of things. The objects are not passive, but use sensors to collect information about their environment, and actors to trigger actions. On top of the hardware, software layers enable applications. IoT middleware provides a common way to access heterogeneous IoT devices and simplifies the development of IoT applications. The technical challenges of IoT are not yet solved and its diverse areas are subject of active research. Nevertheless, IoT technology has matured sufficiently to be commercialized and to be used as an enabler for research, including educational one.

Most IoT applications and services have a common underlying service pattern, which can be characterized by four distinct activities. These activities are Acquire, Analyze, Action, and Achieve, which we describe as the 4A service pattern. The 4A service pattern is depicted in Fig. 1 in more detail.

Each IoT application or service has a desired goal or impact in the real world it aims to achieve. Typical, noneducational, examples are maintaining an adequate level of comfort and user experience in a home environment, providing optimized utilization of energy or water resources in a utilities context, providing an optimized end-to-end supply chain, or the minimization of congestion and maximization of throughput in a transport scenario.

In order to achieve their objectives, IoT applications and services can trigger a set of actions that impact real-world processes underlying them. These could be notifications and visualizations to users to trigger further actions or encourage longer-term behavior change. Actions could also be triggered without the human in the look by re-routing delivery of packets in a logistics process, adjusting the behavior or features of objects or machines, by changing the environment through actuators, such as adjusting the temperature in building or opening or closing windows or gates. Actions require the right decision-making processes to be in place, which is encoded in some of knowledge base such as rules or more complex algorithms.

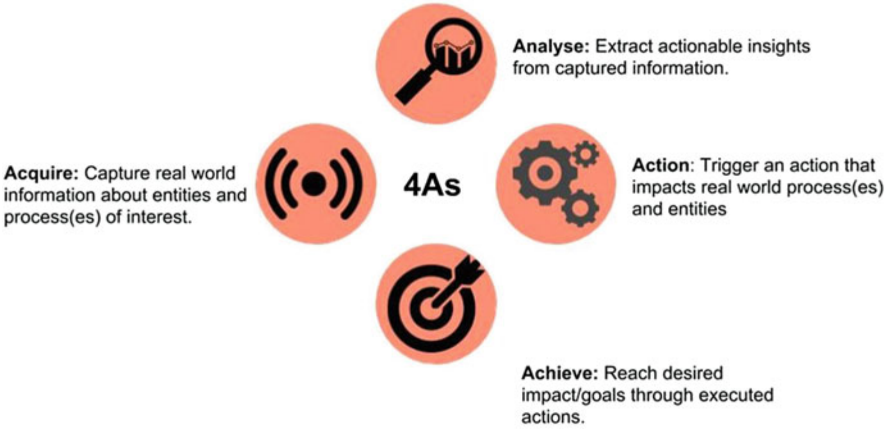

Fig. 1 4A service pattern for IoT applications and services

Making the right actions requires the right information for decision-making processes to be in place. In IoT systems, these decision-making processes rely mainly on real-world information that is acquired through IoT nodes providing one or multiple modes of sensing capabilities. In some circumstances, IoT systems also utilize soft-sensing capabilities to acquire real-world information. The latter refers to crowdsourcing information from human users by prompting them to input perceived qualities about their environment or real-world processes.

In some cases, it may be sufficient to implement actions directly based on the acquired real-world information. However, often more information processing is needed to analyze the acquired real-world data and make it more suitable for (autonomous) decision-making. Data cleansing, fusion, augmentation, and analytics are important elements to extract actionable insights from the captured real-world information.

3.2 The Architecture of End-to-End IoT Systems

IoT systems typically follow a three-tiered architecture as shown in Fig. 2. At the edges of an IoT system are IoT devices, which are low-end computing devices empowered by sensors and actuator – providing the ability to capture information from the real world and able to influence the state of it. IoT devices come in many shapes and forms; they can be installed in the environment and attached to objects and persons. Their main goal is to provide effective capture of real-world information from the real-world entities they are observing or influence the real world through actuation by operating valves, temperature controls, or other control feedback devices. IoT devices are severely resource constrained and are expected to operate often on battery over long periods of time. Therefore, they generally

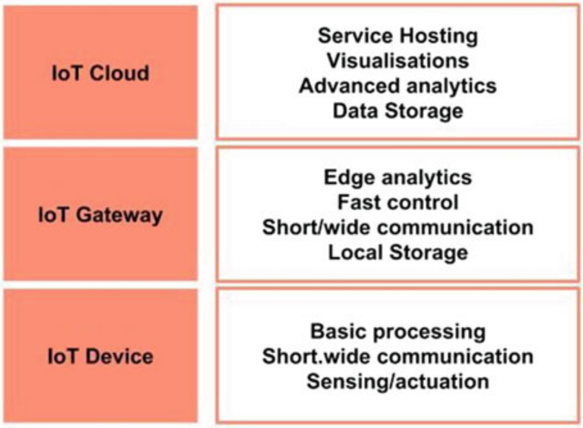

Fig. 2 Device-centric view of an IoT system architecture

provide only limited data processing capability. They are connected in many cases through wireless protocols designed for resource efficient short-range or long-range connectivity.

The second tier in typical IoT systems consists of IoT gateways, which are devices that bridge IoT devices with cloud and service infrastructures on the Internet. IoT gateways are often mains connected and are thus not as resource constrained as IoT devices. Apart from providing a connectivity bridge, IoT gateways can also offer local storage and processing capabilities to provide edge analytics. Edge computing is becoming increasingly important to ensure that only relevant information is streamed from IoT devices toward the cloud and that decisions that require control and actuation can be faster implemented at the edge for latency-sensitive applications.

The IoT cloud tier is realized by so-called IoT platforms, which are extensions of cloud platforms optimized for IoT data processing and device management. These platforms typically offer a rich set of data processing and storage capabilities and support advanced analytics, rules engines required for autonomous decision-making capabilities. They also offer a rich set of tools to build end-user-focused IoT services such as dashboards and visualization and provide integrations to existing enterprise systems (Fig. 2).

3.3 Communication/Sensor Protocols

With a broad range of networking options, hardware and platforms, selecting the right products to enable an IoT project can be a daunting task, and choosing a suitable network is vital to ensure that data can be obtained in a cost-effective and practical manner. Most large-scale IoT projects have similar basic wireless connectivity needs:

- Monitoring devices are often deployed without reliable access to power. The use of low-cost batteries or of energy-harvesting technologies aids a device's lifespan in the field.
- Devices may send only a few bytes of data a day. Using low bandwidth also supports field lifespan.
- IoT nodes can be deployed in thousands; therefore, connectivity costs must be low, and networks must be able to support a high density of devices.
- Devices may be deployed in rural or urban areas, including underground. Networks must have a strong penetration and reach.

In some cases, one network will not be able to satisfy all the requirements of an IoT project, and some devices will require a longer range or higher data capacity. It is therefore sometimes required to deploy two or more networks that provide data to a single server and the interface.

3.4 Licensed vs Unlicensed Spectrum

In order for multiple technologies to transmit over the airwaves simultaneously, wireless spectrum is segmented into frequency bands. Licensed bands exist where organizations pay a fee for exclusive rights to transmit on assigned channels within the band in a geographic area. For example, Telefonica has exclusive rights to 40 MHz of 2.3 GHz spectrum in the UK, for providing some of its 4G services.

Licensing is a way of ensuring that wireless operators do not interfere with each other's transmissions. In the licensed spectrum, interference usually only occurs at the outer edge of the license holders' coverage area.

While the licensing process works well for some use cases (such as cellular communications), spectrum is expensive (€15 m/MHz) and impractical for smaller wireless networks, such as connecting wireless keyboards and other accessories. For these use cases, the unlicensed spectrum is utilized.

Unlicensed spectrum technologies (such as Bluetooth, LoRaWAN, and Wi-Fi) do not require any permissions, provided that the products and users comply with the rules associated with the unlicensed band (e.g., maximum transmission power). These bands are unlicensed but are regulated. Unlicensed spectrum technologies are much more susceptible to interference; for this reason, adjustments are sometimes required to avoid interference, and radio environments are likely to change over time (Fig. 3).

3.5 Short-Range Communications

Short-range communication is typically used for in building and on-premise networks. The most common communications protocol worldwide is Bluetooth

	Short Range Wireless	Low Power Wide Area Network (LPWAN)	Cellular network
Usage (M2M)	70%	5%	25%
Pros	Well established in buildings & consumer electronics	Low power Low cost Long range	High coverage High data rate
Cons	Low battery lifetime Short range	Low data rate Emerging standards	Large power requirement High cost
Use cases	Smart home, wearables, streaming	Asset tracking, sensor networks, smart cities, industrial monitoring	Cell phone, automotive
Main revenue source	Hardware sales	Dependant on provider	Network subscription
Key players	WiFi, ZigBee, Bluetooth	NB-IoT, sigfox, LoRaWAN	4G LTE, 5G

Fig. 3 Different network types for IoT projects

(with an installed base of approximately 12.2 billion units), most widely used to connect cell phones to wearable devices and speaker systems, and ships an estimated 880 million devices annually. Wireless personal area network (WPAN) communication takes place over the unlicensed spectrum and typically operates on the same frequencies worldwide. The open nature of WLAN networks means that devices can be connected easily by nonexperts and are typically plug and play. These technologies are well established, with their first implementations in the early 1990s.

3.6 Long-Range Communications

Cellular communications Cellular communication suits high volume and high data rate requirements, typically audio/video feeds. Cellular communication typically transmits data for cell phones and vehicles. Cellular networks are deployed worldwide by a large range of mobile network operators, operating on local and international scales.

While cellular communication is well established globally and can transfer a large amount of data over a long distance, it is expensive computationally, financially, and in energy requirement.

The advent of 5G, expected to launch commercially across Europe in early 2020, provides faster data transfer (1 Gbps), increased capacity for the ever-expanding variety of connected devices, and data requirements of consumers and enterprise as well as enables high-volume machine-to-machine communications.

LPWAN Low-power wide-area networks are low-power, low-volume and long-range networks designed for the Internet of Things. Typically used for monitoring of systems and asset tracking, these networks suit sensors that have long battery lives and are designed to be placed and forgotten and collect data over a long period of time. The long range of LPWAN base stations means that a single base station is often sufficient for an entire deployment and can support many devices, resulting in reduced infrastructure costs. Typical examples of LPWAN deployments include temperature and humidity monitoring of industrial sites and waste monitoring of bin fill levels. LPWAN systems require little infrastructure and can be easily set up and deployed, typically in a number of hours. There are three main suppliers of LPWAN technologies in Europe.

- LoRaWAN is an open technology that operates in the unlicensed spectrum and is administered by the LoRa Alliance, a consortium of over 550 companies. Deployments are largely undertaken by private enterprise and provide private networks to universities, companies and other building management firms. Nationwide networks have been rolled out in France (by Orange) and the Netherlands (by KPN).
- Sigfox is a proprietary technology, operating in the unlicensed spectrum. Sigfox charges between €1 and €12 per year/per device, depending on data requirements. Sigfox has deployed and manages networks in 45 countries, and users are able to use devices on networks in all territories.
- NB-IoT is an LPWAN system operating in the licensed spectrum and administered by mobile network operators and in most cases, will utilize the same technology used for 4G communication. NB-IoT networks are deployed in 24 countries, primarily by Vodafone and Deutsche Telekom.

3.7 Sensor Choices

A wide range of sensors are available today, and identifying the right sensor for the right use case can be tricky, as many sensors serve multiple use cases and can be utilized in a number of different configurations. Selecting the right sensor for the right application is crucial to a successful IoT deployment. Table 1 gives an overview on different IoT sensors and use cases.

4 Managing Highly Secured Industrial Use Cases

4.1 The Challenge of Security and Secrecy

Assembly in aviation is both a challenging and also relevant use case for sensor usage for workplace support, as it represents a manufacturing environment with currently limited usage of sensors and automation solutions. This stands in contrast to, e.g., the highly automated automotive industry. It, therefore, serves as an example of how such environments can be digitized, i.e., extended with sensors to make information about worker's activities available to digital support systems. However,

Table 1 IoT sensors and use cases

Sensor	Potential use cases
Temperature	Temperature, human/animal presence, switches
Humidity	Humidity detection
Pressure	Atmospheric pressure, altitude, flow, depth
Magnetic	Presence of objects, navigation, DC measurement, fuel level
Accelerometer	Movement, navigation, vibration, shock, step counting
Chemical gas	Air quality, chemical leak
Microphone	Position, presence
Gyroscope	Movement, position
Current	Detection of components in use
Biometric	Identification

the assembly line of Airbus is an example of an extremely secure environment due to safety and secrecy reasons. Assembly in aviation is highly regulated to ensure process and product quality. In this section, we describe the challenges raised in this environment and present our solutions, as a guideline of interest for similar research projects in such settings.

Challenges include access to networks and documents. Airbus regulations take utmost care is that potential malicious third parties cannot gain access to their digital networks. In consequence, Airbus does not grant maintenance and service access to any third parties from outside the Airbus network and denies access to the internal networks on-site. Also, the precise assembly processes, documents, etc. are kept in high secrecy. The usage of documents of any kind requires permission of the document owner. While we have performed research projects in other secure industrial settings, Airbus guidelines exceeded anything encountered previously. In sum, this made the setup of an exemplary exploring use case on the factory floor impossible.

To overcome these problems, we developed an autonomous and analogous use case: autonomous in the technical sense, meaning that the complete hardware setup was independent of any Airbus network and also mobile. Therefore, it can be installed wherever needed. The first physical installation was at the Center of Applied Aeronautical Research (ZAL), which serves as an interface between academic and research institutions, close to the actual factories. It was analogous in the sense that it consists of tasks that require the same skills as on the assembly line, as well as raises similar problems and difficulties, but is abstracted so that third parties cannot draw conclusions about sensitive details of the real manufacturing. Similarly, internal Airbus documents and relevant Airbus data were replicated, so that they "mirror" the originals, but without revealing real Airbus information. We call the analogous use case the "public use case," as we can discuss and disseminate this scenario publicly. The original, abstracted use case is called the "source use case."

4.2 Identifying Suited Source Use Cases

In an industrial setting, a suited source use case has to be of interest not just from a research point of view, but also from a commercial perspective, i.e., involved stakeholders should be able to see a potential return on investment. There, it helps that companies typically keep track of problems occurring during their manufacturing processes. In the Airbus case, these problems are called "nonconformities" (NCs). The assembly workers enter an NC into a database whenever they encounter a situation that does not conform to the set standards.

Workshops with participants from the human resource and training department and operatives from the assembly lines served to identify potential source use cases. These were then further analyzed with respect to complexity (required training time, duration of assembly process) and occurring problems (according to the number and type of NCs, and feedback from workers).

In the Airbus case, we settled for the installation of the mixer unit as the source of the public use case. The mixer unit serves to mix air from the inside of the aircraft with outside air. It is a device located in the cargo compartment of aircrafts and is connected to several ducts that are attached to the primary structure of the aircraft. The installation is a complex manual task that requires an extensive training of up to 6 months of an aircraft mechanic. It requires the adjusting and installation of ducts and pre-assembled components. From process planning perspective, the installation is rated with a total time of about 7.2 hours and occupies two workers. In general, the installation takes longer than foreseen by process planning and requires up to 10 hours. Similar to most other installation tasks in aircraft assembly, these tasks are not effectively automatable (performed by a robot) as they require handling brittle parts in difficult to access spaces. Problems during the mixer unit installation caused by human error raise NCs resulting in a loss of about 100.000€ in 2017 alone.

4.3 Categories of Problems in Industry

To ensure that the public demonstrator captures the relevant activities and tasks of the source use case, we first identified the different types of problems occurring in the source use case and then created the analogous environment, with activities that raise instances of the identified problem types. Thus, on the abstract problem-type level, both use cases are equivalent, while at the specific activity level, they are different.

On a general level, two categories of errors can be distinguished: production errors caused by external causes, without any influence from the worker, and human errors, caused by the worker. Both categories were further divided into subcategories: internal problems into subcategories (following the categories of human errors according to (Reason 1991), illustrated in Fig. 4), and production

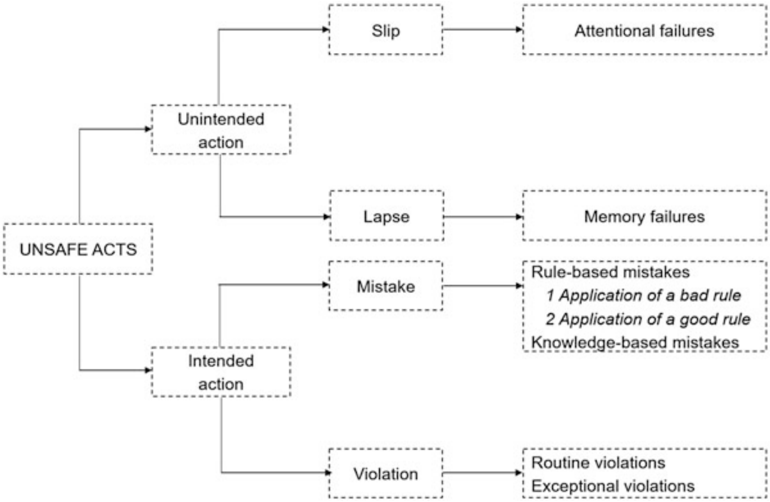

Fig. 4 Categories of human errors according to Reason (1991)

Table 2 Problem categories with criteria codes

Human error		Production error	
Error type	Code	Error type	Code
Slip	AF	Material	PMA
Lapse	MF	Workflow	PWF
Rule-based mistake:		Instruction	PIN
Application of a bad rule	RBM1	Environment	PE
Misapplication of a good rule	RBM2		
Knowledge-based mistake	KBM		
Routine violation	RV		
Exceptional violation	EV		

errors by the cause of the problem. Table 2 lists the categories, including criteria codes used in the remainder of the paper. In the following, we describe the categories in detail.

- Production error:
  - Material (PMA): errors, where parts to be installed by the worker are missing or were previously damaged.
  - Workflow (PWF): problems within the assembly workflow can lead to preventing the worker from starting or continuing his work. These are often due to the missing clearance of the quality assurance team or to inaccurate or incomplete work from previous stations.
  - Instruction (PIN): errors due to insufficient or unclear instructions given in standard operating instructions. Standard operating instructions specify the

official sequence of installation steps for specific tasks, and are written by workflow designers not on the shop floor. Therefore, often these instructions differ from best-practice experiences.
  - Environment (PE): workers perform installation tasks in environments where space and light are limited and which consist of fragile parts. Therefore, if the worker does not move and act carefully, he will cause damage.

- Human error:
  - Slip (AF): errors due to a slip in the attention of the worker. In aviation, such errors often occur during the assembly of "symmetric" parts, i.e., parts that are laterally reversed, such as a pipe on the right-hand side of a device and a pipe on the left-hand side. Despite the parts looking the same, but mirrored, their assembly processes are different.
  - Lapse (MF): errors due to memory failure, e.g., forgetting. They often arise when ongoing work is interrupted and after resuming, non-obviously observable tasks are forgotten, such as tightening a screw.
  - Rule-based mistake, application of a bad rule (RBM1): the worker has learned or formed a habit of an incorrect behavior. The conditions of a rule (specifying when an action should take place) or the action of a rule (specifying what is to be done if the condition holds) or both can be incorrect.
  - Rule-based mistake, misapplication of a good rule (RBM2): the worker performs an action that has a proven utility in the current context, but does not apply due to very specific conditions unnoticed by the worker. For example, a torque value that is typically used to tighten a screw might not apply to specific materials.
  - Knowledge-based mistake (KBM): the worker faces a situation in which previously learned rules do not apply and has to resort to reasoning, but comes to an incorrect conclusion.
  - Routine violation (RV): these occur if there is a more convenient way to perform an action than the officially prescribed one (for instance, the violation of apparently trivial safety procedures). Here, steps in standard operating instructions are sometimes ignored, which might result in errors (but not always).
  - Exceptional violation (RV): errors due to an exceptional concatenation of circumstances, which typically cannot be remediated by the worker.

In our analysis, we assigned all problems that occur in the mixer unit installation, to one of the categories. As a basis, we used the collected NCs, but slightly abstracted. For example, the specific problem "Tube DUCT160 is difficult to position in between C34 and C35" is abstracted to "Tubes are difficult to adjust," which in turn is an instance of the category KBM. Then, we devised the public demonstrator such that it replicates the errors, in a different environment.

5 Description of the Public Demonstrator

5.1 Overall Setup

The public use case, called "Connecting Unit Installation," replicates the original working environment: workers are required to install a connecting unit, a task that requires to install and tighten tubes of different sizes with varying levels of accessibility, in difficult light conditions due to an encasing. To simulate the installation conditions in the cargo compartment, the height can be adjusted from 1.60 meters to 1.20 meters. Figure 5 shows the setup (the figure does not show the encasing). The assembly processes are analogous to the real processes that require the skills of an aircraft mechanic, e.g., when installing tubes belonging to the air-conditioning system. Tubes need to be aligned, attached to mounts, and adjusted. When connecting the tubes with bellows, tolerance standards must be met. Bellows are fixed with clamps, with the danger of damaging the fragile tubes, if clamps are adjusted too tightly.

The public demonstrator consists of three different structures, shown in Fig. 6. The primary structure sets the area in which the work is performed. First, the worker assembles the connecting unit, then installs the duct system, and finally inserts and connects the connecting unit.

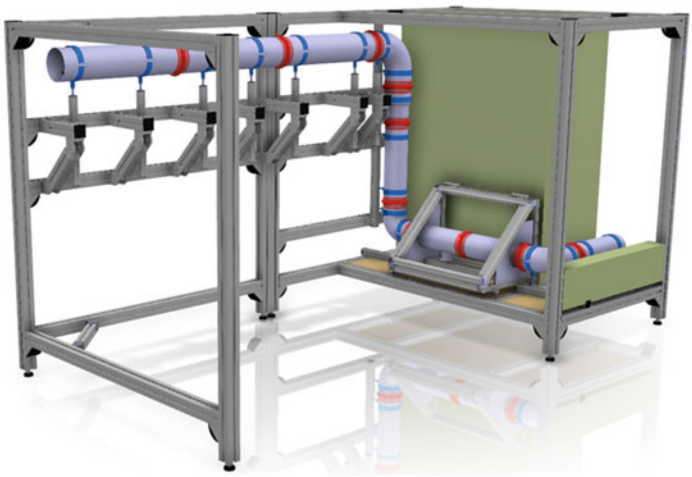

Fig. 5 Public demonstrator: connecting unit installation

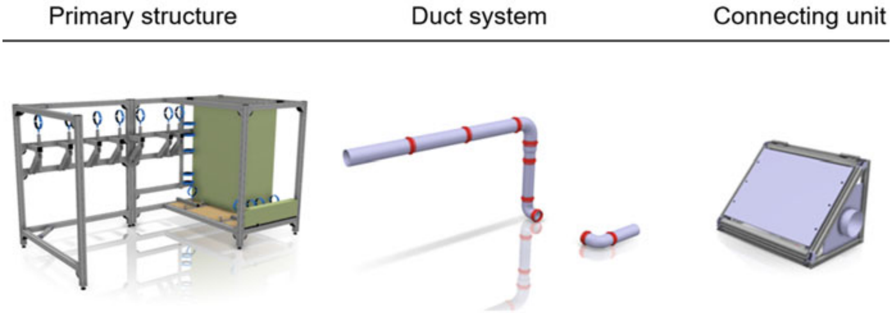

Fig. 6 Demonstrator structures: primary structure, duct system, and connecting unit

5.2 *Potential Errors*

In the following, we give examples of how we set up the demonstrator to ensure that different categories of problems will arise. We focus on the first part, the assembly of the connecting unit:

- The outer frame of the connecting unit is assembled earlier and arrives in one piece at the worker's station. Manipulating the frame allows triggering errors production errors of type PMA and PWF, e.g., by not pre-assembling the hinges, the panel, or smaller components of the structure such as joint angles.
- Modifying the standard operation instructions offers a second venue for creating errors. Here, errors of category PIN, KBM, and RV are triggered through incorrect installation instructions. These state that workers should directly install the side panels, which is actually impossible due to the diagonal profiles that make the area inaccessible. Workers have to remove and afterward put back the diagonal profiles.
- Connecting two tubes using a bellow is difficult if the bellow is not placed on one of the tubes prior to attaching them to the structure. Also, the connection requires two clamps, which come in different sizes. Performing the connection correctly requires explicit reasoning, and thus can give rise to errors of category KBM.
- The tolerance field of the connection, marked by two red lines, is too wide. In consequence, a correctly installed bellow does not touch both red lines and has to be installed in the middle, which violates guidelines (RV). These instructions are not included in the SOI and rely on past experiences.
- PWF can also be triggered by inefficient workflows. Here, the last task *Install Front Cover* is a so-called zone-closing, i.e., after this step, an area is no longer accessible to inspection. The general workflow requires that prior to a zone-closing, a worker checks his work and then informs the quality assurance (QA) team, which again inspects the work result. They give the final clearance so that the zone can be closed by installing the front cover. Typically, the QA team will take some time to arrive. In the meantime, instead of waiting, the worker will

work on another open task. However, he will not receive feedback once the QA has completed the inspection.
- Additional potential errors of the categories AF and KBM are triggered by unintuitive action sequences and symmetric parts. For example, the front cover is fixed with six screws, which have to be tightened in a diagonal sequence. This sequence is rather unintuitive. Also, the connecting unit consists of two side panels, two tubes, and two connectors that are symmetric but have to be installed either on the right- or left-hand side of the frame.

5.3 IoT for Supporting Assembly Tasks

In this section, we describe the overall setup of the IoT infrastructure. We start by the hardware configuration, followed by details on how sensors and instructions interact, and a detailed example from the user perspective.

Hardware and Network Setup We realized a deployment independent of any internal network by setting up a LoRaWAN network using an IoT gateway (a Kerlink Wirnet iBTS IoT gateway), with a wired connection to a standard 4G router. This allowed a full network infrastructure without requiring access to any of Airbus infrastructure as well as allowing the network to easily be moved to a new location without any reconfiguration. The gateway costs about 1000€ but is not necessary if LoRaWAN coverage is available. Figure 7 contains the network diagram of the Airbus use case.

Each part within the demonstrator used in the installation was tagged with a small magnet to provide a unique magnetic signature. In some cases, multiple magnets were used per part to identify different sections of a single part. Within the demonstrator, 38 Sagemcom Siconia multi-sensor devices were deployed to monitor each action. The devices contain a magnetic detection sensor and an accelerometer to monitor shock and can monitor an upper and lower threshold of magnetic flux (in Wb). A single sensor costs about 30€, and magnets cost about 10€ a dozen.

Each device was assigned to a particular step on the process and individually calibrated: when either of the upper or lower thresholds is crossed, a message is sent over the LoRaWAN protocol to a Kerlink data management system. The crossing of a threshold may indicate that the correct part is in place in the correct orientation, the correct part is in place in an incorrect orientation, or an incorrect part has been put in place. The Kerlink system takes the raw sensor message, translates it into a message that carries semantic on the operational level, i.e., from the point of view of the activities of the human operator, and subsequently sends it to the support system responsible for determining the actual worker support. In the Airbus case, we use the adwisar system, a revised version of APPsist described in Sect. 2. Within adwisar, it is broadcasted as an event to which different support services will react to, e.g., by displaying appropriate information to the user.

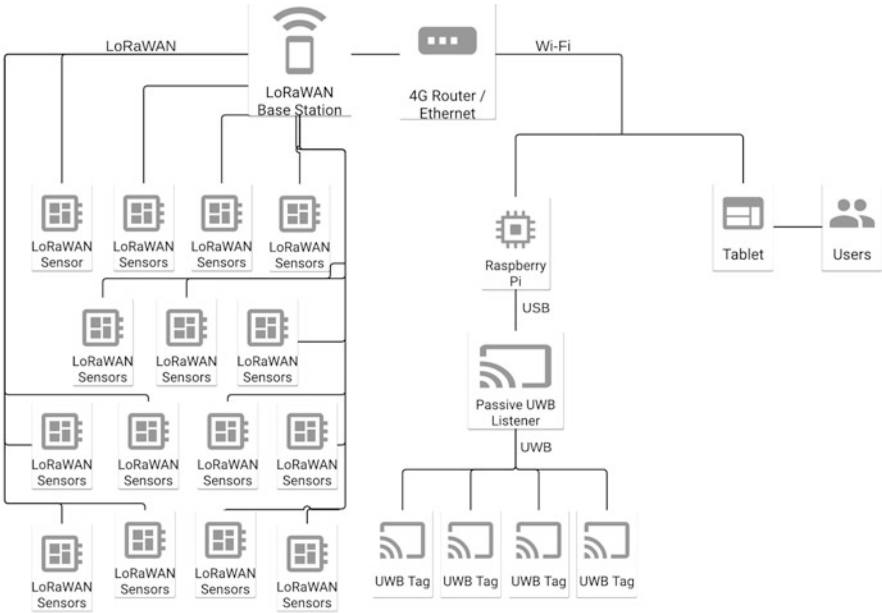

Fig. 7 Network diagram demonstrating all IoT devices deployed in the demonstrator

The device also contains a vibration sensor to detect shock and identify any potential damage that may be caused to parts. A vibration threshold (in Hz) is set individually for each sensor, depending on its position within the demonstrator. When the vibration threshold is crossed, a message can be sent via LoRaWAN to a Kerlink data management system and subsequently onto the adwisar system to alert of any potential damage that may have occurred in the system and the location within the system.

An ultra-wideband (UWB) positioning system was deployed within the demonstrator to track the movements of workers in the system with a high degree of accuracy. UWB positioning is able to measure the position of a person or item with an accuracy of around 30 cm through time-difference-of-flight signals. UWB utilizes a train of impulses rather than a modulated sine wave to transmit information. The time difference of arrival (TDoA) scheme is based on the precise measuring of the time difference between signals arrival to the anchors. In this scheme, the anchors need to be accurately synchronized (they need to run the same clock).

The UWB positioning system was implemented through a Decawave M1001 system, using four anchor tags at known positions in the corners of the demonstrator to geofence the area. The Decawave system costs approximately 300€. Workers using the demonstrator are provided with a battery powered tag, held in a 3D-printed wearable housing that clips to the workers' belt. When a tag enters the demonstrator, the UWB system begins recording x, y, and z coordinates of the tag at waist height.

Table 3 Overview of IoT technology employed in Airbus use case

Name	Functionality	Usage	Price for individual unit, total (as of September 2018)
Kerlink Wirnet iBTS IoT gateway	LoRaWAN network	Sets up the IoT network	1000€
TP-Link Archer MR200 4G router	Router to connect to the Internet	Connection to cloud-based Kerlink data management system	120€
Sagemcom Siconia multi-sensor	Magnetic detection sensor and an accelerometer	Determining correctness of assembly process	30€, 38 × 30€ = 1140€
Magnets		Attached to assembly parts to trigger recognition by Sagemcom sensors	1€, 100 × 1€ = 100€
Decawave M1001	Positioning system	Tracking worker's position to decide what procedures and content to display	300€
Raspberry Pi 3 model B+	Small single-board computer	Processing of Decawave signals	35€
		Total	2695€

Measurements are made once every second when stationary (1 Hz) and 10 times a second when moving (10 Hz). One tag, connected via USB to a Raspberry Pi 3 model B+, logs the coordinates of the worker's tag along with a timestamp. This data is logged in a cloud directory for real-time monitoring and also allows analysis of historical positioning data.

Table 3 summarizes the IoT hardware used in the Airbus use case. For each piece of hardware, we specify the use case independent functionality as well as how it was used in the Airbus use case. The complete costs of the IoT hardware are below 3000€, which is relatively affordable given that the use case covers a rather complicated assembly process.

Usage of Sensor Data for Assistance in Work Processes In the following, we use a sub-process of the overall work procedure to illustrate how the adwisar system processes the abstracted sensor data. The complete process of assembling the connection unit requires installing the left- and right-hand side. The left-hand side installation involves the three parts side panel 1, connector 1, and tube 1, and the right-hand side installation the parts side panel 2, connector 2, and tube 2. All parts are stored in the material delivery unit. The left- and right-hand parts are almost indistinguishable and are therefore marked with a functional item number. Installing

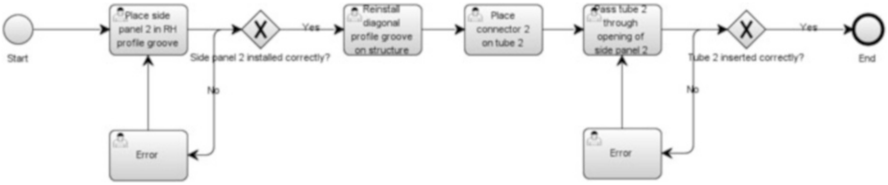

Fig. 8 Subprocess “Installation of side panel 2”

all parts correctly requires that the worker knows that a functional item number ending on an odd digit relates to the left-hand side, whereas an even number relates to the right-hand side.

In order for the adwisar system to support a work process, the process has to be formally described. An established standard for modeling processes is the Business Process Model and Notation, BPMN (Object Management Group 2011). Figure 8 shows the graphical representation of the BPMN model describing the process of installing side panel 2.

The process begins at the right-hand side, at the “Start” node. Each square node (called tasks) contains information relevant to the worker, either a description of an activity to perform or other information about an error or warning, etc., displayed in a mobile application. After the worker has confirmed that he performed the action or read the information, the system proceeds to the next node. The nodes marked with an “X” are gateways. These allow selecting the next node depending on conditions.

In the process, those tasks that are especially relevant to quality standards are followed by gateways that verify the actual work result performed by the user. There, the sensors come into play, as they allow to detect the outcome of the activity. The subprocess for side panel 2 contains two gateways.

The first gateway tests whether side panel 2 has been installed correctly. A correct installation requires using the correct part (side panel 2), the installation on the correct side, as well as the correct orientation of the part (side panel 2, label with FIN is pointing outward). The second gateway checks the correct installation of tube 2. This requires the selection of the correct parts, as well as their installation on the correct side. In both cases, if the worker performs the correct tasks, the process continues. Otherwise, the adwisar system displays an error message that asks the worker to check his work and redirects him to the incorrect task.

5.4 Example

As an example, we describe the flow of information during a typical assembly task. First, a new work order is created, typically through an enterprise resource planning system (ERP). The adwisar system receives the work order through the ERP service, which triggers a corresponding adwisar software event (*SAPWorkOrder-*

PublicDemonstrator). Several adwisar services are subscribed to software events. A knowledge service searches for content potentially of use for the currently logged-in workers and displays links to these content items, while an assistance service displays work procedures applicable in the current context by the user.

Figure 9 shows the mobile interface of the system. The top row contains the main menu showing the available tabs, with the currently opened tab ("Vertiefung" meaning "Content") being highlighted. The main screen below shows two documents the system determined to be relevant to the employee in the current situation (the bill of materials for the current and a standard operating instruction for the current work order). The worker can click on the documents to open them.

The other relevant tab is on the top right, "Assistenz" meaning "assistance" (see Fig. 10). There, the system displays work procedures that are applicable in the current context. If the employee selects one of the work procedures, she will see instructions for each step of the process.

Figure 11 shows the interface when the user has entered a work procedure. The system displays detailed information on the precise action to perform. The action of the worker triggers a magnetic detection sensor attached to the frame, and the sensor sends the current force value to the Kerlink data management system. In this example, the raw sensor data is translated by Kerlink into *side panel2PlacedInRHGroove*, meaning that the operator inserted side panel 2 into the right-hand groove correctly. The Kerlin system then sends this message to the adwisar machine information service through a post request. There, the message

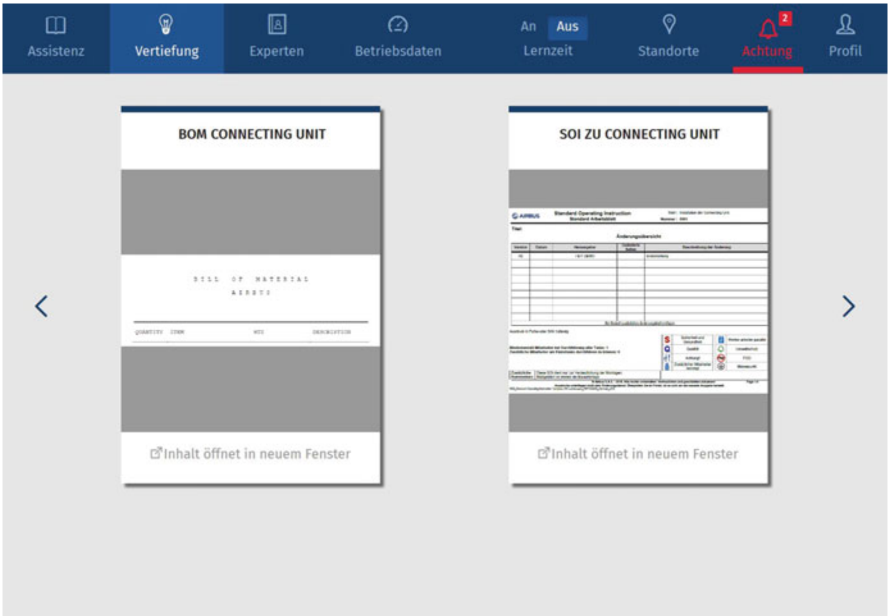

Fig. 9 Mobile interface of the adwisar system, showing the "content" tab

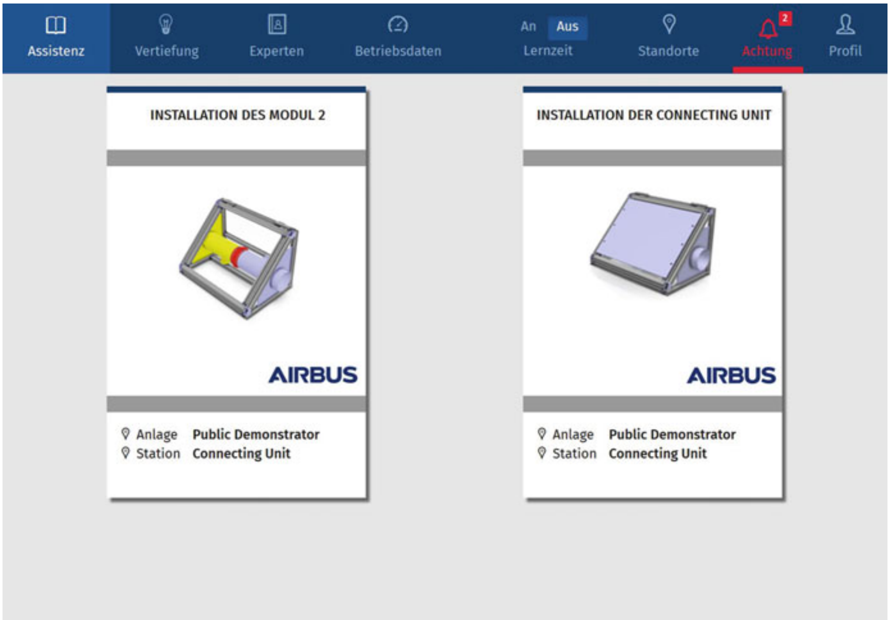

Fig. 10 Mobile interface of the adwisar system, showing the "assistance" tab

triggers an event and causes the machine information service to store the received value. The user does not perceive any of this underlying logic. From her perspective, after she has performed the step, she has to confirm by selecting "Bestätigen - Weiter" ("Confirm - Continue"). Now the process support service inquires at the machine information service about sensor data for this step and either proceeds to the next step or displays a warning that the system is not in the expected state and that the action should be redone.

From a technical viewpoint, the manual confirmation step could be skipped, and the system could advance automatically to the next step or display the warning. However, due to warranty and safety considerations, we decided to add the manual confirmation. This removes a potential source of problems that might result in injuries and is recommend from a legal perspective (similar to a driver having to confirm that one adheres to traffic law before being able to use a navigation software).

Note that the event processed in adwisar is abstracted from the sensor data. For the assistance and knowledge services, the source of the event is irrelevant. It can be triggered by a magnetic sensor, as in this use case, but it could also be triggered by a completely different source, such as a real-time video analysis of the workers' actions.

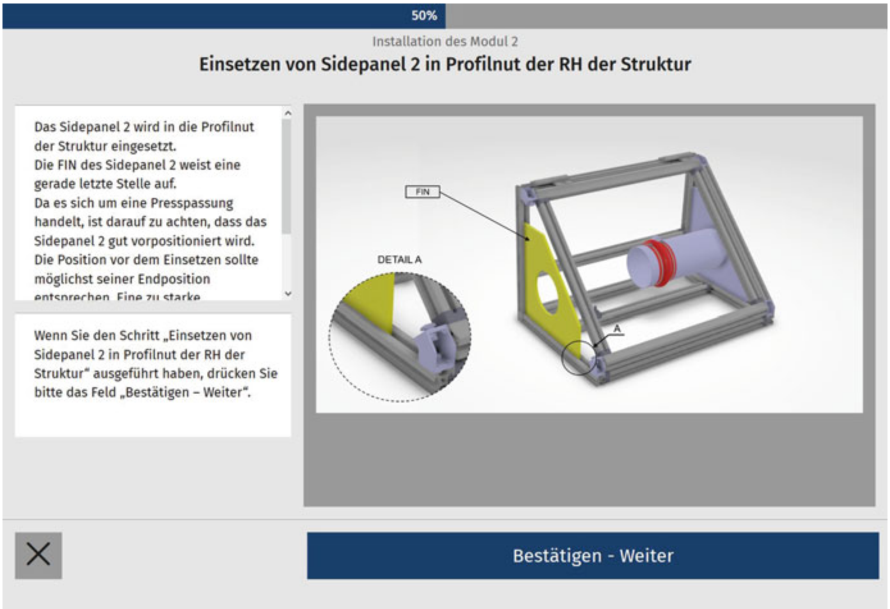

Fig. 11 Mobile interface of the adwisar system, showing the assistance provided for a step in the work process

6 Conclusion

In this contribution, we described how to support workers in industry while performing assembly tasks. The described solution covers sensors that capture the workers' actions, the processing of the sensor data, and how it is integrated into an adaptive support system. We have shown that off-the-shelf IoT devices can digitize a complex assembly process with relatively low costs. LPWAN solutions are designed to be scalable, supporting up to 10,000 devices with a single base station and allowing to cover a large number of deployments. We also presented categories of errors in industrial work processes and how these can be used for analysis of existing use cases and the development of new ones.

For industry, such work support comes with several benefits. In this chapter, we focused on the training aspect: by providing step-by-step instructions in a risk-free environment, training time for new employees can be reduced. Additional benefits arise through the implementation on the factory floor:

- Check correct assembly: near real-time feedback is provided through the use of a tablet that is able to provide instruction and respond when parts are installed correctly and where any issues have arisen.
- Capture how experienced fitters are assembling a specific section: identifying new best practices that may not have been captured previously, allowing to adjust standard operating instructions to incorporate the most efficient manufacturing techniques.

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Part IV
Pedagogical Frameworks and Didactic Considerations

On the Feasibility of Using Electronic Textiles to Support Embodied Learning

Olivia Ojuroye and Adriana Wilde

1 Introduction

Electronic textiles (e-textiles) are textiles with integrated electronics that can sense, respond and intelligently adapt to their environment. Depending on their integrated circuitry, e-textiles can even communicate and collaborate with other digital devices, i.e. any object with a central processing unit (CPU), data memory database, and input and output (I/O) ports. To be able to affix such electronics on flexible, bendable and twistable substrates would allow the textile to still drape, bend and twist, helping the electronics become unobtrusive.

The choices of the specific location of such hardware will be largely dependent on the methodology of integration of the textile fibres and, thus, are numerous, e.g. hardware adhering on the textile surface via embroidery of conductive threads (Linz et al. 2005), on flexible circuit substrates which are then woven into the textile by treating them as yarns (Cherenack et al. 2010), or contained in rigid detachable components that connect to the textile (Dobbelstein et al. 2017), to cite some examples. Wireless technologies for e-textiles are becoming increasingly prevalent with the progressive miniaturisation of electronics, though powering e-textiles is often still limited to external power supplies (Bhatia 2016). Wireless power transmission techniques such as inductive charging (Carvalho et al. 2014) or integrating flexible batteries (Pu et al. 2015) are feasible solutions to integrate power operation into textiles.

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For an e-textile to work in an Internet of Things (IoT) ecosystem, it would need to operate as a transceiver, i.e. hardware capable of data sensing, data processing and data transmission. In practice, an e-textile transceiver would typically have an antenna, circuitry including a CPU, memory and I/O ports, allowing them to send and receive information wirelessly. In this sense, an e-textile transceiver could be considered a device within an IoT network and connected to other devices or networks by technologies such as near-field communication (NFC) for short range and Wi-Fi for medium range and even utilise third-generation (3G), fourth-generation (4G) or fifth-generation (5G) technologies. As an alternative to wireless communication, such a device could be connected to the IoT via the "wired" Internet, as long as a lightweight operating system (such as Contiki) is used for the embedded devices and a RESTful protocol is adopted for the communication (Wilde et al. 2013).

Once an e-textile is IoT-enabled, it can be used to support "learning-by-using" pedagogical approaches as whole-body learning activities could potentially be captured. This chapter explores the use of e-textiles in an IoT network as pedagogical tools, proposing a framework about how wearable and non-wearable e-textiles can operate in an IoT network and how this system can be used within an embodied learning approach, with some examples. Lastly, we propose a future application of e-textiles as pedagogical tools and discuss how these can be used to enhance learning.

2 A Historical Overview of Educational Technology

The introduction of digital technologies in education has historically been met with varying degrees of enthusiasm and reticence, as explained by the theory of diffusion of innovations (Rogers 1962). According to this theory, the personal outlook of a person, as well as their existing familiarity with the technology prior to its use, are determinant factors to when and whether it is adopted. This is also true for innovations in educational technology. In addition, other important factors at play are hidden costs regarding the reliability of that technology and maintenance of that technology over time – as well as whether it is fitting with the curriculum of the academic institution and its vision. This means that innovative technologies for education need to be designed with purpose and the risks managed to increase their likelihood of a successful uptake. This will make educators' and learners' experience with the technological innovation a positive one, encouraging their use and the benefits long-lasting. Many times over throughout history, influential digital technology has had a positively transformative impact on the education experience. Education and learning have been enhanced by the use of digital innovations, changing how information is delivered, presented, taught and acquired. As summarised in Fig. 1, from the introduction of educational and instructional film, television and radio as a post-war effort (Saettler 1968), the use of digital technology was centred on media before a shift from the twentieth to the twenty-first

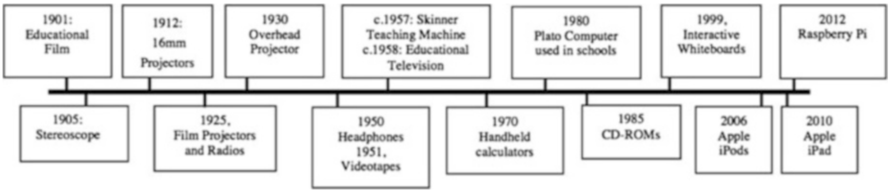

Fig. 1 Timeline of adoption of various educational technologies

century occurred where devices such as interactive whiteboards, microcontrollers like Raspberry Pi (Bruce et al. 2015) and the Lilypad Arduino (Sobota et al. 2013) and the introduction of tablets (Neumann and Neumann 2014) have become integral to the information technology teaching experience. These have helped to introduce technology at all ages, diversifying the exposure to technology across genders (Volman and van Eck 2001) and in overcoming disability (Shah 2011), to create a community of technologically literate world citizens.

The advent of the Web has made online learning accessible for all (Bates 2005), which has undoubtedly transformed access to information and knowledge in the last 20 years, through distance learning and Massive Open Online Courses (MOOCs) (Yuan et al. 2013). Stakeholders in education (teachers, learners, administrators in educational institutions and others) have had access to multimedia portable devices connected to the Web (Fisher 1999). As the technology becomes ubiquitous, constantly developing and advancing at an unprecedented pace, we posit that e-textiles are the next type of digital technology to have a ground-breaking effect on education. Research suggests wearables and e-textiles have such a potential. Like the digital technologies before them, wearable technologies such as smartwatches, clothing and surfaces beyond the body such as furniture, wall-tapestry, flooring and handheld versions could also enable educators to engage their students whilst teaching academic and societal knowledge that serves a wide range of learning preferences. This is the case for using wearables as teaching tool in medical higher education (Sultan 2015). Google Glass had been proven to offer remote teaching of medical practices and procedures (Knight et al. 2015) and to ensure patient safety (Vallurupalli et al. 2013). Fitness trackers have been utilised in clinical trials to help aid weight loss (Jakicic et al. 2016). Furthermore, virtual reality headsets have been used to simulate surgery (Gallagher et al. 2005) to make medical education ubiquitous – independent on the quality of education available to a student locally. So, it is possible to forecast that a similar level of transformative impact by wearables in the educational sector as it has been in medicine and other health sciences (De Freitas and Levene 2003).

Aforementioned in *Part II, The Topography of Wearable Enhanced Learning*, in the earlier chapter of "Engaging Students in Co-Designing Wearable Enhanced Learning Kit for Schools" using wearable technologies in education is being encouraged globally. For example, the Estonian Lifelong Learning Strategy 2020 (ELLS) supports using novel technologies (including wearables) as learning tools in classrooms. This will make learning more engaging and creative and use more human-computer interaction (HCI) to grasp academic concepts. Yet, it is worth considering if the learning experience would be enhanced by integrating sensing electronic systems in textiles to offer even more seamless interaction and diversify the novel technologies to learn from.

By embedding sensors and actuators into textiles to make them smart, by examining sensor data with machine learning algorithms, this presents a new age of HCIs (Ojuroye et al. 2016). The extent to which wearables and e-textiles can profoundly influence educational settings is dependent on the miniaturisation and processing power of microelectronic systems. The existence of e-textiles in education enables the idea of having soft, tactile and digitally interactive textile surfaces as teaching tools. In addition, their level of electronic integration will impact on the different use-cases and invisibility of the electronics within textiles (Ojuroye et al. 2017).

For education, the potential of connected e-textiles (both wearable and non-wearable) to be used as pedagogical tools is paramount, for it can become a more diverse and equal medium to teach digital literacy, skills and IoT system operation. Especially as today's learners are being exposed to advanced technologies, it becomes more of a duty for educators to teach the academic operation and societal implications of using these technologies (Lei 2009). How e-textiles can be more advantageous compared to other digital technologies is due to the inherent familiarity, interaction and comfort that come with textiles. Hence, textiles – technologically enhanced or not – are unbounded by computer labs or designated work areas. This makes every area of textile interface a potential source of education and a seemingly limitless opportunity for educators to teach concepts in a multitude of ways. Overall, it allows a way of teaching about technology not being just for entertainment (Bugeja 2006), but it now part of the fabric of our everyday lives.

3 Deployment of E-Textiles in IoT-enabled WSN

The Internet of Things (IoT) describes a network of physical or virtual objects connected to the Internet that can wirelessly communicate with each other by sending and receiving information in the form of data packets. This is possible as physical objects are identified by attached micro-sensors that can communicate to the Internet. A wireless sensor network (WSN) is comprised of nodes – the physical and virtual objects – that can measure, monitor, react and learn to understand their environments. Access and management to this WSN data stored in the Cloud can be done by services via a data-on-demand manner (Gubbi et al. 2013). With a number of interconnected devices already becoming the norm in educational institutions, the next step is for the adoption of WSNs including wearables and e-textiles as nodes in these institutions. This would make more innovative, smart environments (Fig. 2).

Within a smart environment, an IoT network would operate to monitor sensors communicating within a WSN. The minimum infrastructure required includes

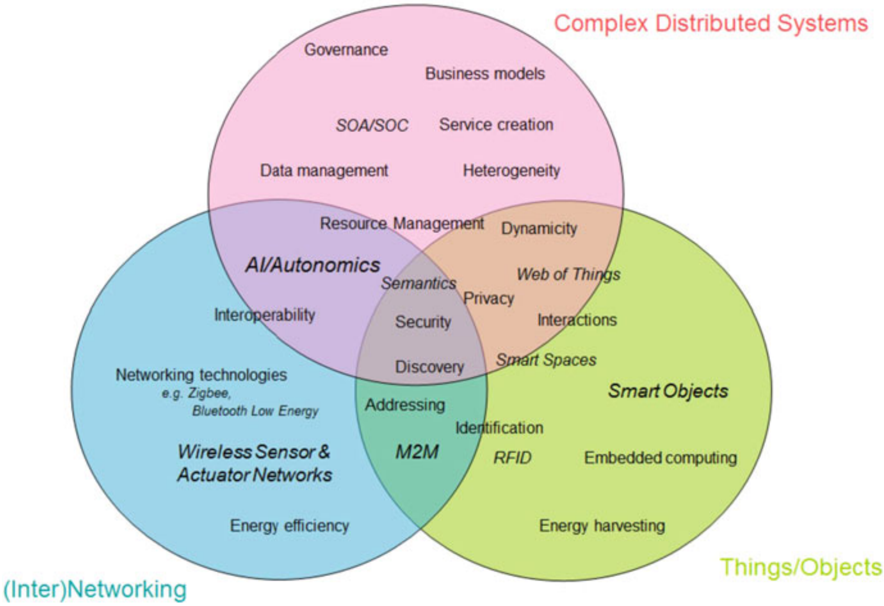

Fig. 2 Three perspectives of IoT. (Reproduced from Lee et al. 2013)

networked devices and a service at the most basic level. The devices are the physical, everyday objects made smart by having transceiver micro-sensor chips that can send and receive data. These physical objects can include hardware, such as smartphones, laptops, smartwatches, televisions, automated vehicles, and the switch, router, and cables, and wireless base station to enable communication. The network provides a service via software that can be accessed by these connected physical devices to access and/or respond to data access requests.

WSNs can cover areas of a range of sizes. In a home, people connect to the Internet wirelessly or by physical cables and a WSN can be constituted by merely a few transceiver devices (e.g. a private network formed by a personal computer with a wireless printer) communicating with each other. At a larger scale, there are many private and public WSNs connected to form the Internet across the globe sharing and exchanging information continuously. The more physical objects in an IoT network, the more ubiquitous the intelligence generated from the system becomes (Xia et al. 2012). The data produced by these physical objects combined with data already existing in the Web can create new pervasive-based services (Kopetz 2011). Complex distributed systems arise when the number of objects in an IoT network rises and/or a higher level communication infrastructure of methodology is needed to be managed (Lee et al. 2013). Hence, scalability of system requires intelligence to support dynamics such as ad hoc interactions, as nodes move around and as a result have data exchanges with nearby nodes (Miorandi et al. 2012).

Despite the advancement of physical objects connected to the Internet and the prediction that 50 billion devices will be connected to the Internet in 2020, it has been estimated that more than 99% of physical objects in the world are not yet connected to the Internet (Barakat 2016) – textiles included. E-textiles of the future will have the capabilities of today's mobile and wearable technology, i.e. portability, high processing power and interconnectivity. Now fitness trackers and smartwatches used in the home or even at school have been adopted by many as health personal assistants. They collect physiological data from its user, and using machine learning these are able to make anticipatory suggestions based on user-behaviour. Textiles can be connected to the Internet through wireless sensor networks standards and specifications (e.g. Bluetooth, ZigBee, NFC and LoWPAN), suitable for communication amongst devices over a short range. Applications for educators may include options to teach how connected devices can wirelessly communicate in an engaging and intuitive way, whilst ensuring security and privacy, which should not be compromised in the name of unobtrusiveness and convenience.

Furthermore, using wirelessly communicating e-textiles that are portable can teach digital literacy concepts such as IoT. Ways that e-textiles in a WSN can be implemented include a range of technologies. Most commonly used is RFID technology that relies on electronic identification (ID) tags that have a unique and known address to turn physical, everyday objects into virtual, digitally communicative equivalents. Each ID tag contains a unique identifier, historical information and current information about the tagged object. This also includes its origin, owner, physical properties and sensory context (Welbourne et al. 2009). The infrastructure of the network can be multiple networks, whereby separate services and communication with different end devices take place on separate networks, or converged networks where multiple devices are communicating on one network.

Current technology that hints at this eventuality is "Fog Computing", coined by Cisco as an alternative to Cloud which addresses the limitations of unwanted extended delays on IoT communications (Bonomi et al. 2014), an end-to-end horizontal architecture (Chiang et al. 2017). This is when the operation of an IoT network occurs closer to the nodes of the network themselves. The services of the Cloud are extended to the edge of the network, reducing data transmission latency and traffic (Gupta et al. 2017).

The potential of Fog Computing could allow real-time decision-making and a streamlining of data query processing closer to the nodes which is attractive from the systems point of view (as communication overheads and high power-consuming devices detract from the overall performance) but also from the ethical point of view, as data remains processed at the point of collection, preventing data privacy breaches and misuse. However, a challenge within IoT is to operate contextual-aware computing (Perera et al. 2014). This is especially important for e-textiles and wearables in WSNs, as the data generated is collected from a user that has a unique digital identity. This digital identity covers personal information, such as how the user behaves, their hobbies, beliefs and with whom/what they interact with within a monitored environment. Sensors and actuators produce big data that only have value in data analytics processing when it has contextual meaning. As a result, for intelligent interaction and usage of nodes in WSNs to be represented in a virtual space, an IoT framework needs to show how situation-based interactions can be treated as contextual packages and how this contextual knowledge can be shared around the network to enhance the personalisation of the entire WSN system.

4 Advanced E-Textiles in IoT Networks for Learning Environments

The important difference between individual learning and team training was emphasised by another chapter of this book, "Toward Wearable Devices for Multiteam Systems Learning". It describes a multiteam system (MTS) formed of grouped teams with specialised skills and experiences who work towards a common goal that an individual cannot complete alone. The same reasoning can be applied to a proximity sensing wearable. If deployed in a localised area, they can be used to identify different members of the team in emergency situations. Expanding this, if a MTS is comprised of intelligent textiles, advanced e-textiles that can compute machine learning algorithms, each will have its own intelligence to gain a contextual awareness of its environment. A diagram, highlighting the difference between e-textiles and intelligent textiles and more, has been created and shown in Fig. 3.

If a group of intelligent textiles were localised in an educational environment and communicating to each other within an IoT network, this can offer greater personalisation to users – for interaction and learning – and adapt themselves to the users' needs as they learn more. In this case, each intelligent textile will have its own *situational awareness* (SA) that can be implemented over a local area network. As a group, they would form a shared situational awareness of the learning environment and learners within it. This section will explain a vision on how this can work with e-textiles and when intelligent textiles exist in the future.

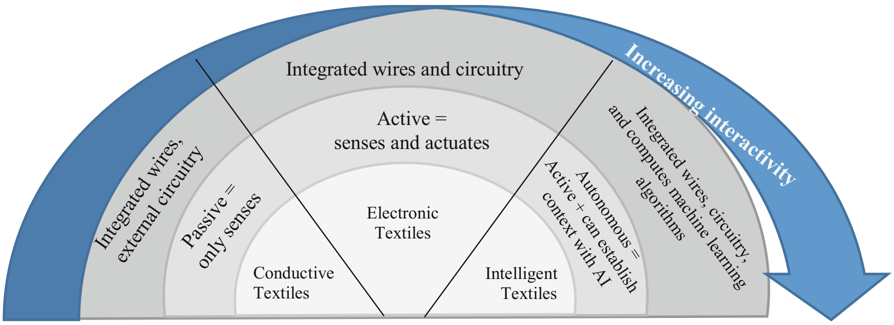

Fig. 3 Diagram of types of technologically enhanced textiles with increasing levels of interactivity – conductive, electronic and intelligence textiles

SA is used in the military to control the efficient communication between team members. SA may be a promising model to show the creating and sharing of contextual data in localised areas (Salmon et al. 2017), and this chapter theorises that it can be applied to communication between intelligent textiles. SA describes the extent of awareness an individual has on a situation. When this individual is within a team, multiple information sources are needed to be identified and processed in order to accomplish a common goal via collaborative effort. Tasks must be completed in order to achieve this common goal. The situation awareness collectively formed by individuals within the team is described as *team situational awareness* (Salmon et al. 2017). Importantly, the comprehension of data within a team is affected by the interpretation of other team members. So, the SA of an individual is influenced by other members. Consequently, the team SA can be modified based on the shared extent of comprehension individuals have of their task. In this context, an individual can be synonymous with an e-textile node, and a team can be synonymous with a collection of e-textile end devices in a network. This team SA is shared between the individual intelligent textiles that form it. Therefore, the team SA of intelligent textiles describes the group's comprehension of its context, awareness of its location and understanding of its collective role.

Now, let us consider a hypothetical scenario of a smart home with multiple intelligent textiles in close proximity. For example, one of these intelligent textiles can be part of a living room sofa with touch sensor arrays integrated into the body to gather complex data such as location distribution (Rus et al. 2017) – such as Fig. 4. The group of intelligent textiles can be sensor-actuating, able to sense the proximity of users and anticipate their interactions with the textile. In this scenario, we consider sensors able to access the Internet directly (e.g. via UDP/IP). This will allow the textiles to not be solely reliant on communicating with a smart home hub, or any other equivalent controller that can communicate with a router or base station (such as the prototype implemented by Wilde et al. (2015)). Hence, this will mean that the intelligent textiles can communicate between each other and keep track of each other's individual SAs, whilst it monitors its environment to form a collective team SA. With a touch, this sensory intelligent textile will send a message notification to the user's smartphone, smartwatch or activity tracker to establish consent. This consent means the user gives permission for the e-textile to access their digital identity, for their behavioural activity profile to be stored in the network, and for this awareness to be shared amongst other e-textiles also in the

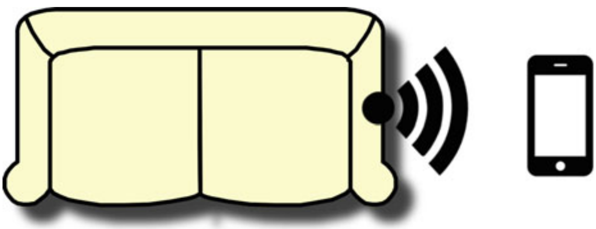

Fig. 4 Furnishings with e-textiles allow for sensors and actuators within a network. (With user consent managed via smart devices)

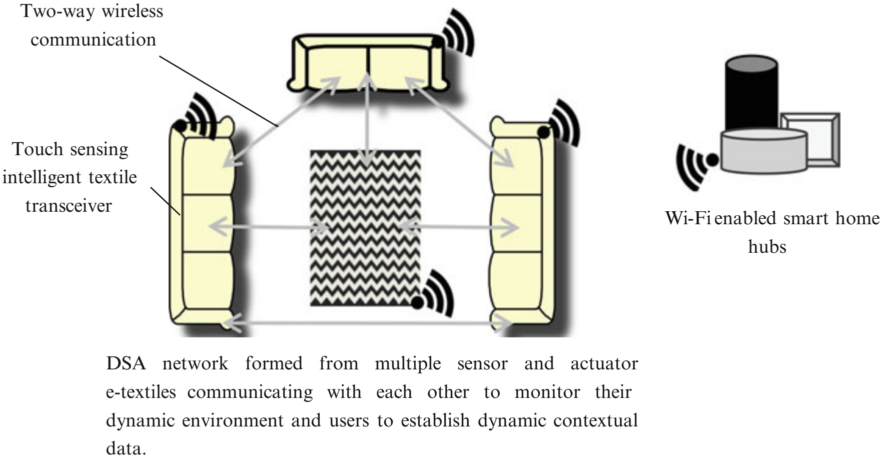

Fig. 5 Transmitting proximity and touch sensing advanced e-textiles communicating to connected devices using distributed situation awareness

room. This is one way to shift responsibility of any data exchange implications to the user and to establish trust.

As the e-textile has its own IP address and the other connected device has its own IP address, this consent can be given by an agreed protocol, such as TCP/IP or UDP/IP. Once consent has been given by the user accepting this request, actuating functions are activated – specifically in this example, biometric sensors typically found in fitness trackers (e.g. temperature sensor, pressure sensors) that can measure levels of comfort for a number of people using the e-textile in real time. Figure 5 illustrates such an example.

Distributed Situation Awareness (DSA) is when the SA established by a team of individual members is treated as an entity in its own right (Salmon et al. 2017). That is, when a collaborative team of people have SA they exhibit cognitive behaviours that could not be executed by an individual alone. Hence, in addition to executing their own tasks, e-textiles or intelligent textiles in a DSA network monitor each other's understanding of their environment and their roles in executing the collective task. This solves the problem of high storage demands on individual devices, as labour is divided between e-textiles as they perform interdependently.

By comparing the already registered user identities stored in the DSA-WSN with unidentified presences, the intelligent textile can recognise new users. The task of one intelligent textile may differ to its teammate in a DSA-WSN network. If one intelligent textile is owned/preferred by a particular user who has specific needs, its task to monitor the health and location of this user would differ from another e-textile that has more of a general task – such as monitoring the identities and locations of multiple people in a room and tailor services, e.g. temperature, light intensity and media accordingly. Having one intelligent textile of this type in a localised space could not generate a reliable SA to offer sufficient personalised interactions to multiple people, e.g. a teaching classroom. This is especially in an environment with changing needs, such as facilitating differing learning or teaching styles. When a network is formed from multiple intelligent textiles collaborating together, a DSA generates enough cognition to have an awareness of the entire localised space and analyse how users have personalised time frames and use-cases for the space. As a result, each intelligent textile in the network has a different perspective and understanding of the space it is situated in. This perspective is temporal, task-oriented and user-centred meaning that the context of the system is short term rather than long term. As shown in the example in Fig. 4, each e-textile will have a different SA dependent on its location, usage and duration of usage which influences its knowledge at an individual level and network level. However, long-term contextual understanding is required for accurate personalised responses to be repeatable in detecting behavioural patterns and activities. Hence, this would mean that the intelligent textile nodes could communicate between one another and whilst keep track of their own SA. Collectively, they would monitor its environment when not interacted with by a user. If this operation occurred in a learning environment, a group of these sensing intelligent textiles with a generated DSA would be able to collaborate together to offer an engaging, interactive and personalised learning experience to a group of students. The DSA will be dynamic as the changing people in the monitored space and the collective needs of those people. Individual e-textiles could interact with the students on a one-to-one basis. Moreover, with intelligent textiles also in the learning space using AI, the textile will be able to learn about the user through interaction. The intelligent textile would tailor how it teaches knowledge to its user through embodied learning based on the individual user's learning style and comprehension of the learned topic.

Artificial intelligence (AI) plays a role within this DSA framework through unsupervised learning leading to increased data personalisation. If textiles in an educational environment executed machine learning algorithms, three technology concepts could be taught by interacting with the IoT e-textile network:

- Awareness: Network can capture real-time data from a broad set of information sources (Baker et al. 2009);
- Predictive analytics: Data mining techniques to establishing patterns in this captured data over time can help the network predict future outcomes and trends in data to make the network operation more efficient (Tsai et al. 2014);
- Responsiveness: Network becomes more dynamic and adaptable to new configuration of information sources or organisation setup and reducing number of inaccurate predictions.

Deep learning approaches, e.g. neural networks and clustering, applied to IoT can operate in complex environments to overcome noisy environments that are monitored. It has disadvantages such as high energy consumption on devices that operate such machine learning algorithms leading to inaccuracies. However, by having a more efficient and compatible implementation that does not drain mobile and embedded devices of their energy, it can create a reliable and robust network capable of recognising categories of behaviour and their context and build a knowledge base from the data it has processed (Lane et al. 2015).

As the devices are mobile, the intelligent textile objects can even be moved to different locations within a room or between rooms. For example, to explain how WSNs of e-textiles or intelligent textiles communicate to enable personalised actions of a smart car, a teacher can create an example of the car interior using three sensing seats (Kivikunnas et al. 2010) and a pressure-sensing carpet/mat (Bränzel et al. 2013) in the centre – made from intelligent textiles. These textiles would form a DSA-WSN if they can implement wireless communication between each other in the theory previously outlined. If this intelligent textile pressure-sensing carpet/mat is deactivated and moved from the classroom space to elsewhere, the DSA three of the intelligent textile sensing seats in the classroom would still be undeterred. Meaning, the contextual understanding and awareness of the classroom environment would still be known by the remaining textiles in the room and still provide data-personalised responses. If this intelligent textile pressure-sensing carpet/mat is moved to another location, for example, outside the classroom, when the carpet/mat is reactivated, a new DSA is formed in that localised space, and its task can be redefined. In this way, the SA of each intelligent textile is not identical and not shared as the tasks, goals and interactions with the environment are not the same. Nevertheless, for DSA to occur, each SA must be compatible to collectively produce the cognition that represents the overall contextual understanding of the environment it monitors.

5 Pedagogical Considerations for E-Textiles' Users

Students of today have had unprecedented access to a breadth of technology, and this trend is only to increase in the future. This increased access offers many valuable opportunities for data collection that can be used to tailor services and interventions through interconnected devices as discussed in Sect. 4. These interconnected devices are sensitive to the learners' context as determined by the processing of sensor data, and can output a timely, appropriate response which has the potential to support learning.

Though innovations in educational technologies have focused on the delivery of learning resources to students (as shown in Sect. 2) and the provision of virtual learning environments, the current innovations of interest have the added benefit of helping identifying what learners do. In particular, the use of e-textiles in educational settings has a great potential from two perspectives, namely, learning analytics and personalisation. As discussed earlier, and shown in Fig. 1, once new technologies become feasible and well understood, they can be adopted in educational settings; often with the purpose of facilitating the delivery (such as in the case of overhead projectors, CD-ROMs, and more recently, content management systems) as well as for facilitating the assessment of students' work, measuring engagement, attendance and attainment of learning. Such monitoring is done in educational contexts using learning analytics to understand learners' progress and engagement, and to enable personalised interventions – be it directly, in the form of "nudges" (Wilde 2016), or indirectly, via institutional processes, when stakeholders are able to update and consult databases (such as Learning Management Systems) where students' progress is trackable.

The use of textiles provides an additional opportunity to gather further context. However, there are ethical considerations attached to the gathering of such data beyond the educational context, as this is increasingly less well-defined and constrained. Learning takes place anywhere/anytime, and the students can access their materials at a personalised pace, at a time and a place that suits them best. This flexibility often means that the boundaries between personal activities and learning activities are more fluid than they have ever been in the past, and students may be reticent to allow their educational institutions into their personal spaces (Wilde 2015). Indeed, in a survey of 285 students exploring the use of smartphones in higher education, when asked whether they would welcome personalised interventions ("nudges") via mobile technologies, whilst the majority declared not having any objections to the use of their known data for such purpose, many participants still expressed concerns about privacy and the practicalities of receiving feedback despite the apparent benefits of such a personalisation.

Despite such self-reported concerns, in practice, students tend to trust their educational providers and very few opt-out from making personal data available to the stakeholders, such as in the case of the very many massive open online courses or MOOCs (Wilde 2016), which is a model of technology-enabled instruction which allows learning at scale via the Internet. Furthermore, there is a disconnect between the self-reported privacy concerns and the actual practices, given that the same participants that expressed reluctance to share their information for behavioural interventions in the survey also declared their high engagement in social media. This perceived disconnect does not absolve technology-makers of any responsibility with regards to the poor data literacy of the users, which in turn may lead to their engagement in poor behaviours to safeguard their digital identities. It is a further reason to consider the role of technology and data sensing and the ecosystem through which the data is processed for the benefit of the user. Digital signal processors becoming sufficiently advanced to keep this process as close to the user as possible (through these being power-efficient, inexpensive and highly specialised for context-sensing).

6 E-Textiles and Embodied Learning

Technology and textiles share a common thread: their pervasive use in our daily lives. However, they have yet to be used together in education, such as in teaching how interacting with objects can extract personalised data and influence how other devices collaborate with each other. This can happen when the Internet of

Everything (Hussain 2017) is realised, that is, an intelligent network of devices, people and services that includes the reported 99% of devices currently not connected to the Web (Yang et al. 2017). This has largely been driven by Moore's Law, now reaching its physical limits, under which the rapid development of integrated circuits at increasingly smaller scales was encouraged over the years. As a result, micro-sensors with integrated wireless functionality has made possible to "hide" the hardware in wearable technology and e-textile products for increased unobtrusiveness (Moinudeen et al. 2017). The availability of such technology and its integration with textiles opens possibilities for their use as a pedagogical tool for tangible interactions.

Indeed, exploiting the capability of interacting with objects for learning is a welcome challenge to traditional pedagogy which presumes higher learning as a "disembodied" activity, as if it happens only in the brain (Stolz 2014). The disembodied/embodied learning divide is artificial, arguably a mere artefact of how curriculum design has evolved around teaching activities and due to the methods of content delivery being dependent on technologies which presuppose the learner a passive receptacle of knowledge such as many of those listed in Fig. 1.

A more natural approach to learning considers that "rather than a mind *and* a body, man is a mind *with* a body, a being who can only get to the truth of things because its body is, as it were, embedded in those things" (Merleau-Ponty 1948), where perception, emotion and experiences are always embodied. However, traditional learning technologies have been unable to exploit this fact in the way that e-textiles and wearable technologies in general can.

Embodied learning is defined as learning which explicitly uses physicality and tangible interactions amongst learners and with physical objects rather than with just abstract concepts. An embodied pedagogy therefore encompasses embodied learning as defined, but also embodied teaching, in which the spatial relationships between teacher and students are of relevance as these physical interactions cement the learning process (Dixon and Senior 2011).

Lindgren and Johnson-Glenberg (2013) proposed a number of precepts to embrace embodied learning with immersive technologies, particularly mixed reality, which can be materialised through the use of e-textiles for educational purposes. For example, to "ascribe benefits of body-based learning to everyone" can be realised by using e-textiles in shared surfaces in educational settings such as museum exhibits and school classrooms. Another precept, "assert action-concept congruencies", rests on the capability of activating concepts through sensing and motion, where the gestures are congruent with what is to be learned. This can be fulfilled by using e-textiles which give visual or auditory feedback when they are manipulated correctly, say, for example, in the case of a medical student practising on an anthropomorphic mannequin which is able to illuminate when the appropriate pressure is applied to a given area, or able to emit pre-recorded sounds when the stethoscope is placed in the correct place during an auscultation.

In all the previous examples, we have deliberately excluded the cases which constitute the typical interaction with traditional learning technologies, including the more recent devices for computer-assisted instruction, such as smartphones, tablets and laptops. All of these primarily rely on a screen as the output of the computing system and require the user to input words (typically through typing). Though these may have become second nature to the proficient user (the infamous term "digital native" comes to mind, see below), and though such familiarity frees them to concentrate on the concepts and the message rather than on the medium and the technicalities of how to manipulate it, this manner of interaction is arguably still rather unnatural with respect to how humans best acquire knowledge and skills: by doing. Therefore, a truly revolutionary learning innovation will need to take these principles into account to be successful at all, and it is quite feasible for e-textiles to support a learning-by-doing pedagogy through embodied learning as discussed above.

A word of warning comes from some innovative learning environments (Wells et al. 2018) being recently designed with the purpose of transforming pedagogic practice and preparing post-millennial students for the future, under the premise of them being digital natives and requiring unprecedented levels of openness and flexibility. There have been numerous studies debunking the myth of the "digital native" as being a fundamentally different type of learner (Wilde and Zaluska 2016) just because of their ample exposure to digital technologies and practices. Indeed, it is misguided to embrace technological innovation for on the basis of this myth, without real pedagogy at the heart of the decisions, otherwise the expenditure will result on a not-fit-for-purpose resource, unable to cater for the very needs of the learners instead of the investment it is meant to be, as in the cases reported by Wells et al. (2018).

7 Conclusions

There is a rising interest for wearable technology and electronic textiles (e-textiles) in both public and private spaces which gives hope that sectors, such as education, can benefit from the ubiquity and assistive technologies that come with them.

The concept of wearable and non-wearable e-textiles communicating with other digital devices, and used a educational pedagogical tools, may seem incredibly abstract at first. However, through this book chapter, it is hoped that such a concept is not actually an unattainable reality. In fact, through this book chapter, it has suggested that historically technology in education has benefited how academic and societal topics are taught and comprehended. Technology has enhanced the delivery of teaching and arguably has increased the convenience of teachers and engagement of learners in educational settings. Technology introduced into educational settings has become smaller and technologically advanced and exhibits more telecommunication abilities that it seems like the next logical step to consider what other innovative, emerging technologies will have the same impact on the educational system like the disruptive technologies before them. This chapter has suggested that wearable and non-wearable e-textiles capable of receiving and sending digital information to and from the Cloud and other digital devices are one of the innovative and emerging technologies. They are adaptable and diverse that allows any textile item we currently use on a daily basis can become a computer interface that can leverage existing and future Internet of Things (IoT) technologies in the inherently familiar manners we interact with textiles.

This chapter has conceptualised a new vision in which technologically enhanced textiles operating in an IoT system can be used in different smart environments for embodied learning. This mentioned e-textiles that demonstrate degrees of intelligence, intelligent textiles. Intelligent textiles, using AI, can capture identities of its users; the dynamic contexts that they operate in and furthermore with inspiration from distributed situational awareness (DSA) can efficiently collaborate to capture accurate real-time knowledge of a dynamic environment.

However, it is undeniable that the educational revolution lags somewhat with the technological innovations, and users may have privacy concerns in principle which in practice are waived in a trade-off for convenience and practicality. E-textiles offer a promising solution to the problem of achieving high personalisation and context understanding whilst collecting or transmitting the minimum amount of data to external entities beyond the control of the concerned user. By making the data processing closer to the point of sensing, unwanted data leakages are minimised.

In addition to the above, the integration of computation in the very fabric of our everyday lives, quite literally in the case of e-textiles, gives unique opportunities for engaging in teaching and learning in an active, experiential, tangible way, at levels which have not been seen before.

As many as 99% of objects in the world are currently not connected to the Internet, wearable and non-wearable e-textiles are part of this statistic. When textiles are digitally interactive, it enables educators to have new tools and mediums to teach academic and societal topics in innovative and more tailored ways irrespective of age, disability and location of the learner. Wherever there are textiles, there could be internetworked e-textiles, where a surface, a seat or series of clothing is able to be used as an individualised pedagogical tool.

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Embodied Learning: Somatically Informed Instructional Design

Jessica J. Rajko

1 Introduction

The first time I stepped into a physical computing course, I was nervous, excited, and quite convinced that I would not be able to keep up with the curriculum. My disciplinary knowledge is rooted in movement-based practices such as dance; practices rarely applicable to introductory software and hardware design curricula. As such, I was under the impression that I did not have the adequate skills to succeed. Throughout my first physical computing course, I found that I did struggle at times, but through physical experimentation and hands-on play, I excelled. As soon as I spent personal time experimenting with the course's hardware components using various movement practice methods, I was able to better understand physical computing techniques and concepts covered in class. The movement practice methods I applied were not about the "act of dancing" but about exploring materials without restricting myself to their known objectives or outcomes. This initial experience led me to investigate how curricular concepts originating from somatically informed dance could enhance interaction design learning, particularly for students like me whose home disciplines were outside the fields of computer science or engineering.

I begin my chapter with a more personal recounting of my initial physical computing experience because this method of self-reflection is akin to the ethos of somatically informed practices. Practices are often termed "somatically informed" when they integrate knowledge and values from the field of somatic practices. Intentionally ambiguous, somatic practices are rarely defined in a succinct, one-sentence definition, as such efforts typically undermine the prismatic approach of

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the work. At its core, somatic practices use self-observation techniques to consciously recognize and unlock habitual behavioral patterns through both movement and "stillness"[1] (Eddy 2016). The field of somatic practices is not comprised of a single practice but is made up of several practices originally cultivated over two generations of somatic pioneers (Eddy 2016). These original practices provide a foundation for the field, which continues to grow and evolve with each new generation. The term *somatics* was first used to define the field in 1970 by Feldenkrais practitioner Thomas Hanna (1970); however, the first generation of somatic techniques were cultivated in the 1930s–1980s by eight people who are largely referred to as the founders of somatic practices. These founders are FM Alexander (Alexander Technique), Irmgard Bartenieff (Bartenieff Fundamentals of Movement), Gerda Alexander (Gerda Alexander Eutony), Moshe Feldenkrais (Feldenkrais Method), Mabel Ellsworth Todd (Ideokinesis), Charlotte Selver (Sensory Awareness), Ida Rolf (Structural Integration, Rolfing, and Rolf Movement), and Milton Trager (Trager Method) (Eddy 2016). Their personal, somatic explorations lead them to develop methods and tools that could be used by others wishing to consciously recognize and address their own behavioral patterns (Eddy 2016).

Given the physical nature of somatic practices, it may be easy to assume that such practices are solely concerned with physical and bodily health, habits, and behaviors. While this is a large component of the practice, its application and use extend far beyond traditional notions of "body." Hanna defines the field as somatics in part because of its root word, *soma*. Soma is a Greek word that simply means the *living body* (1988). A living body is different than a body, as a body is something comprised of cells, and a body can be either living or dead. It is the physical stuff that shapes us, but it does not define soma alone. Soma refers to the union of body, mind, and spirit together with a conscious awareness of its fluid and ongoing relationship to anything we choose to define as *other*. Coming back now to somatic practices, it is not only about understanding one's own anatomy but about consciously understanding the ways in which our BodyMindSpirit interacts with our world in a given moment. As such, somatic practices have been both cited and integrated within other fields such as cognitive science (Shear and Varela 1999), philosophy (Schusterman 1999), and HCI design (Lee, Youn-kyung and Richard 2014; Schiphorst 2009a); however, the development of the contemporary somatic practices field has been most intimately connected to field of dance. The coevolution of contemporary dance and somatic practices has occurred in part due to each field's respect for and shared interest in movement-centered, practice-based approaches for prolonged physical health (Batson 2007), enhanced proprioception (de Lima 2013), ethical awareness (Rouhiainen 2008), and increased equity (Schupp 2017). The term "somatically informed dance" is often used to describe dance practices that integrate these two fields. Both fields' richness is most palpable within the active

[1] In somatic practices, the body is never seen as truly still. Moments of guided stillness within somatic practices often bring attention to the ongoing movement of our bodies, such as breath, blood flow, and micro-movements of the joints and muscles (Eddy 2016).

classroom or studio setting; however, their integration is also supported through written scholarship – perhaps most notably by the Journal of Dance & Somatic Practices.

2 Somatic Practices and Human-Computer Interaction Design

I was introduced to the HCI design field through collaborative research in full-bodied gesture and embodied interaction (Martinez et al. 2009; Ingalls et al. 2007; Swaminathan et al. 2009).[2] As I began to navigate the unique disciplinary approaches to embodied practice, I realized what we practice drastically influences how we define the term *embodiment*. Speaking directly to the differences between HCI and somatically informed dance, I learned that while our goals are related, our disciplinary approaches to understanding embodiment are vastly different. A point clearly articulated by Thecla Schiphorst:

> We have identified that the common ground between HCI, and the body-based practices within the fields of somatics and performance is found in the need to understand and model human experience, and that somatics and performance differ from normative HCI in their epistemological frameworks of embodiment. This is particularly evident in their histories of knowledge construction and representation with regard to the body as a site of experience. (2009b)

Much work has already been done to articulate why practices rooted in the somatically informed areas of dance, performance, and movement improvisation are a valuable contribution to the discussion of embodiment within the field of HCI by designers and somatically informed movement practitioners such as Yves Candau (2017), Sarah Fdili Alaoui (2015), Lian Loke (2013), Susan Kozel (2012), Thecla Shiphorst (2004, 2009a, 2009b), and Sarah Whatley (2017). This work is deeply transdisciplinary, as it connects somatically informed practices to other contemporary disciplines that conceptualize and implement more holistic understandings of embodiment and human experience. These complementary fields include embodied cognition (Candau et al. 2017; Warburton 2011), neurophysiology (Batson et al. 2012), and Western philosophy, particularly phenomenology, pragmatism (Schiphorst 2009b), and somaesthetics (Schusterman 1999). Furthermore, transdisciplinary research has been used to augment contemporary HCI design methodologies such as participatory design, user-centered design, and embodied computing by offering unique insight into the needs, goals, desires, and interests of system users (Schiphorst 2009a).

To understand why somatics provides insight not already elicited through contemporary HCI design practices such as those listed above, we must understand a few fundamental differences. The first difference worth noting is somatics'

[2] My last name at the time of publication was Mumford.

very specific focus upon *intra-bodily* awareness (Schiphorst 2009a). Somatically informed practices help shift a person's attention away from an external action to the internal experience of moving and sensing. This is done through practice-based methods that engage participants in the question, "how does it feel when I engage in the world?" rather than "how am I acting upon the world?". An attentional shift from external action to sensory and physical sensations helps practitioners uncover unconscious habitual, physiological patterns of being and behaving often overlooked when our attention is directed outward. The atrophy of awareness to one's own internal processes and sensations is often referred to as *sensory-motor amnesia* (Hanna 1988). Sensory-motor amnesia locks people into habitual ways of moving, behaving, and focusing. This in turn results in what FM Alexander (1923) describes as *end-gaining*, or the tendency to keep one's mind and actions focused on an end result of a task, thusly losing sight of the process by which the result is achieved. The purpose of revisiting our internal sensations through somatic practices is so that our own physiological and behavioral habits can be made conscious, acknowledged, redirected, and if necessary changed (Eddy 2016). Within the context of HCI design, somatically informed practices teach users not only to be aware of how and why they engage with a technology but also how this engagement impacts their own holistic sense of self and physiological state of being. Similarly, designers who engage somatic practices within their own design process learn to become aware of habits and biases that may be impacting their design choices.

This leads to the second and perhaps most often overlooked difference, which is that somatics engages self-study as a way of knowing oneself, not as a way of knowing oneself as a designer or user. Somatic practices are crafted to help practitioners notice their own habitual patterns regardless of the specific scenario or situation. While somatic practices may be applied to a design process, much of the work must be done with oneself outside of a specific, goal-oriented environment. HCI designers who integrate somatically informed practices within the design process typically begin by facilitating movement-based explorations that attune participants to their own embodied experience *without* the aide or integration of technology. For example, in the design of *whisper* Shiphorst (Schiphorst and Andersen 2004; Schiphorst 2009a) engages users in somatic experiences that facilitate refocused attention on one's own embodied experience without the use of the designed wearable system. This includes exercises such as deep listening to one's own internal body sounds and movement sharing across participants. Loke and Khut (2013) engage workshop participants in activities specifically informed by Feldenkrais practices before introducing the elements of making and design. If designers wish to integrate somatic methods and ways of knowing into their design practices, this will mean some of the necessary work will not be directly related to a specific design task or technological application. Some of the work will be about learning to witness one's general way of acting, engaging, and being in the world. This is an asset of the practice, not a limitation – especially as we consider the field of wearable technology design.

The integration of somatic practices is applicable anywhere designers are engaging humans with digital technology; however, it is particularly pertinent to the wearable technology design field. Wearable technology is entangled with our everyday corporeal and sensory experiences, both when such technologies are in active use and when they recede into the background. Wearable technology, like many of our personal, portable devices, does not neatly couple with a specific purpose, task, or environment, meaning there is no specific design scenario that can encompass all experiences a user might have with a wearable device. Furthermore, wearable technologies cannot be taken off the body and maintain their basic functionality. They actively coexist with users even when they become unconscious (Rajko 2018). As such, the integration of somatic practices within wearable technology design offers strategies for considering the implications of wearable technologies beyond specific design scenarios and helps designers recognize how scenario-specific approaches can cultivate misguided perceptions about how wearable technologies coexist with users.

This leads me to my own curricular design work. The purpose of my pedagogical model is to teach wearable technology designers and design students how to augment their own design projects with somatically informed methodologies. This builds upon the research described above and connects to an emerging area of pedagogy design in which students learn to implement somatically informed practices into their own design scenarios, rather than into a project of the instructor's making (Erkut and Dahl 2017). To support student design opportunities, I developed wearable rapid prototyping bands and custom software to introduce students to somatically informed wearable technology design methods. My pedagogical approach mirrors related work, in that it begins by engaging students in physical experimentation, movement improvisation, and self-learning prior to introducing digital technologies. The movement work is then applied to somatically informed interactions with wearable technology to elicit deeper understandings of how technologies entangle with our somatic, corporeal experiences. Finally, students imagine and design new wearable technologies based on their personal explorations. As much as students learn about technology, they also learn about specific values rooted in somatic practices.

3 Implementing Somatic Values

Within this section I focus very specifically on terminology and knowledge rooted in somatically informed dance practices. This terminology may parallel but is not exclusively tied to HCI design or related fields. In each subsection, I explain how and why I identify specific somatic values as meaningful to my curricular design and how each shapes student learning.

When devising the curriculum, I considered the importance of integrating somatic practice knowledge into both the specific exercises and the general values that guide the content. Somatic exercise integration will be outlined later in this chapter; however, to contextualize my work, I will begin with a deeper discussion of somatic values. Dance educator Karen Schupp (2017) defines somatic values as “the beliefs and ethos that permit somatic exploration,” which can be but are not explicitly tied to somatic practices. Imbuing any pedagogical method with somatic values can offer an experience in which student learning takes on a more self-directed, process-based approach, leading to increased student agency and holistic reflection. To contextualize, Schupp articulates her somatic values as “prioritizing process over outcome, honoring individuality, paying attention in the moment, proactive reflection, and the teacher as a facilitator rather than an authoritative expert” (Schupp 2017). This approach intentionally offers open-ended and ambiguous activities to students, encouraging knowledge cultivation from personal and collaborative in-class experiences. As such, somatically informed practices can take time for students to warm up to, particularly for those new to embodied practices. Despite this, I have found somatically informed pedagogy offers room for me to facilitate a wide array of students with diverse perspectives. Furthermore, it leads to greater student empowerment and an increased sense of agency for those who do not as easily thrive in classroom spaces built upon meritocracy and deference to computational excellence. In the next sections, I will articulate the somatic values that have inspired my wearable technology curriculum and address specific considerations for working with students unfamiliar with movement-based practices. My somatic values are as follows; achieving balance through unlearning and self-study, heightening conscious awareness of embodied experience, and shifting expertise to the learner.

3.1 Achieving Balance Through Unlearning and Self-Study

Work grounded in somatic practices builds its knowledge from the philosophical viewpoint that everything we experience in our lives is a bodily experience (Hanna 1988). One of the defining features of somatic approaches is its *whole-part-whole* model inspired by the philosophies and structures of somatic study (Eddy 2016). This approach emphasizes the importance of balancing specificity with an understanding of how details relate back to the larger whole. Moreover, it fosters what Schupp (2017) calls *proactive reflection* or reflection that is consciously approached with the new knowledge acquired from breaking down a specific concept through physical engagement. To take an example from a dance studio setting, a student may be asked to perform a large movement phrase. Afterward, the instructor would address an unconscious habit or movement pattern inhibiting the student’s full performance of the phrase by facilitating an “unlearning” of the habit through movement. Once the student is made aware of the habit and can begin to articulate understanding, the student would then be asked to perform the phrase again while applying the correction. This whole-part-whole learning model ensures that students do not get caught up in the details of their work but always bring new concepts and methods back into a holistic understanding of their own practice.

Another way this model is expressed within contemporary modern dance is through the concept of *deconstruction and bricolage* (Bales and Nettl-Foil 2008). This expression emphasizes the importance of *deconstructing* or unlearning inhibitory, unconscious habits in order to reassemble knowledge into a newly transformed whole (*bricolage*). The concept of "unlearning" is often flipped upon its head in somatic study and referred to as the "relearning" of healthy or beneficial practices that we once knew but have forgotten through the repetition of unhealthy habits. Coming back to the concept of *sensory-motor amnesia*, Hanna notes that as we move into adulthood, we are conditioned to disregard our own physical sensations and experiences (Hanna 1988). This conditioning is reinforced through myths of what it means to "become an adult" and generally "to age," particularly when such perceptions teach us to pay less attention to our own physiological sensations, emotions, and felt experiences. Such myths emphasize a separation of knowledge from the physical self and prioritize third-person perspectives as presumably more "neutral" or objective. Somatic practices push back against this ideology by arguing that "first-person human experience must be considered of equal importance as outside, third-person observation" in order to achieve a balanced understanding of embodiment (Hanna 1988). This yearning for balance is an implicit theme throughout somatic study and as such, a critical component of my curricular design. In the case of designing wearable technology, seeking balance helps designers recognize their own implicit habits manifested through corporeal biases shaped by previous lived experience. This type of unlearning is paramount to creating designs that go beyond only fulfilling our own needs, wishes, and desires, or worse, unconsciously encouraging users' needs to reflect our own.

3.2 Heightening Conscious Awareness of Embodied Experience

To achieve unlearning, it is critical that students begin to understand how to tune into their own embodied experience by heightening conscious awareness. This is made available through heightening or highlighting embodied experience through structured, physical play. In dance practices, we call this type of play *structured improvisation*. Structured improvisation is not frivolous, though at times it makes new practitioners feel silly and childish because it pushes up against perceptions of what it means to act like an adult. While humor and feelings of joy and pleasure can arise during such practices, the main purpose is to help practitioners resist the temptation of end-gaining actions into a specific, achievable outcome.

As mentioned earlier, I often use improvisation techniques both without and with wearable technologies. The students and I first engage in play without technology so that students learn how to be consciously aware of their present embodied experience. After this, we apply what we learned to a facilitated exploration with digital technologies. This places embodied practices and experiences at the forefront of learning and reverse engineers the traditional model of making a new design. Traditionally, students are asked to take on an idea, build a prototype (an experience often end-gained by the design objectives), and then finally play with the object (play typically conducted with the desired goals in mind). A somatic approach engages in an embodied experience first, reflects upon the experience second, and then explores design ideas rooted in this learning. This tends to keep movement and physical exploration central to learning. Furthermore, students begin to notice how their own personal experiences shape the ways in which they approach, engage, and make choices within the design process. By using embodied practices to ask the big questions of how and why we make a new design, students learn to implement and value more holistic, embodied approaches to answering such questions.

3.3 Shifting Expertise to the Learner

As students become more accustomed to the intentional ambiguity and self-directed methods of somatically oriented learning, they also gain agency over their own exploratory process. This goes beyond working with a sense of independence, as independent learners can still go about end-gaining their own learning experience. Students working somatically learn how to sustain curiosity in their own learning process and trust themselves as the expert of their own embodied experience. This takes time and patience. For example, a dance student might be asked to "spend fifteen minutes exploring the different movement that starts from the fingertips," or in the case of wearable technology design, I might ask a student to "spend fifteen minutes exploring a wearable light sensor through movement." This task does not tell students how to explore, which is where student agency (and student anxiety) can arise.

Working within open structures can at first feel overwhelming and uncomfortable. To alleviate this discomfort, students will often unconsciously defer to the instructor or another peer as the expert. This deferral arises as questions such as "What do you want me to do?", "What should I try next?", or "Is there a right way to do this?" These questions reflect an implicit assumption that there is a universally right way to go about the task. Going back to the concept of "unlearning" or "relearning" articulated in Sect. 3.1, part of the work is *unlearning* the need to conform to an implicit right and *relearning* the joy of experimentation and self-expression through movement improvisation techniques.

As I articulated in Sect. 2, the purpose of this curriculum is not only to teach students how to engage in somatically informed practices within one's own design process but also to facilitate others, be it users or designers. To do this, the curriculum typically tasks one student with being the "mover", while another student witnesses as a "facilitator." This teaches students how to openly observe their peer at work and gives them insight in how to facilitate others within a somatic experience. Important to learning how to facilitate of someone else's exploration is learning how to keep the mover engaged in and conscious of what they are doing, rather than deferring to outside direction. Moving students new to somatic practices tend to habitually defer to their peers or the instructor for affirmation. Simultaneously, facilitating students tend to fall into the trap of trying to direct the moving student's exploration, particularly when a moving student appears nervous. While this may temporarily alleviate a moving student's anxiety, it thwarts the purpose of the work and places the facilitating peer in the position of the expert. To help students address this as facilitators, I devised a series of tips for "observing like a somatic practitioner."

Facilitation Tips: How to Observe a Peer Like a Somatic Practitioner

- You being fully present and available for your partner is the most important part of your role. Think of it as silently listening with your whole body. Just because you're not talking doesn't mean you're not active.
- Consider how your body is performing. Even when you find yourself bored, remember: what your partner is doing is important to them. How you perform presence for your partner in these moments can be critical to your partner's learning.
- Observing while remaining silent is difficult and exhausting work. It might not feel easy, and that's okay.
- Don't be a "backseat driver." Remember, you are there to support your partner's own self-discovery. They, as the active person, have the knowledge they need, and your job is to help them find it for themselves.
- This work is hard for your partner too. We're not often asked to lead our own embodied discovery. Most of us tend to end-gain our own experiences. This type of openness can feel overwhelming. If your partner looks to you to end-gain their experience for them, help them find the confidence to learn from themselves with empathy and compassion.
- Most of your time will be spent in silence. If you choose to speak, do so thoughtfully and carefully. Remember, every time you interject (particularly when it's unsolicited), you are redirecting your partner's attention from their own experience to you.
- If you want to offer your partner verbal feedback, consider this: Are you helping your partner deepen what they're already doing, or are you redirecting their attention to something new? If you're redirecting their attention to something new, then this is likely more about what you want to do than what your partner is discovering. Consider saving your idea for your own explorations.
- Let your partner lead. If they ask you a question or ask you for assistance, give it, but don't overdo it. Remember, a question is not an invitation to take over. Less is more.
- Sometimes the best way to answer a question is with another question. This keeps the learning centered on your partner and keeps them accountable for their own self-discovery.

Here, I want to highlight a few of the key features of this list. The first is that silent observing is active observing. Witnessing someone move is as much an embodied activity as physically working with a technology. For many students, the facilitator role is just as difficult as that of the moving student, particularly for students who are accustomed to directing group work. The second feature is the differentiation between fixing and facilitating. Facilitators tend to be good about actively observing when silent, but when students begin to dialogue, it becomes difficult for facilitators to resist their own desire to "fix" the problem. This leads to facilitators taking power over the situation and directing the moving student on what to do next. The unconscious power shift is rarely malicious or ill intended but again arises from a need to relieve a moving student's anxiety. In these cases, when I see a facilitator beginning to direct a moving student's practice, I will kindly remind them of the observation tips handout and ask them to keep the moving student focused on their own knowledge production. This brings me to my third feature, which is fostering an environment of care. Both roles are a learning process, and as such both roles can feel new and uncomfortable. As a facilitating instructor myself, it is critical I approach suggestions and redirection with an ethos of care.

4 Wearable Technology Design Curriculum

Now that I have articulated the foundational somatic values that anchor my pedagogical methods, I will describe the tools I created, why I designed custom tools, and how I integrate them into a somatically informed wearable technology design curriculum.

4.1 Rapid Prototyping Wearable Technology Band

When designing the curriculum, I found it critical to provide students the means to explore multiple sensors, algorithmic concepts, and feedback possibilities without having to spend significant time building out the supporting infrastructure. As such, I designed a "rapid prototyping wearable technology band," which I will hereafter refer to as the RPWTB (see Fig. 1). This custom-designed band allows students to wirelessly engage with a variety of sensors and responsive stimuli without the need to rebuild a new technology each time. I designed the RPWTB so that students could quickly and smoothly move from engaging in a somatic exercise to exploring somatic concepts with wearable technology. This seamless transition keeps embodied learning central to the curriculum, thusly supporting the somatic values of my pedagogical approach.

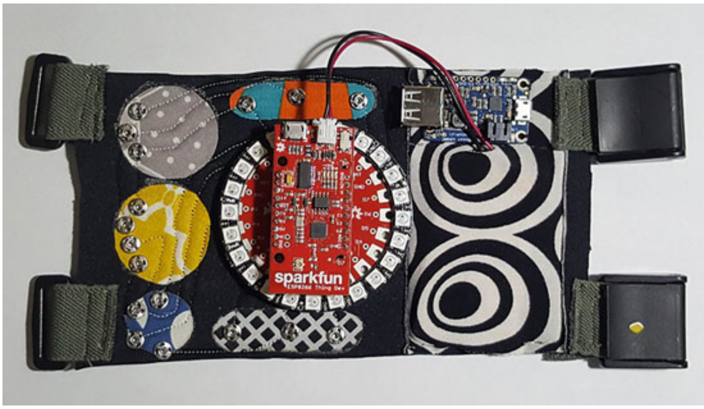

Fig. 1 Image of the rapid prototyping wearable technology band, or RPWTB

4.1.1 Layout

The foundational fabric of each band is neoprene, which is both structurally resilient and waterproof. The band's circuitry is sewn into the neoprene using conductive thread. Each band is visually laid out into four unique areas: sensor input, microcontroller, feedback output, and power. Each area is visually denoted by colorful fabric patches, which makes assembly easier to discuss and visually parse in a group setting. All external electronic components are modular and are either attached by snaps or held by fabric pockets. The sensors, microcontroller, and feedback components snap into the band, and the snaps serve as the electronic connection between the band's circuitry and the other electronic components. The electronics chosen to work with the RPWTB can be found in the following list:

Microcontroller

- Sparkfun ESP8266 Thing Dev

Sensors

- LSM9DS0 (9DOF)
- BNO055 (absolute orientation)
- MAX4466 (microphone amp)
- TSL2561 (luminosity)
- TCS34725 (color)
- variable resistors[3]

Feedback

- neopixels (independently addressable RBG LEDs)
- disk motors (independently addressable)

Power

- 3.7 V LiPo battery
- 5 V power boost 1000

[3]The RPWTB is setup to accommodate any variable resistor sensor that can be used to create an adjustable voltage divider circuit.

Fig. 2 This is a composite image of the modular strapping. The above images show how straps are attached to the RPWTB (top left), general strap design (top right), and the range of lengths provided (bottom)

The elastic strapping brings another form of modularity to the RPWTB. Each band can be connected to elastic strapping of variable lengths (see Fig. 2), which accommodates a variety of bodily placements including those beyond traditional wearable technology bodily locations, such as wrists and forearms. Variable elastic strapping also accommodates a wide range of body shapes and sizes so that students are not excluded due to gender or body type.

4.1.2 Integration with Feedback

Students can use sensors to influence "on-body" feedback such as LEDs and vibrotactile motors in real-time. All on-body sensing is controlled using a single Arduino program designed and developed by myself and software engineer Stjepan Rajko. Each unique feature is accessible through a clearly defined tab making the program a compact and intuitive introduction for those new to text-based coding (see Fig. 3).

Data can also be wirelessly sent to a computer via Wi-Fi. The Sparkfun ESP8266 Thing Dev uses the ESP8266, a low-cost Wi-Fi microchip used to send data in real-time. For the purposes of this curriculum, data is received by a visual programming language called Max. Here, I designed a suite of Max patches (visual software programs) that receive sensor input and transform the incoming data into real-time sound, video, image, and lighting changes. As shown in Fig. 4 all algorithmic processes are visually displayed, allowing students to follow how data is affected by the different algorithmic transformations. For example, the top rectangle displays incoming raw data, the middle rectangles allow students to manipulate the minimum

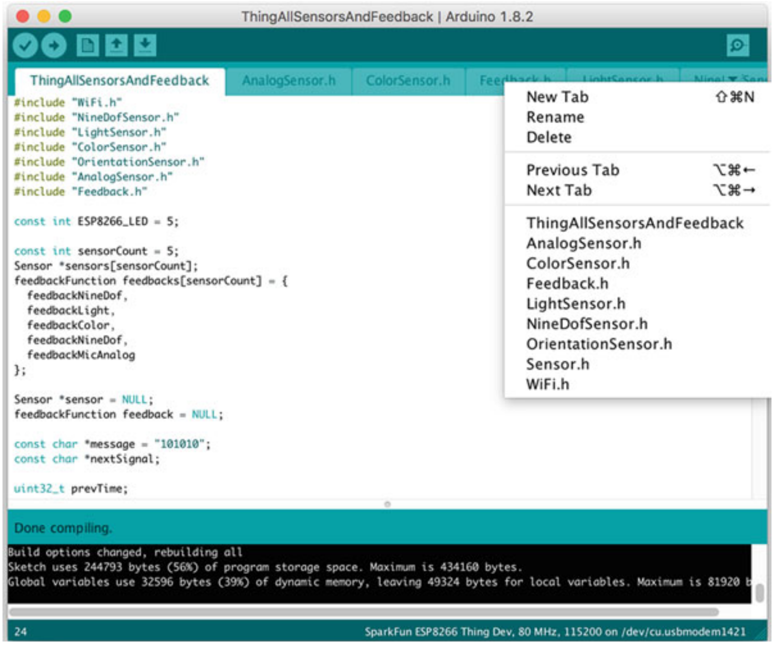

Fig. 3 The Arduino program displayed above demonstrates the multi-tab layout provided to students. Each tab represents an key feature of the code, making navigation more intuitive. The dropdown menu in the top-right corner gives a full list of all available tabs

and maximum data value output using sliders, the thin middle rectangle displays data scaled to work with a particular feedback modality, and the large, bottom rectangle allows students to smooth data using a pair of sliders. The same visual layout is repeated across all Max patches. This keeps algorithmic processes clear and easy to intuit from patch to patch. Students can use digital sliders and buttons to adjust algorithmic parameters and change the feedback outcomes.

4.1.3 Custom Tool Logic

While each RPWTB requires a significant amount of time to design and develop, the bands are critical to my pedagogical approach. Reflecting upon their practicality, the RPWTB offers modularity. All components can be removed and replaced, allowing students to easily change out sensors and feedback modules. Furthermore, the modularity reinforces play, in that any component can quickly be replaced if broken or malfunctioning. The invitation to play is also amplified by the soft, squishy neoprene and colorful fabric circles. Several students have verbally commented on the playfulness of the design, noting its use of color and pattern differs from the more utilitarian designs commonly found in general use consumer technologies.

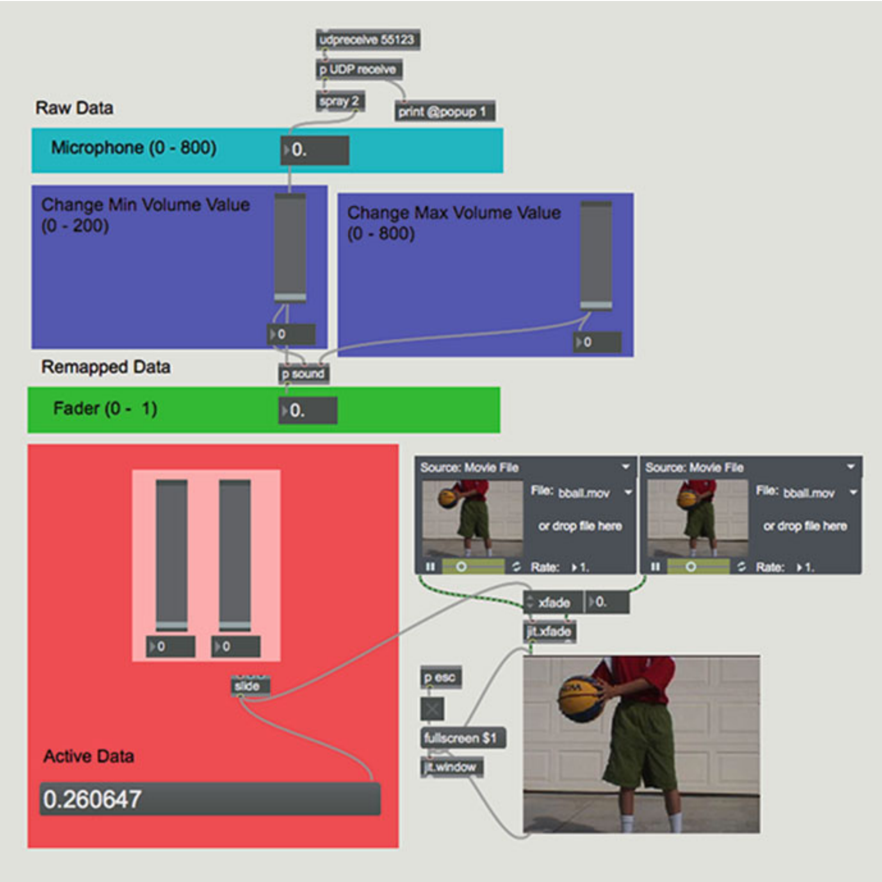

Fig. 4 Max patch demonstrating the visual layout used throughout all patches designed for the curriculum

The RPWTB also affords transparency. Unlike consumer wearable technologies that intentionally black box design processes and functions, the custom bands make both the hardware and software transparent to users. This helps students understand how such technologies function and manipulate various parameters quickly and easily. Furthermore, the RPWTB provides an applied introduction to discussions about black box design ethics and user agency.

Lastly, the RPWTB affords curricular design in which more time is spent in active rather than passive learning. This setup requires very little time to change from one layout to another, and the band itself needs minimal adjustment to work with new sensing. Each Max patch has a similar visual layout so that students can quickly parse out new information. The Arduino program affords several tasks, which are individually labeled and tabbed for quick, legible navigation. Collectively these intentional design choices mean students spend more time working through the nuanced questions of how the technology responds to their own embodied interaction, rather than learning and relearning the functionality of the setup or sitting down to build software.

4.2 Curricular Design Example

The following curricular example is from a week-long intensive course co-designed and co-taught by myself and Stjepan Rajko and hosted by the Digital Humanities Summer Institute (DHSI) at the University of Victoria. This curriculum was built and refined over the summers of 2016 and 2017. DHSI is a faculty-level retreat in which students, educators, and local community members attend week-long intensive courses on various digital humanities topics. The course we developed, *Palpability and Wearable Computing*, was inspired by Schiphorst's paper of similar title (2009a), and it incorporates movement activities and technological exploration grounded in somatics practices and movement improvisation, with some integration of intersectional feminist theory.[4] Students were comprised mostly of digital humanists and art historians with various levels of physical computing experience. Student interest in the course varied greatly, ranging from an interest in building upon existing physical computing skills to integrating applied knowledge into scholarship on wearable technology design ethics. Most of the students were new to somatic practices, though a few had regular movement or mindfulness practices. Each course offering served 14 students.

4.2.1 Curriculum Overview

The course outline listed below demonstrates the general flow of the week-long intensive. Looking closely, one can see the "whole-part-whole" model discussed in Sect. 3.1. Students begin Monday with a holistic introduction to somatic practices. Tuesday, students focus on individual sensorial systems such as vision, hearing, and touch, all of which are related to digital sensor/feedback configurations. Wednesday, we apply this new knowledge back into a more holistic approach to embodied learning, which we then use to explore various consumer wearable technologies. Thursday and Friday are designated as design days in which students apply learning to create new design ideas. These final days are intentionally open, which gives

[4]Intersectionality is a theoretical framework used to articulate the complex, overlapping, and intersecting systems of oppression. In this, intersectionality both acknowledges and critiques sociocultural categories such as, but not limited to race, gender identity, class, education, ability, sexual orientation, age, and religion. The term originates from black feminist thought, most notably from the early work of lawyer and American civil rights advocate Kimberlé Crenshaw (1989), in which she writes about the unique marginalization experiences of those who identify as both black and female.

students the freedom to make choices about who they want to work with and how they want to articulate their ideas. Some students build out their conceptual ideas with the RPWTB and others create new designs with raw materials. Choices are often based on their physical computing comfort level and larger research goals beyond the scope of the course.

Course Outline

Monday: Introduction to Somatic Practices, Wearable Technology, and Real-time Processing

- Morning – introduction to somatic practices; analogue introduction to wearable technologies.
- Afternoon – software setup; learning the digital side of our wearable tech; introduction to real-time processing.

Tuesday: Witnessing Our Somatic Experiences

- Morning – deconstructing habits of seeing; hearing our own bodies, space, and each other.
- Afternoon – experiencing complexities of touch; engaging in multisensory experiences (bricolage).

Wednesday: Embodied Critique of Consumer Wearable Technologies and Computational Processes

- Morning – questioning the mind/body split.
- Afternoon – unboxing consumer wearable technologies with a somatic approach to unraveling implicit bias; dreaming up new wearable tech from a somatically informed lens.

Thursday: Imagining New Wearable Technologies

- Morning – open play, small group sessions to learn different wearable tech design processes.
- Afternoon – open play, imagining new wearable tech experiences from a somatically informed lens.

Friday: Imagining New Wearable Tech (Continued)

- Morning – open play, imagining new wearable tech experiences from a somatically informed lens.

4.2.2 Example Activities

To approach the somatic value "achieving balance through unlearning and self-study" described in Sect. 3.1, we guide students through a series of facilitated exploratory experiences both without and with the RPWTB. This suite of exercises draws inspiration from several artists and designers, including the somatically informed HCI workshop designers described in Sect. 2.

In each case, students begin with a basic perceptual awareness exploration and then apply this perceptual awareness to a specific sensory modality and finally work with digital sensors in real-time. The following example exercises engage students in the "act of seeing." The activities in this series lead to the exploration of an on-body luminosity sensor, which is attached to the RPWTB. As articulated in the course outline above, we go through a similar progression to explore hearing and touch.

Exercise 1 (Observation Walk) This exercise is inspired by artist Allan Kaprow and revised by Springboard for the Arts (Irrigate). The purpose of the Observation Walk is to learn how to visually observe our environment without immediately naming objects, analyzing space through a sociocultural lens, focusing on pleasing aesthetics, or providing solutions to potential design problems. This teaches students how to observe and describe space, architecture, and objects without resorting to personal experience or domain knowledge.

When introducing the exercise, I often talk about this walk as "seeing the world for the first time." I encourage students to imagine that they have no previous personal history to reference, as if everything is new. This encourages students to look at and describe structures by their shapes, colors, textures, and size, rather than their generally understood name or functionality. For example, students are encouraged to denote a flower by describing it as an object defined by its colors, shape, and size, rather than calling it a "flower."

If the weather is favorable, I take students outside. Prior to the activity, I define the route path and denote an ending point. When selecting a path, I look for a route that is varied, but not particularly visually stunning. This encourages students to look beyond social constructs of beauty to questions of form. The walk consists of the following steps:

1. The instructor introduces the exercise at the beginning of the route and denotes the endpoint of the path.
2. Everyone slowly walks the route in silence, taking a full 10 min to take in the landscape and walk the length of the path. Instructors can set the walking tempo.
3. As students finish, people quietly wait for everyone to join the group at the end of the path.
4. The instructor introduces the next step by explaining that the group will slowly take a return walk together. If there is something students noticed and want to share, they are encouraged to stop the group and verbally explain what they noticed. When necessary, instructors can remind the group to steer away from criticism, analysis, and solution development. This is critical to the unlearning process.
5. Everyone walks back slowly. Instructors can encourage everyone to make verbal observations and may interject with their own observations to help the group as needed.

6. This activity concludes with a facilitated group discussion and reflection about the process of walking and observing.

Exercise 2 (Modified Blind Lead) This exercise is inspired by a *Blind Lead* activity found within the Liz Lerman Dance Exchange Toolbox, a widely used series of activities created to support a variety of creative processes and practices (Lerman). This modified version directs student's attention to the sensory experience of light, which closely mirrors the functionality of the TSL2561 luminosity sensor. Students work as partners to complete the activity; one student acts as the "leader" and the other as the "receiver." Receivers put in earplugs and close their eyes, while leaders guide them through space. Before beginning, I prompt receiver students to pay particular attention to light changes perceivable through their eyelids with eyes closed and to consider how this small amount of information helps intuit the surrounding environment. This exercise is best conducted in large, open spaces with variable lighting, and it consists of the following steps:

1. The instructor asks students to partner up and then introduces the activity. During the introduction, I offer two methods for leading receivers through space: one in which the leader holds the receiver and one in which the receiver holds the leader. Receivers choose which option they prefer.
2. Before students begin, the instructor and students collectively define the exploration space so that students do not wander too far away.
3. The instructor encourages leaders to challenge receivers as long as receivers appear to remain invested in the task-at-hand. Because this activity is conducted in silence, leaders are given great responsibility to recognize and acknowledge nonverbal cues from the receiver.
4. Receivers put in ear plugs and close their eyes.
5. Leaders slowly begin guiding the receivers through space in silence, paying attention to nonverbal cues from the receiver about their comfort with speed, directional changes, and environmental changes. If receivers become overwhelmed, leaders should slow down their progression.
6. As both partners become more comfortable with their roles, leaders are encouraged to move receivers through spaces with varying light intensities.
7. After about 10 min, leaders are prompted to stop walking and inform their receiving partner that they can open their eyes.
8. Students are given 3–5 min to talk in pairs and write down observations.
9. Partners then switch roles and repeat the exercise.

Students in the receiver role often feel initially overwhelmed by walking with their eyes closed. It is critical that leaders give receivers the time to become comfortable before trying to introduce challenges. I am very direct and clear about the importance of leading compassionately and prioritizing the receiver's experience in how one leads. This reminder reflects the somatic value of "shifting expertise to the learner" described in Sect. 3.3. Maintaining student awareness is critical in this exercise. Instructors new to this style of activity are encouraged to visit the Liz Lerman Dance Exchange Toolbox website for further tips and suggestions.

Exercise 3 (Luminosity Sensor Exploration) Combining what students learned through the previous activities, partners stay together to explore the TSL2561 luminosity sensor. In this exercise, students take on the roles of "mover" and "facilitator." Movers wear the RPWTB, while facilitators witness their work. For this activity, students explore luminosity sensor data that detects the amount of light cast upon the sensor. This real-time data is sent to Max, where it is transformed into dynamic lighting that fades between black to white via grayscale. Black denotes the sensor's perception of complete darkness and white as the sensor's maximum light input capacity. I encourage students to explore many places in space within the limitations of the Wi-Fi network. Depending on the space, this might mean working outside, in hallways, or within the classroom. I often observe students squeezing into corners, under desks, and hovering near windows. All such activities are encouraged as long as they are done safely. This exercise consists of the following steps:

1. Instructors begin by giving students a verbal reminder of the facilitator's role. I find it useful to revisit the affiliated "how to observe a peer like a somatic practitioner" worksheet.
2. The instructor and students collectively define a space for exploration.
3. Movers openly explore the luminosity sensor for about 10–15 min while facilitators silently witness.
4. Students are encouraged to explore the minimum/maximum sliders and scaling sliders in Max as they relocate in space.
5. As movers explore, they are encouraged to verbally articulate their observations. Facilitators write down these observations for the mover.
6. After 10–15 min, students review their notes, switch roles, and repeat the exercise.

Upon the conclusion of this exercise, we bring the students back together for a group discussion. I typically lead the discussion with the most recent luminosity sensor exploration and then ask students to relate the experience to the modified blind lead and observation walk exercises. I often try to minimize my own interjections, letting the students lead the conversation. At times, I will highlight a connection between exercises or student observations, but again, I try to keep this to a minimum. By this point, students have accumulated a vast array of reflective observations and typically feel comfortable leading the conversation. Many begin to connect experiences within the exercises to their personal research goals beyond the classroom, which is encouraged.

From here, we take a deeper look at how the sensor functions, often referring to the sensor's datasheet. As we move from the exploratory learning activities to more detailed information about how the technology functions, we continuously relate the information back to students' previous embodied experiences and observations. This makes the information more palpable, helping students better retain information.

4.2.3 Summary

The curricular examples provided above reflect my approach to somatically informed instructional design for wearable technology. The novelty of this approach has less to do with the individual activities or digital technologies and more with the overall structure. The centering of somatically informed movement improvisation and sensory exploration anchors the course in lived experience, rather than technology design. This human-centered approach keeps students' applied experiences intuitively at the forefront of the design process. Furthermore, it allows students from various experiential and disciplinary backgrounds to enter into a shared experience and meaningfully dialogue about wearable technology. The following feedback is from students who participated in the 2017 DHSI summer workshop. Students were asked to fill out a brief online survey and reflect upon the class by video interviewing each other. In the survey, students were asked, "Could you give us a short description of what you learned in this class?", and responses included comments such as:

- Making and coming to understand the body as embodied consciousness or consciousness as an embodied product/concept.
- Openness, curiosity, respect, and group work.
- I think the fact that we engaged in various conversations helped situate this kind of work and its relevance to my own research questions.
- I really liked how the course elegantly sutured technology and somatic research practices.
- This class was a great opportunity to learn about both the technology and the connection between devices and sensory perception, embodied experiences, and movement. I greatly appreciated the use of mindfulness and kinesthetic exercises to ground the unfamiliar aspects of the technology in familiar (and even new) experiences of the body.
- I am impressed with how many peripheral technologies and disciplines (electronics and diagramming, introductions to programming through Arduino, modular interfaces in Max, etc.) were introduced and made very familiar in such a short time.
- I feel very confident that I could use this week as the foundation of going much further with these tools and technologies, and I can't say how much I appreciate the inspiration this gave me in terms of using these ideas to go further with my research.

These written responses reinforce the somatic values that provide the foundation for my pedagogical framework. To further synthesize, I now return to the three somatic values described in Sect. 3 and provide examples of how student feedback reinforces the importance of these values in student learning.

Achieving Balance Through Unlearning and Self-Study The use of somatically informed practices within the course was a highlight for many students. This work helped students either unlearn their own perceptions of wearable technology design or build a more balanced, embodied relationship to their existing design practices. For example, in a video interview, one student stated:

> It was really valuable to have a space to workshop and think through all of these different ideas about how sensors work and…just unlearning a lot of assumptions I had and taking apart everything that I thought I knew and wanted to know about this. I learned a lot, just not the things I thought I was going to learn.

Another student had this to say:

> It was like, unhinging yourself from the regular constraints you put on how to think about these sorts of things. It gave me a new bunch of skills to think about and anticipate how tech works.

The balanced nature of the curriculum surprised many students who had preconceived ideas about how they would be asked to engage in class. Furthermore, unlearning supported by a focus on self-study challenged notions about how design "could" or "should" be taught. This was refreshing and liberating for many students, regardless of their previous design experience.

Heightening Conscious Awareness of Embodied Experience As mentioned in Sect. 3.2, embodied practices teach students to implement and value more holistic approaches to embodying the big questions about how and why we design. In this course, students were often surprised by how much they learned both about embodiment and design. This points to the potential for somatic integration to not only make design learning more meaningfully holistic but also retainable. It also points to the ways in which thoughtful knowledge integration from seemingly disparate fields (in this case, somatics, movement improvisation, and wearable technology design) can deepen and enrich knowledge in each area. For example, when asked what she expected coming into the course, one student said:

> Coming in I thought it was going to be a very technical course, but I didn't anticipate how it was going to include all of these other lenses to get at the conversations that we did. I think about how the activities in class, and [the class itself] was the antithesis of what I anticipated [a class about] tech would be.

This quote, along with the written feedback listed above, expresses students' surprise in the breadth of material we were able to meaningfully cover within a week-long class. Their comments point to the importance of creating a clear curricular flow from movement improvisation to wearable technology exploration. Maintaining this flow made the curricular progression more intuitive, which allowed students to settle into the daily rhythm and focus on the present experience.

Shifting Expertise to the Learner As described in Sect. 3.3, first-person methodologies consider the instructor's role as that of a facilitator rather than an authoritative expert. This gives students agency over their own exploratory process, resulting in several positive outcomes, such as meaningful relationship cultivation within the student cohort and opportunities to connect classroom learning to larger research goals. Several students mentioned they concluded the class feeling connected to their peers in ways not similarly achieved in other classroom settings. For example, one student was asked what she would tell future students who were considering the course. She responded with:

> Be open and have fun. This has been so fun, and play has been an integral part of it. It's gotten us, as a cohort, close in a way that I haven't really experienced in a lot of other classes.

The open classroom environment encourages students to learn by looking to themselves and each other for discussion, knowledge, and insight. My active facilitation of this process along with the "how to observe a peer like a somatic practitioner" list (see Sect. 3.3) ensures that students do not feel lost in the process or overpowered by a more dominant peer. Additionally, the somatic exercises elicit playful relationships across students, which reinforces empathetic and compassionate peer-to-peer relationships.

The open framework of the course allows students to repeatedly synthesize the material within their own lived experience and disciplinary frame of knowledge. For many students, this resulted in feeling like they came away with tools deeply meaningful to their own research goals. For example, when asked what's next after the class is over, one student replied with:

> Now it's the big project design bit. I've learned so much and I feel like I have a much better vocabulary for that. Now it's getting together with a team and talking through our options with wearables and the sensors available and working on the next machine. I think coming at it from the perspective of somatic practice is really going to transform the way in which we go about building the next device.

Another student just beginning to integrate virtual and augmented reality into his research had this to say about his experience:

> [The class was] really interesting as I'm trying to go down the roads of virtual and augmented technology. It had a really useful focus on the actual sort of ethics around all of these [ideas] and the sort of gender, race, and social justice questions that go along with bodily technologies. I have a couple of really useful things to go back and think about and work on. Bridging some gaps that are really threatening the edges of these technologies that I work with.

Here, it is important to note that many of our discussions surfaced questions about the relationship between wearable technology, intersectionality, and social justice. While these topics were not explicitly encouraged by the curriculum, they were important to many within the cohort, as they are related to students' larger research goals. As such, the activities and related discussions of embodiment and embodied agency naturally surfaced such discussions, which I co-facilitated along with other students who had expertise in critical race and feminist theory.

The openness of this instructional method can be both exciting and anxiety provoking, particularly when the conversation moves into topics unfamiliar to the instructor. With this, I encourage instructors who choose open discussion frameworks to become comfortable with not always being the expert. At times I would have to defer to the expertise of a student and acknowledge that their proficiency in a given topic outweighed my own. This takes practice to do confidently.

Other Curricular Applications I have incorporated the course's activities into semester-long courses for different student groups in HCI design and dance. In each case, I slightly modify the material to reflect the skills and knowledge of the group. This can be done through minor curricular adjustments rather than complete overhaul. As a facilitator, one of my primary roles is to listen to the students and keep them invested in the given moment. This often means adjusting the speed with which I move through material, carefully choosing the words and metaphors I use to describe a process, and occasionally reordering curricular material to reflect the disciplinary practices of the students.

5 Conclusion

As a dancer working in HCI, I recognize that the strength of incorporating somatically informed dance practices into HCI curriculum has little to do with a dancer's ability to perform virtuosic movement. It has much more to do with how we value corporeal exploration as a rigorous research method for understanding human experience. Reawakening the senses helps us recognize how much of our own lived experience is made possible because we have the capacity to move. As Ceclia de Lima (2013) writes:

> Although the dancer gains a formal and muscular habituation to the movements he or she practices, different from other physical activities, dance as an artistic practice puts great emphasis on the experience of movement itself. Therefore, through several techniques of somatic awareness developed within dance practice (Eddy 2009), this habituation does not lead consciousness towards the regular desensitization of the kinesthetic sense, but towards an intensified sensorial awareness of the body in movement. Such awareness leads to the dancer's perception of self not as being in movement, but as 'becoming movement.'

It is from this place of heightened embodied awareness, yearning for somatic balance, and endless fascination with "becoming movement" that I approach design. Awakening students to their embodied experience deeply influences the ways in which they attend to themselves, others, and their own design practices. I refer to it as "keeping humans and human experience at the forefront of how we design, who we design for, and why we design at all." This goes beyond common discussions of design functionality to address more evocative questions of user agency, power, trust, and joy facilitated or inhibited by the physiological and embodied potentials of a design. As our design practices continue to blend and blur the boundaries between ourselves and our digital technologies, my continued desire is that we think deeply about what choices we make and how we come to choose them.

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A Conceptual Framework for Supporting Expertise Development with Augmented Reality and Wearable Sensors

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1 Introduction

Developing expertise is difficult for apprentices alone (Rikers et al. 2004). Ericsson et al. (2007) emphasize the importance of experts as mentors for supporting expertise development. However, experts tend to underestimate how difficult a task can be for apprentices (Hinds 1999). Moreover, experts are often unaware of all the knowledge behind their superior performance (Patterson et al. 2010). Therefore, while experts are indispensable for expertise development in apprentices, learning from them is difficult. Limited access to the experts for apprentices also hinders their development even further. In order to mitigate these challenges, the WEKIT framework introduced in this paper aims to capture expert performance, making it accessible to many apprentices. By capturing expert performance as a resource, the WEKIT framework supports apprentices by emulating an expert-based guidance and feedback.

Sensors have the capability to unobtrusively measure physical properties. Wearable sensors (WS) have been successfully used in training to provide feedback based on expert data (e.g., Jarodzka et al. 2013; Schneider et al. 2017). A systematic review of literature and applications of WS and augmented reality (AR) posits a rich educational potential of these technologies (Bacca et al. 2014). A sensor- and AR-based training environment with the expert recording can supplement training

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by providing guidance and feedback when expert is not available. The WEKIT[1] project aims to exploit this potential of WS and AR for supporting training using expert performance data.

AR provides a rich multimodal and multisensory medium (Azuma et al. 2001) for apprentices to observe the captured expert performance. Such a medium would enable apprentices to have access to expert data in authentic contexts when required. A key aspect of AR is to overlay the real world with virtual content to create an immersive platform (Bacca et al. 2014; Bower and Sturman 2015) which places the apprentice in an authentic context while engaging all his/her senses. The affordances of AR and WS have the potential to supplement the expertise development in apprentices by using the captured expert performance (Guest et al. 2017). This has been reflected in the learning methodology adopted by the WEKIT framework.

The WEKIT framework is based on the learning methodology that aims to utilize the valuable experience and knowledge of the expert with AR and WS (Fig. 1).

This learning methodology consists of three major phases: capturing expert performance, reenacting expert performance by apprentices, and reflection (Fominykh 2016). In addition, before the capturing phase, preparations are required to ensure

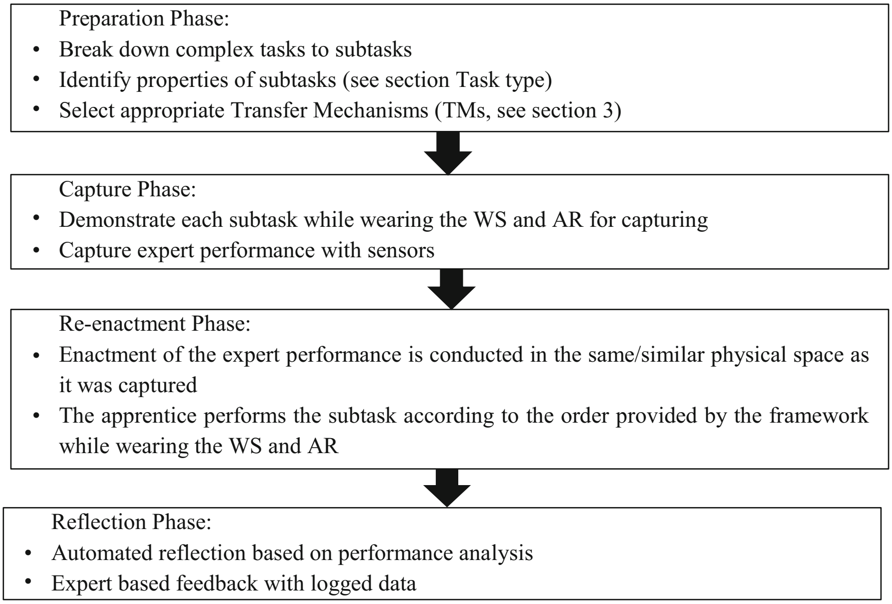

Fig. 1 Phases of WEKIT framework learning methodology

[1] Wearable Experience for Knowledge Intensive Training: Project No 687669

that essential aspects of the expert performance are identified for capturing. The capture phase ensures that the expert records all the relevant information needed for apprentices to perform the task. The reenactment enables apprentices to learn from the recorded performance, while the reflection phase allows the expert and the apprentice to reflect on the apprentice's performance by observation or/and from the data collected. The capture and reenactment are supported by AR and WS. While AR and WS posit a rich educational potential for training such as contextual information, in situ feedback, etc. which allow apprentices to get immediate feedback and guidance (Bower and Sturman 2015) have emphasized putting pedagogy before technology. This is especially true for maturing technologies such as AR and WS which provide a range of affordances potentially beneficial for training and education. Therefore, we structured the proposed framework around the pedagogical model known as Four-Component Instructional Design (4C/ID) model.

Four-Component Instructional Design (4C/ID) model supports training of complex task for development of expertise (van Merriënboer and Kester 2014). The 4C/ID model (Fig. 2) is a nonlinear and systematic processing model for designing a complex learning environment. It is a holistic approach that decomposes the complex task into their simplest and smallest elements such that can be easily learnt by apprentices through a combination of these elements (van Merriënboer et al. 2002).

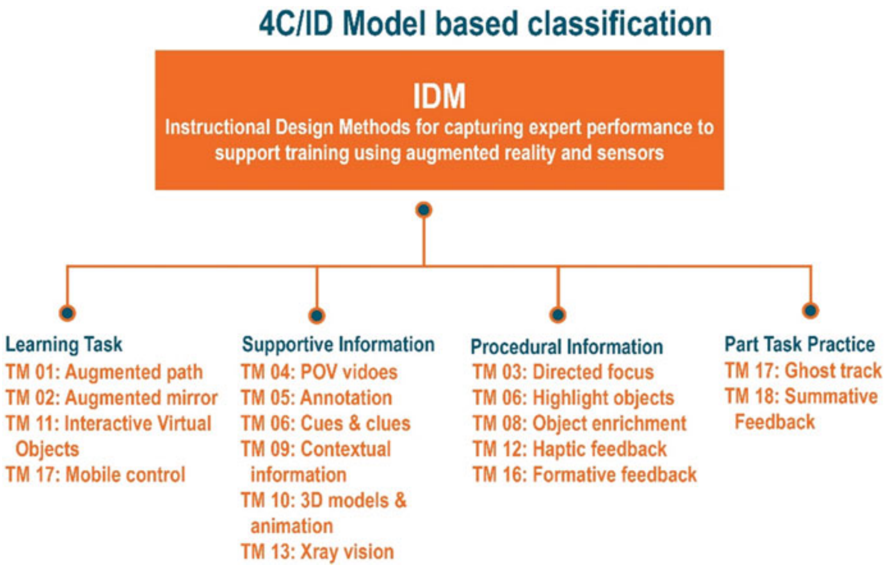

Fig. 2 WEKIT framework based on 4C/ID model

2 Four-Component Instructional Design

The 4C/ID (Four-Component Instructional Design) model supports training of complex skills and has a close resemblance with underlying principles of deliberate practice (Neelen and Kirschner 2016). Deliberate practice is a focused practice on development of particular skill and is crucial for development of expertise. Sarfo and Elen (2007) assessed educational systems developed with 4C/ID specifications and positively indicated that the 4C/ID model promoted deliberate practice. Evidence about the effectiveness of training environments designed in line with specifications of the 4C/ID model for promoting deliberate practice in training contexts has also been documented by Merriënboer and Paas (Merriënboer and Paas 2003) and Merrill (2002).

Sarfo and Elen (2007) reported positively that the 4C/ID model promoted development of expertise, which was based on their assessment of the technology-enhanced learning environments developed with 4C/ID specifications. This claim is further backed by Neelen and Kirschner (2016), in their study where they found that the 4C/ID model supports expertise development. In addition, the sensors by personalizing training in authentic contexts (Bacca et al. 2014) and the AR by supporting apprentices in real time, both facilitate deliberate practice and thus, eventually expertise development.

The WEKIT framework builds upon 4C/ID model by facilitating the model with transfer mechanisms in order to support expertise development in apprentices with the help of augmented reality and wearable sensors. By doing so, it bridges the pedagogic aspects of 4C/ID model with the affordances of AR and WS. The basic assumption of the 4C/ID model is that all complex learning can be represented in combination with four components (learning tasks, supportive information, procedural information, and part-task practice) described by the model (van Merriënboer and Kester 2014). The WEKIT framework supplements the four components of the model with TMs (Fig. 2). In their turn, the TMs support specific parts of training using AR and WS. Therefore, the WEKIT framework enables instructional designers to implement 4C/ID training using AR and WS. Figure 2 lists the TMs that support each component of the 4C/ID model followed by a brief description of its components.

2.1 Learning Task

Learning tasks are authentic, whole task experiences that are provided to the apprentice in order to promote schema construction for nonrecurrent aspects of the task (van Merriënboer et al. 2002). For example, construction of schema by the apprentice can be facilitated by observation or imitation of the expert. The *learning* *tasks,* which are subtask derived from the whole complex task, are administered in an increasing complexity and its dependency on other *learning tasks*. Each *learning task* is scaffolded to reduce the support and guidance when the apprentice attains higher form of expertise. In Fig. 2, all the TMs that actually allow apprentices to perform the task by imitating or observing the expert performance are placed under this component. It should be noted that this component overlaps often with *part-task practice*, which emphasizes the repetition of *learning tasks* to enable automaticity. For the clarification sake, we will place the TMs which support repetition aspect more in the *part-task practice component.*

2.2 Supportive Information

Supportive information is the information provided to support schema construction, the learning, and the performance of nonrecurrent aspects of *learning tasks*, by supporting apprentices to deeply process the new information. The *supportive information* component aims to elaborate the whole task model by establishing nonarbitrary relationships between the new elements and what the apprentice already knows. Supportive information is usually provided before the task execution and during the task execution if needed which can be on demand or automated depending on the context. Figure 2 allocates all TMs that provide domain-level information for support as compared to procedural information provided by the *just-in-time* component.

2.3 Procedural Information

Just-in-time procedural information is the prerequisite information to the learning and performance of recurrent aspects of learning tasks in a just-in-time fashion. AR has been frequently found to be well suited to provide procedural information in recurrent task such as an assembly task. In Fig. 2, TMs that assist in providing procedural information in a just-in-time fashion have been categorized under this section.

2.4 Part-Task Practice

The last component of the 4C/ID model is the *part-task practice* which recognizes that some parts of the task are automatic and recurrent. *Part-task practice* items are provided to apprentices in order to promote rule automation for selected recurrent aspects of the complex task by means of "strengthening", in which cognitive rules accumulate higher strength on repeated successful executions (Kirschner and van Merrienboer 2008). All TMs that facilitate repetition of *learning task* fall under this component.

The WEKIT framework was built upon the 4C/ID model as the foundation for the framework. The WEKIT framework supports the implementation of this learning methodology by collecting a pool of abstract AR- and WS-based instruction design methods which can be applied to capture expert performance for training purposes. These instructional design methods are termed as "Transfer mechanism (TM)". These TMs are units of the framework that enables customization of platforms for trainings in various domains to meet the 4C/ID specifications.

In the following section, we present the TMs used in Fig. 2 in detail. These TMs were identified from the literature studies. TMs mentioned here are not an absolute list. New TMs can be added if they meet the definition. Furthermore, as technology matures, new TMs are bound to be identified.

3 Transfer Mechanisms (TM)

The WEKIT framework is designed to be flexible enough to be used in different tasks. It manages to achieve this complex goal by building itself upon a pool of TMs. TMs are learning design methods that leverage on the expert performance to support expertise development using AR and WS. The term "transfer" is not meant to be taken in a literal meaning. Transferring knowledge as packets from brain to brain is not what we aim to achieve. Rather the word signifies the concept of capturing the observable and measurable aspects of expert performance and using them to train apprentices (Limbu et al. 2018b). We also do not claim to capture or explicate expertise, which is a complex notion in itself. By capturing relevant and measurable aspects of expert performance, we aim to support the development of expertise in the apprentices.

TMs are abstract from the domain, and other factors such as the particular AR hardware and vendor sensors. The majority of TMs were extracted from earlier literature by conducting a review of recent studies that exploited AR and WS for training (Limbu et al. 2018a). We identified three general characteristics of TMs based on our observation of the implementation of TMs which are given below (Table 1). Each TM is characterized by a description that answers questions such as: "What is the type of skill being trained?" The other characteristics include requirements for recording, such as hardware and software and requirements, and for reenacting by the apprentice which may include WS. Some of the TMs identified have been presented in Table 2.

Table 1 Transfer mechanism characteristics

Description:	
How can the features be described?	
What skills are being addressed?	
Methods for capture: How is the mechanism enabled during the recording? What types of sensors are required?	**Methods for enactment:** Which conditions need to be met to allow this feature to be present? Which interaction means does the learner have? What type of sensor/display technology does the learner require? How is this feature enabled by/for the learner?

Table 2 TMs which uses expert demonstration

Description	Capture methods	Reenactment methods
TM 01: Augmented paths		
Augmenting virtual path atop the physical world in a way which allows the trainee to guide his/her motion with precision	Motion sensors and depth cameras Tracking of positional data	Visualizing guidance paths using AR Providing haptic or visual feedback based expert performance data
TM 02: Augmented mirrors		
Augmented display where trainees can track their body postures	Tracking of postures Posture sensors such as infrared camera and infrared cameras	Large display where the trainee can see himself/herself Posture tracker to provide feedback
TM 03: Directed focus		
Visual pointer for relevant objects outside the visual area of the trainee	Eye tracker and video recording Task analysis for pointing to the next location	Eye tracker for formative feedback AR display for feedback
TM 04: Point-of-view video		
Provides expert point-of-view video which may provide perspectives not available in a third person	Head-mounted high-definition video recording Zoom capabilities in the camera	Interaction mechanisms to display the video Possibility to zoom into the recordings
TM 05: Annotations		
Allow a physical object to be annotated by the expert during task execution (similar to sticky notes but with more modalities)	Methods to tag media into physical object Manual annotation or done by expert on the fly	AR display mechanism to read the annotations Mechanism for unobtrusive playback of information

	Attributes of an expert			
Transfer mechanisms	Motor skills	Cognitive skills	Collaborative skills	Perceptual skills
Learning task				
TM 01: Augmented path	✔			
TM 02: Augmented mirror	✔	✔		
TM 11: Interactive virtual objects	✔	✔	✔	
TM 17: Mobile control				
Supportive information				
TM 04: POV videos	✔	✔	✔	✔
TM 05: Annotation		✔		✔
TM 06: Cues & clues		✔		✔
TM 09: Contextual information	✔	✔	✔	✔
TM 10: 3D models & animation		✔		
TM 13: X-ray vision	✔	✔	✔	✔
Procedural information				
TM 03: Directed Focus		✔		
TM 06: Highlight Objects		✔		✔
TM 08: Object enrichment		✔		✔
TM 12: Haptic feedback	✔	✔		✔
TM 16: Formative feedback	✔	✔		✔
Part task practice				
TM 17: Ghost track	✔	✔		
TM 18: Summative feedback	✔	✔		

Fig. 3 Mapping of TMs with skills that can be trained

3.1 Demonstration of the Task

3.2 Modeling of the Expert

In addition to the TMs identified out of the literature, three other TMs were derived via other means such as interview with domain experts, trainers, and community participation. These TMs while not evident in the literature have been highly regarded by the experts and are listed below. These TMs do not require experts to be implemented.

In conclusion, the list of TMs we have identified through various methods (Limbu et al. 2018b) is outlined above along with their characteristics. The first group includes TMs that require expert to demonstrate a task which allows sensors to capture his/her performance. The second group includes TMs that modeled the expert using various manual task analysis methods. The list is not exhaustive and will only grow as technology improves. What the framework offers is the insight on how to use these TMs to capture expert performance for training. In the following section, we provide a guideline with example on how to operationalize the framework.

4 Operationalization of the Framework

The WEKIT framework provides flexibility to adopt the WEKIT training approach to various training domains. The TMs enables the trainer to select a proper set of TMs for the current task being trained. The selection of the TMs is based on the task attributes identified via extensive task analysis of the task to be performed. To facilitate the transition from task analysis to the WEKIT platform, TMs have been categorized according to the skills which the authors of the original literature aimed to train using the TM (Limbu et al. 2018a, b). The figure below provides classification of the TMs with the attributes (Fig. 3).

Figure 3 assists the system designers and trainers to select the best set of TMs for their use-case. Once the TMs are selected, the information in Tables 2, 3, and 4 can assist them to implement the system. However, before all this is done, the use-case must be analyzed to extract important attributes of the task. This can be done with the help of task analysis or a domain expert. The task can then be structured according to the frameworks 4C/ID approach for training. The list of steps or guidelines is provided in the following section.

4.1 Guidelines/Steps to Implementing the Framework

The framework is designed to be abstract from the domain of application. Thus, it is crucial to perform task analysis of the task to be trained by involving an expert of the domain. Task analysis can be done using interviews or other methods. Below, we provide a set of guidelines to assist in implementing the framework.

1. Design learning task: Break the complex task into a set of subtask and determine the performance attributes such as mentioned in Fig. 2, for each subtask. A subtask is a fundamental task that constitutes the whole complex task and can

Table 3 TMs which uses expert modeling

Description	Capture methods	Enactment methods
TM 06: Highlight object of interest		
Highlight physical objects in the visual area indicating to the trainee that the expert marked it as an object of interest	Eye tracker and video recording Record gaze behavior of the expert Manual tagging of the physical object as relevant	AR display for interventions
TM 07: Cues and clues		
Cues and clues are pivots that trigger solution search. They can be in the form of image or audio. They should represent the solution with a single annotation	Task analysis Mechanism to allow content creation to be used for clues and cues	AR displays the clues anchored to the physical object Additional help when requested
TM 08: Object enrichment		
Virtually amplify the effect of the process to enable trainees to understand the consequences of certain events or actions in the process which may be too subtle to notice	Task analysis	Mechanism such as animations or interventions to make the effect more observable
TM 09: Contextual information		
Provide information about the process that is frequently changing but is important for performance	Task analysis to know where knowledge of the process is important	Method to know when and where to provide the information Mechanism to provide the information to the trainee
TM 10: 3D models and animation		
3d models and animations assist in easy interpretation of complex models and phenomena which require high spatial processing ability	3D objects and animation where required Mechanism to be anchored to real world by the expert	AR display for the 3d models Interaction mechanisms using sensors to
TM 11: Interactive virtual objects		

Interactable virtual objects to practice with physical interactions relying on the 3d models and animation	Interactive 3D objects and animation where required Task analysis to determine the level of interactivity	Sensors for motion recording
TM 12: Haptic feedback		
Lightweight force feedback for perception and manipulation of authentic objects by means of haptic sensor, to provide feedback and guidance	Fine motor and motion tracking Task analysis to define criteria for errorless operation	Fine motor and motion tracking Rotatory directional motors to provide haptic feedback
TM 13: X-ray vision		
Visualizing objects and processes that are hidden behind physical surfaces and invisible to the eye for enhanced understanding	Task analysis needed to simulate the process being visualized with accurate results	Visualization of the phenomena atop the physical object Object recognition
TM 14: Summative feedback		
Summative feedback is a versatile TM that is provided at the end of each practice session. It should allow reflection on the current performance	Mechanism to infer mistakes in process based on expert data Track the attributes on which the performance is judged	Mechanism to assess the overall performance
TM 15: Tele-assistance		
In instances where a remote expert is needed, it acts as an instant communication channel without having to divert from the workflow		Scaffolding may be required to reduce over-reliance on the expert Communication channel between the expert and the trainee
TM 16: Formative feedback		
Formative feedback is any lightweight feedback that can be provided by sensors and AR. It could be provided in visual, auditory, or haptic form and should assist in conveying the procedural information	Recording of any relevant sensor data in a meaningful manner such that it can be used for comparison with incoming stream of data	Measure of trainee performance based on attributes

Table 4 TMs which do not rely on expert

Description	Capture methods	Enactment methods
TM 17: Ghost track		
Allows visualization of the whole-body movement of the expert or the earlier recording of the trainees themselves for imitation and reflection	Sensors to capture the whole-body movements Recording of results of the action performed by the expert	Visualization mechanisms Tracking of current state for feedback and evaluation
TM 18: Mobile control		
Allows execution/visualization of remote action or controls which would otherwise require leaving the current workplace	Task analysis to determine what actions and outputs are relevant Implementation to control devices remotely	Interaction mechanism Implementation to control devices in mobile manner

represent a skill. Subtasks may be routine or nonroutine. Routine task may benefit from TMs in learning task category such as interactive virtual objects; however, authentic task should be preferred where possible. IT may be supplemented by TMs in part-task section such as ghost track for quick progress. Nonroutine tasks are best left to authentic scenarios as they are better learnt in this manner.

2. Sequence the task: As complex task usually constitutes of more than one subtask, it should be ordered in progression of increasing difficulty. However, the sequence of task should support variability of practice for better learning (van Merriënboer et al. 2002). It should be projected into the learning plan that when the apprentice finishes the last task in the list he/she would have mastered the task.
3. Determine performance objectives: Criteria for allowing the apprentice to progress to the next subtask should be outlined. This also helps in focusing the type of feedback that can be provided.
4. Design supportive information: Information that help apprentices perform the nonrecurrent aspects of the subtask are determined. This step should generate contents that the expert will not be able to create or overlook during the recording of expert performance as nonrecurrent task may not occur. Supportive information can be provided using one of the TMs in the supportive information category, depending on the nature of information. Supportive information is usually only provided when requested so as not to overcrowd the AR vision of the apprentice.
5. Record expert performance: Based on the subtask and its attributes, proper set of TMs from the learning task category is selected. Each TM consists of set of recording requirements which should be met. The expert proceeds after wearing all the sensors and beings to demonstrate the subtask. The sensor records all the information and generates the learning content which supports the procedural task. It should be noted, when recurrent tasks are practiced, procedural information should be scaffolded. Procedural information should be provided only when needed or requested during the practice.

6. Train in the same/similar environment: It is crucial that reenactment of the learning task is done in the same or closely similar environment. Technical requirements aside, it also helps in learning of the task by the apprentice without any overhead load.
7. Follow through reflection: The system can provide feedback on procedural task, but it does not replace the expert. Providing the expert with logged data of apprentices, performance in a simple readable format will facilitate the learning process.

5 Operationalization Example

This section is meant to provide an overview of how the framework is intended to be operationalized at the current state. We will present a use-case scenario from the perspective of the framework as an example. The complex task of "preflight inspection" task was broken into ten subtasks after performing a through task analysis. In the first subtask, "ensuring that the baggage compartment is secured," task analysis performed revealed a set of attributes which will lead to proper selection of TMs.

5.1 Task Types

Perceptual ability is required in the first subtask of the preflight inspection task to be able to detect errors by means of observation. Similarly, high memory is also required to remember all the specifications regarding the task to be performed. In addition, in case of error detection, the technician is required to be able to cognitively analyze the situation. Experts also mentioned technicians are usually put through long hours resulting in fatigue. This may cause the technician to overlook details, and thus they must be self-aware of their current state and their surroundings to avoid the risk associated with the task.

5.2 Transfer Mechanisms

Based on the task types directed focus, TM04 was used to train the perception of the trainer. Contextual information and think-aloud protocol were implemented to assist with memory. A checklist of the task needed to perform was provided for supporting the apprentice cognitively. Self-awareness was implemented with the help of biosensors and other sensors in the WEKIT prototype during the trial but is not accepted as TM as it does not involve recording of the expert data. TMs such as TM16 may be selected based on expert's opinion.

5.3 Capture

Each TM possesses a set of recording requirements. After ensuring that all recording requirements are met, the expert will record the procedure ensuring that all the relevant information required for the reenactment of the TMs by the apprentice are recorded. Following a successful capture of data, the apprentice, with all the relevant information required to perform the task, may initiate practice. Some information may not be available through the expert. Such information must be identified through the task analysis or through collective analysis of the sensor reading.

5.4 Reenactment

The apprentice uses AR glasses and sensors which are used to project the captured data along with time and space. Depending on the set of reenactment requirements from the task types and TMs, proper sensor setup is selected to track the apprentice performance. TMs such as TM16 will provide lightweight feedback by using sensor readings.

5.5 Reflection

By comparing the expert performance with the apprentice performance, summative feedback may be provided. Comparison will be done between the current performance and earlier performance to facilitate self-reflection. The export will use the apprentice performance record to provide qualitative feedback.

6 Conclusions

The WEKIT framework attempts to provide a methodological approach to a newly emerging method of instruction using AR and sensors. With the technology rapidly developing, there is a need to formalize and explore methods and design for effective implementation of such technologies in learning context. AR and sensors are applicable in various domains and thus, with our framework approach, we defined an abstract methodology of designing training systems for vocational skill-based learning. The framework manages to utilize the full potential of the technology while being able to stay abstract from the tools used to perform the task. Similarly, the framework defines guidelines based on 4C/ID to ensure that the experts are being utilized to the full potential without compromising the training of the apprentice.

Eventually, the work done so far has presented potential and opportunities for further development and research. Even though several milestones have been met in the development of the framework, limitations exist. The system, with the current technological and research limitations, will not be a substitute for the expert. The framework itself is designed to be a support for training where experts as resources are limited. The need to perform an extensive task analysis on the domain also exists. There is no evidence of explicating expertise and we do not claim to do so. While explicating the tacit knowledge is possible by rigorous manual means, by nature it cannot be done unobtrusively. Instead, WEKIT will leverage on the performance metrics of the expert and visible attributes of expert performance to support the expertise development in the apprentice. The work on the framework is still ongoing. The list of TMs is not exhaustive and will be updated as new findings and technology are revealed. TMs and task types will be more clearly defined to make the framework more concrete to meet 4C/ID specifications.

While the work is still in progress, many reflections have been made in the project life span. The proposed framework is effective for apprentices who are novice and need guidance at every step. Scaffolding as proposed by 4C/ID model may be applied in future practice sessions to help apprentices' transition. However, apprentices at higher level of expertise learn differently requiring more cognitive aspects. The proposed framework relies on expertise demonstration for capturing data. Sensors are incapable of explicating cognitive expertise and these needs to be manually explicated. Similarly, many times the captured data needs to be manually tagged by the expert or algorithms specific to the domain is required to make use of the data. Therefore, we recommend using the model in earlier phases of learning to quickly attain a certain level of expertise and transition into more self-monitored learning, if an expert is not available.

In conclusion, the WEKIT framework manages to facilitate training in skill-based learning, where apprenticeship is dominant. For example, it can be used to design systems for training calligraphy by recording the expert's calligraphy data. AR and WS systems designed with the framework will be able to address the shortage of experts and enable efficient attainment of expertise. The framework also assists in the design of the AR- and WS-based learning systems for technology-enhanced learning with expert performance data.

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Learning Manual Skills with Smart Wearables

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1 Introduction

While the teaching of theoretical knowledge through e-learning has been thriving in the form of massive open online courses (MOOCs), one piece is still missing in the complex puzzle of ubiquitous online education: training which requires learning of physical and, more specifically, manual tasks such as crafts, arts, or other related skills. The Australian Master OHS and Environment Guide sees manual and physical tasks as identical (Australian Master OHS and Environment Guide 2007); thus, in the following text, we will use only the term manual task. Currently, manual tasks education is either primarily based on the direct supervision and feedback of the teacher as an independent observer or on self-assessment (Fig. 1) (Kovacs 1997). Students use this feedback to improve their knowledge on the results of their acting and adjust their motor act accordingly. While in the traditional approach to theoretical education, feedback can be given based on standardized tests or questionnaires and can therefore be fairly easily automatized

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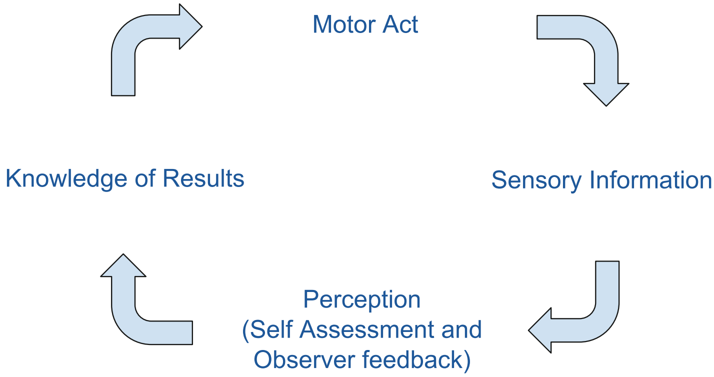

Fig. 1 Learning process of psychomotor skills (Kovacs 1997)

for e-learning purposes, manual tasks have to be addressed in a novel way: new means of quantifying motor skills are needed to provide an automated observer that gives feedback to the student.

Although this problem has been solved for virtual reality (VR) environments using haptic sensors, these devices have their drawbacks. Haptic sensors consist of a mounted handle that is equipped with sensors and actuators. Thereby, resistance or force of a virtual tool can be simulated mechanically. Haptic sensors play a particularly important role in domains like surgery, where the learning processes can be highly risky and expensive (Escobar-Castillejos et al. 2016). In combination with VR technology, haptic simulators may provide a very realistic learning experience. Although the development of wearable haptic sensors is ongoing (Pacchierotti et al. 2017), current systems are usually quite large in size and weight, and straightforward transferability toward wearable technologies is limited.

Alternatives to haptic sensors are wearable devices. While recent developments of consumer-grade wearable sensors opened and keep opening many new possibilities, it is not to be expected for, e.g., classical ballet schools to offer fully online alternatives in the nearest future. Yet, many promising first steps have already been made for relatively simple manual tasks. In this chapter, we provide an overview of the current state of art regarding computer-based support for manual tasks training, including both didactic and technological methodology as well as a sensors overview. A particular type of solution based on gesture recognition with a wearable armband will be explained in more details in order to illustrate the computational approach.

2 Quantification Approaches Toward Manual Tasks

The quantification of the student's task performance is a primary concern of developers of e-learning platforms for manual tasks. It is important for assessing performance both during teaching for feedback and during examinations. In order to describe knowledge about the outcome of the task, we have to find a way of transforming the performance into a set of numbers, which in turn can be compared to a standardized benchmark, for example, a performance recorded by a professional.

Traditional quantification approaches toward e-learning of manual tasks without sensory support are applied in industrial applications. Here, an efficient and safe task execution is of utmost importance. The widely applied theories of business process flow (Anupindi et al. 1999) and ergonomics (Grandjean and Kroemer 1997) provide interesting insights into quantification of performance.

Types of quantification can be divided into three main clusters or aspects:

1. **Final outcome quantification** The outcome of the measured activity needs to be clearly defined. For example, if the desired outcome is an assembled machine part, then the quantification can be done by computing the number of correctly and erroneously assembled parts and comparing these numbers to a certain defined standard.
2. **Procedure execution quantification** If the task of interest consists of several separate parts, then it is possible to assess the correct flow execution by, for example, using time stamps of the particular steps and analyzing the correctness of the order. Formula 1 pit stops may serve as an example of a well-developed and well-executed procedure.
3. **Task execution quantification** This type of quantification is relatively difficult to achieve. Typically, a teacher or a supervisor observes the execution of the task and expresses a subjective opinion, which might be translated to digits or grades. For example, after having received training on the safe lifting of heavy objects, an instructor may ask the trainee to perform such a lifting. During the performance, the instructor is filling a checklist and marks all correctly and incorrectly performed movements.

While the quantification in the first two cases is being efficiently done in the industrial setup, the third objective measurement is not common and has a large potential in improving e-learning approaches through generating a more detailed feedback. Therefore, it will be the focus of our further overview. We will explore measurement options provided by consumer-grade wearable sensors, present chosen solutions, and discuss their advantages and disadvantages. Since a full task can be complex, it may be beneficial to split it into further smaller sub-parts. Therefore, we will define separate levels of granularity within a task that can be quantified: gestures, movements, and muscular activity. A gesture is a set of movements, and a movement is the result of several muscular activities (Fig. 2). We define a task as the correct execution of one or several gestures. For example, in clinical hand hygiene, six gestures are performed to disinfect the hands, each of which is created from repetitive movements of the fingers and hands (WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge Clean Care Is Safer Care 2009).

In what is following, we will introduce a number of exemplary projects, which are either directly focused on e-learning of manual tasks with wearable sensors

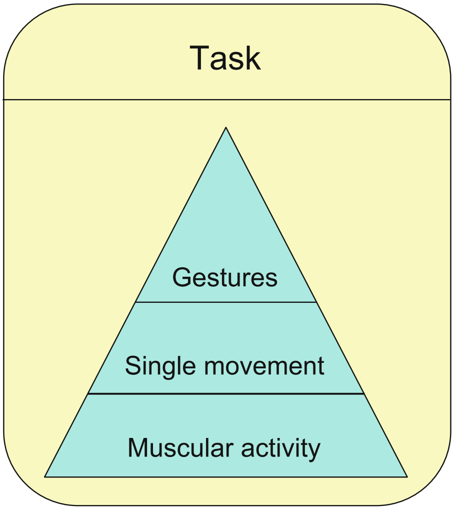

Fig. 2 Granulation within a single task: gesture, single movement within the gesture, and muscular activity

or can be classified as very close in spirit and are building the foundation for the domain of our interest. Our aim is to show the variety and potential of different approaches.

3 Wearable Sensors for Learning of Manual Skills

In essence, the quantification of manual tasks may be provided by a variety of sensors. In recent decades, the market of inexpensive consumer-grade wearable sensors grew massively, thereby enabling new opportunities for assessing human activities or quantifying manual skills.

In one recent market research report (Wearable Sensors 2018–2028: Technologies, Markets and Players 2017), wearable sensors are subdivided into three major categories:

- Wearable sensors which existed before the term "wearables" was established (e.g., microphones in hearing aids).
- "Made-wearable" sensors adapted for wearable devices (e.g., inertial measurement units, IMU).
- "Made-for-wearable" sensors originally developed for wearable devices (e.g., optical heart rate monitor, HRM).

The same report describes 21 types of sensors divided into 9 major groups:

IMU, optical sensors (HRM, cameras, 3D), electrodes (electroencephalogram (EEG), electromyogram (EMG), galvanic skin response (GSR), electronic pill ("Proteus Digital Health" n.d.)), force/stretch/pressure (haptic) sensors, temperature, gas and chemical sensors, microphones, and GPS sensors.

Training of manual tasks has a lot in common with the problem of motion and activity recognition. Therefore, unsurprisingly, many proposed solutions use different combinations of cameras, IMUs, and haptic sensors.

4 Feedback on the Procedure, Task, or Outcome Level

4.1 Virtual and Augmented Reality

It is important to distinguish between the different types of information flow that accompany the learning process of a manual skill, procedure, or desired outcome. Certain knowledge can be transferred relatively easily with the help of textual, visual, or auditory information. For instance, standard training on safe behavior in the working environment or on operating a new machine is traditionally done by human instructors with the help of presentations or by providing the employee with necessary documentation. In the last years, novel and more effective approaches to such trainings were developed through virtual reality (VR) or augmented reality (AR).

In VR, the user is placed in a virtual environment that mimics part of the real world. Here, a full virtual representation of the training environment is needed, which allows the user to simulate certain tasks. Usually, virtual reality glasses are used to immerse the user by blocking outside stimuli and allowing a full three-dimensional experience of the environment. In contrast, AR uses smartphones, tablets, head-up displays, or special glasses to overlay the real world with additional information. For example, it is possible to highlight a specific tool that is needed next or give additional information on a certain object in the user's view. In these settings, a task can be performed virtually (by clicking a "button"), and the outcome or performance of a procedure can be evaluated.

BlueTea, a Dutch company specialized in AR and VR, offers training solutions based on augmented and virtual reality. VR is used as a safe and cheap means to train an employee on a certain task to avoid working hazards or to operate new machinery. AR is used to support the experience with a physical device. Before executing a step in the real world, employees may repeatedly train their skills with a simulated version (BlueTea n.d.). As an example, a hospital insulin pump can be configured by medical professionals in a virtual reality context (Fig. 3a). Alternatively, by utilizing AR, a physical pump can be filmed with a tablet, and certain operating procedures can be tried on a simulated virtual overlay on top of the image of the actual pump (Fig. 3b).

A similar approach is taken by Nazir et al. (2014). Here, virtual reality is used to train operators in industrial plants. The simulation helps the employees to understand the current equipment and environment conditions and aims into minimizing the number of human errors. The authors studied the differences in performance between two groups of participants. Both groups were trained

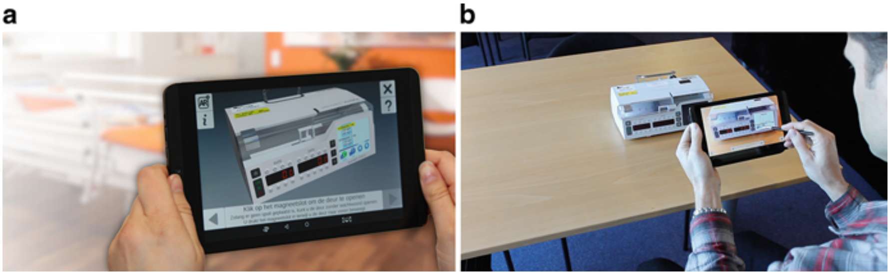

Fig. 3 e-Learning platform for training of insulin pump usage (BlueTea n.d.). (**a**) VR setup for theoretical training. (**b**) AR setup for practical training. (Figures are published with permission and knowledge of BlueTea)

within the immersive virtual environment (IVE). The first group was trained with the support of the trainer, while the second group obtained training through an automated guidance. The first group performed better in terms of accuracy, process understanding, identification skill, and lower help requirements, while the second one performed better in terms of speed. No control group trained without IVE was formed.

As a matter of fact, few results can be found on the evaluation of VR usage in e-learning, and evaluation methodology is still in development (Attwell 2006; Roussos 1997). For instance, Gurusamy et al. (2008) published a systematic review where the authors compared VR solutions in laparoscopic surgical training to video training and conclude that VR might achieve better results in certain aspects, such as accuracy of training or error reduction. Merchant et al. (2014) explored the influence of VR in a broader sense in K-12 and higher education. This paper concludes the overall effectiveness of VR for the learning outcome, with games giving better results than simulations and virtual worlds.

Virtual and augmented reality technologies open many learning opportunities. The possibility of training in a safe environment is of particular importance. The main focus of most applications lies in the evaluation of the processes and tasks executions. With sufficient training time, the simulations may also form the desirable habits and routines. Without additional sensors, the human interaction with these technologies is typically done through controllers such as joysticks or consoles. Therefore, feedback on a deeper level (gestures, movements, muscular activity) is not possible unless additional sensors are employed.

4.2 Impact on External Objects

Another way of assessing task-level performance is to measure the impact the performed movement had on external objects. This approach may be used in situations when the result of an interaction with an external object is easier to understand, quantify, and evaluate than the gesture or movement itself is.

For instance, Murphy et al. (2000) report that an erroneous usage of tools, such as pliers and de-boning knife by industry workers, may cause cumulative traumas of the upper extremities. In order to investigate how the forces are applied in different situations, strain gauge sensors are placed directly on the tools, which allow to quantify the forces acting between a hand and a tool. In a follow-up paper, McGorry et al. (2000) used a sensor-equipped knife to show a strong relationship between the material which is being cut, the used cutting technique, and the resulting average peak torque levels.

This interesting solution did not seem to gain wide popularity in the business context yet, although the recent sensor developments probably make the introduction of "smart pliers" just a matter of time.

In sports, however, this approach seems to already work really well. Multiple sport objects have been recently equipped with sensors in order to improve the performance of the players. Swingtracker by Diamond Kinetics (Diamond Kinetics – Engineering Better Players n.d.) is a sensor based on an inertial measurement unit (IMU), which can be attached to a baseball bat in order to analyze its movements. Another example is MiCoach (Adidas miCoach Smart Soccer Ball – White | adidas US n.d.): a smart soccer ball by Adidas, made with a similar concept in mind.

5 Quantification of Movements and Gestures

The following examples show different approaches toward the sensor-based quantification of gestures or movements without touching the lowest level of manual tasks, the muscle activity. Thereby, more detailed feedback than a "correct" or "wrong" message can be given on tasks, for example, which movement or gesture was missing or improperly executed.

5.1 Biomechanical Models

Ergonomics, already mentioned earlier, is a discipline concerned with design of products or processes, to optimize their interaction with humans. Applied to manual tasks in industry, ergonomics operates multiple measurements standards, such as Rapid Upper Limb Assessment (RULA, McAtamney and Nigel Corlett 1993). RULA provides the scoring system for a variety of upper body motions, which can be used to assess the hazards and risks of a particular working task.

This standard was used in work of Vignais et al. (2013) to design a real-time sensor-based ergonomic assessment system. The authors used seven IMU units (upper arms, forearms, head, chest, pelvis) and two goniometers (sensors measuring joints angle) to build a biomechanical model of the worker. While a task is being executed, the model is compared to RULA standards and generates an according score in real time. The feedback on the global score is provided via audio signal to alert the user. The local score is visualized on a virtual mannequin and presented via a see-through head-mounted display. The evaluation in simulated industrial environment indicated that the group of subjects provided with such feedback performed better on overall RULA scores.

5.2 Biofeedback for Rehabilitation

Physical rehabilitation often faces situations when a correct movement execution needs to be trained. Such training is done under the specialists' supervision and is therefore costly. Thus, automatized solutions are on high demand. The Valedo by Hocoma (Valedo®Motion n.d.) is a lower back pain therapy platform, which helps to perform back exercise movements in a correct way, while providing a stimulating environment for the training. The device employs the concept of biofeedback (Biofeedback – About – Mayo Clinic n.d.) in a setup where a video game is being controlled by a user through a set of sensors attached to the user's back. To achieve scores in the game, the patient needs to perform the movements set by the therapeutic goal.

Another approach to rehabilitation training with wearables was developed by Neofect (RAPAEL Smart Glove | NEOFECT n.d.). The RAPAEL Smart Glove (Fig. 4) is aimed to assist in hand rehabilitation, particularly of stroke survivors. The device is reported to have an IMU unit combined with five variable resistors

Fig. 4 Rapael Smart Glove: a wearable for hand rehabilitation. (The figure is published with knowledge and permission of Neofect)

employed as bending sensors. The rehabilitation process, similarly to the previous project, is based on controlling a video game with the wearable. Here, however, more subtle movements of the forearm are of interest. A clinical study on 46 stroke patients (Shin et al. 2016) showed promising results on 3 types of standard tests for assessment of hand functionality.

More applications of wearables in rehabilitation can be found in the review paper of Patel et al. (2012).

5.3 Cameras and Optical Systems

Cameras and optical systems are often used for gesture recognition. In a situation when a clear view field can be arranged, promising results have been obtained.

In wearable enhanced learning, cameras are often used as a substitution for the human observer. For example, hospital hand hygiene training is traditionally done under the supervision of a teacher. Higgins and Hannan (2013) describe a hand hygiene training system called SureWash. It consists of a semimobile unit with a video camera and a monitor. The student is guided through the learning procedure and then evaluated via a gesture recognition algorithm run on the video data. The process has a form of a computer game to increase the engagement of the student. The authors report a significant improvement of compliance to the hospital hygiene rules.

Other motion sensing devices such as Microsoft Kinect or Leap Motion gained popularity in recent years. These devices are developed with motion recognition in mind. Digital cameras are still playing a major role here but received an important augmentation by infrared light sources and sensors, which allow for depth data collection and therefore enable 3D computer vision. Due to the good resulting quality of motion recognition, these sensing devices have already been considered in a number of wearable enhanced learning projects. Saha (2013) developed a methodology for recognition of dancing poses for standardized dancing types, such as classical ballet with Microsoft Kinect. Although the thesis is mainly focused on the technical solution, the work is done with wearable enhanced learning in mind and illustrates the increasing variety of the future possibilities.

Ebner and Spot (2016) report using Leap Motion device as a controller for an educative video game where children can practice mathematical tasks. The robotic hand controlled through Leap Motion (Fig. 5) is expected to destroy a balloon with the correct answer. Preliminarily tested on 12 children, the solution showed good results in the user acceptance. Potential problems, such as switching the focus from the mathematical task to the exploration of the other possibilities, were discussed.

Motion sensing devices can be also used in cooperation with other sensors.

For instance, Chun et al. (2014) combined in their work Microsoft Kinect with two IMUs to provide learning feedback to golf players during uncocking motion training. The uncocking motion is a part of a golf swing. To capture the wrist motion, one wearable device with an IMU is placed on the player's forearm and another one

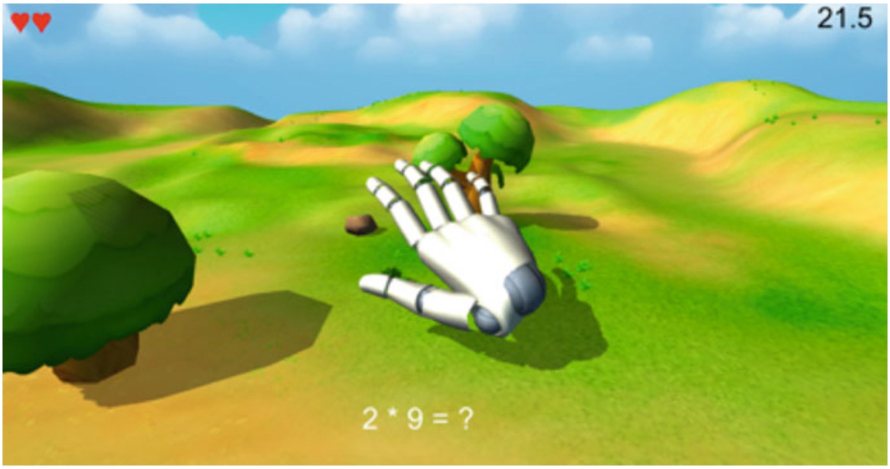

Fig. 5 Leap Motion – based game for basic mathematical training (Ebner and Spot 2016). (Reprinted by permission of the publisher)

on the golf club. The collected data is segmented into sub-movements, and these are compared to the existing research on uncocking motion. In this setup, Microsoft Kinect is used to record the movements, so that the feedback based on scoring from IMU data can be accompanied by the video data. Verbal feedback is additionally generated, based on the specialists' comments stored in the system. Let us notice that wearable IMUs formed the basis of this project, while a stationary Kinect was only needed to enrich the feedback.

In principle, optical systems can be used for gesture recognition in a wearable form.

Baraldi et al. (2015) used a head-mounted video camera to recognize own gestures of museum visitors. A set of gestures is used to customize the access to museum's knowledge database.

Neto et al. (2017) used Microsoft Kinect as a wearable sensor to support blind and vision-impaired people. Their system is able to recognize people in the vicinity of the wearer and to project personalized sounds into the virtual sonar space, with the position corresponding to the actual 3D position.

Optical systems offer a wide range of possibilities for gesture and motion recognition. However, the quality of wearable versions might be lower than those of stationary, and in any case an unobstructed view on the objects of interest is necessary. That makes these sensors difficult to use in situations when a student is interacting with other objects, like it is happening in crafts. Additionally, image processing often requires extensive computations which might not be available in a wearable device or smartphone.

5.4 Summary

In this subsection we reviewed a number of training solutions based on motion and gesture recognition. A large variety of educational goals can be directly reached with the described technologies. Furthermore, continuous usability improvements can be expected as a result of e-textiles and vision-based wearables development. Nevertheless, with the use of such sensors certain limitations in fine movement recognition and in assessing the performance during interaction with external subjects will always be present. These need to be addressed by considering different types of sensors in order to access a desired level of movement quantification.

6 Quantification of Muscle Activity

Assessment of muscle activity is the finest granularity of movement quantification that is not based on neural activity. While, in theory, direct measurement based on neurological processes is possible, the challenges in understanding these processes are yet to be overcome. Therefore, muscle activity is the most promising way for highly detailed movement analysis that is practically possible. Specifically, muscle activity is measured through electromyography. Electromyography (EMG) originated as a means for accessing clinically relevant data about the muscle and nerve function (Aminoff 2012). EMG can be further subdivided into surface and intramuscular types. The latter type is an invasive test, in which an electrode, often in the shape of a needle, is inserted into the muscle tissue. In contrast, surface EMG (sEMG) collects data from superficial muscles with the help of electrodes placed on the skin. While sEMG often lacks the data quality provided by intramuscular EMG, it is a safe and noninvasive measurement. Most importantly, sEMG electrodes can be designed in the form of a wearable device. For example, the Myo by Thalmic (Myo Gesture Control Armband n.d.) is a consumer-grade wearable device capable of measuring sEMG in eight locations around the forearm in addition to an IMU. This device is currently the only off-the-shelf sEMG wearable and is therefore used in all of the projects further discussed in this section.

6.1 Quantification of "Simple" Manual Task Execution with sEMG

Before tackling complicated learning tasks, setups with a limited degree of freedom should be explored. Below we present several gesture recognition solutions which perform assessment of muscle activity, which are applied to relatively simple manual task trainings. All cases have well defined and small sets of involved movements and therefore can serve as a good ground for establishing and evaluating the methodology.

Not all of the described projects are directly linked to wearable enhanced learning, but the methodology of quantification can be easily transferred to it.

6.1.1 Basketball Referee Gestures

Yeh et al. (2017) proposed a solution for automatic detection of the basketball referee gestures defined by the International Basketball Federation (commonly known as FIBA). For this purpose, 14 gestures were recorded, 5 of which are pure finger movements, and 9 of which were arm movements. The authors use a feature set which consists of two parts. The first one is based on the time series form of the sensory input. An autoregressive (AR) model of the order 4 is used as suggested by Hu and Nenov (2004). The second part used deep belief networks (DBN) to access other representative features. Several classification methods were applied to these features with support vector machines (SVM) showing the best performance. As a result, 97.9% and 90.5% recognition rates were obtained for fivefold cross-validation and leave-one-participant-out cross-validation experiments on the arm movements, respectively (Fig. 6). This example shows that sEMG solutions, and thereby the muscle activity level, are highly capable of describing or detecting certain movements or gestures.

6.1.2 WHO Handwashing Procedure Training

The World Health Organization (WHO) provides a set of rules on hospital handwashing and hand rubbing (WHO Guidelines on Hand Hygiene in Health Care: First Global Patient Safety Challenge Clean Care Is Safer Care 2009). The procedure ensures that all parts of the hand are getting cleaned and is an important part of medical hygiene policy. Typically, medical professionals receive training on hand hygiene at the beginning of their education, and the correct execution of the gestures is very soon being forgotten or ignored (Erasmus et al. 2010). In prior work (Kutafina et al. 2016), the authors propose a technical solution based on machine learning to discriminate between the six gestures defined by the WHO. In total, 17 people who were not medical professionals but received training on the correct routine execution individually performed each of the 9 gestures 3 times. Each time the gesture was executed for 5 s, and sEMG and IMU data was recorded together with a label corresponding to the executed gesture. Feature vectors were extracted directly from the raw data. Additionally, Daubechies wavelets coefficients were used as features.

Fully connected feed-forward artificial neural networks (ANN, Bishop 2006) were chosen as machine learning classifier. The parameters were optimized using a fivefold cross-validation approach.

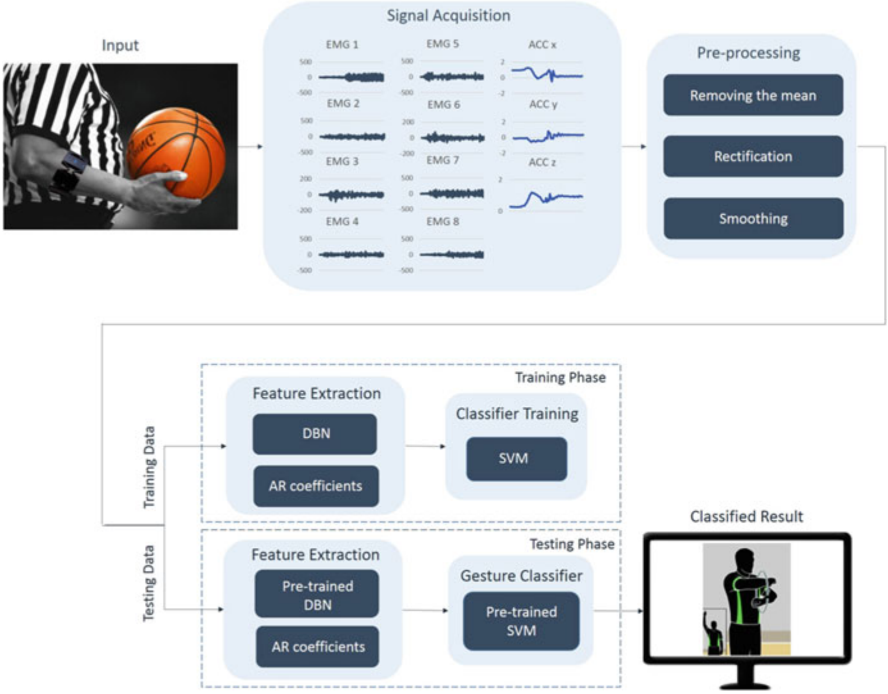

Fig. 6 Framework for basketball referee gestures recognition with surface EMG wearable. (Figure reprinted from Yeh et al. 2017 with permission)

The limited number of gestures and their defined sequence in this setup allow to make use of hidden Markov method (HMM, Rabiner 1989) as a smoothening method (Fig. 7).

The recognition rate for the particular gestures was as high as 98.30% (±1.26%), and therefore the methodology was accepted for further use. This machine learning algorithm became a basis for an Android wearable enhanced learning application IdealPure. Its goal is to coach medical students and professionals on the correct handwashing performance through gamification. It can be used with a mobile phone and a pair of Myo armbands worn on both forearms. At the time of publishing this book, IdealPure undergoes clinical trials to evaluate its effectiveness and acceptance.

6.1.3 Training of Alginate Mixing

While the previous approach is mainly focused on data analysis, the next project faces the challenges of giving real-time feedback to the user and serious gaming (Hannig et al. 2012). Mixing of alginate – a material for dental impressions – is an important skill learned in dentistry training (Frey et al. 2005). Despite the seeming simplicity of the task, the quality of the mixture strongly depends on

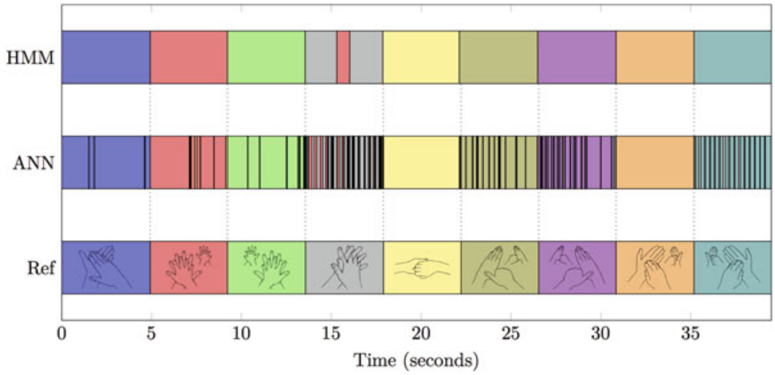

Fig. 7 A Hidden Markov Model allows to correct recognition errors made by artificial neural networks. Bottom row represents individual washing gestures, middle row the results of ANN-based recognition, and upper row the final result after HMM correction. (Reprint from Kutafina et al. 2016)

the mixing technique (McDaniel et al. 2013). A serious game called Skills-o-mat developed at RWTH Aachen University (Hannig et al. 2013) is designed to provide an encouraging and entertaining way to improve the skill of alginate mixing. The training is done by simultaneously watching an instructional video and performing the mixing. One Myo armband worn by the player sends the data to a machine learning module, which returns a real-time feedback on the performance quality (Fig. 8). The application also provides summary feedback accompanied by achieved virtual “points” and “medals.”

6.2 *Quantification of Complex Manual Task Execution*

Multiple research groups quickly noticed the potential of low-cost gesture recognition with the Myo armband. The level of technical knowledge on the data collection and processing is constantly increasing and enables the work on better and more advanced wearable enhanced learning platforms. In this section we take a look on some recent advances in gesture recognition with the Myo.

6.2.1 Feedback for Education of Physiotherapy Students

Proprioceptive neuromuscular facilitation (PNF) is a common treatment concept of physiotherapy, focused on increasing the range of motions (Hindle et al. 2012). The movements performed by therapists typically consist of several sub-movements and, unlike the WHO washing procedure or FIBA gestures described above, form a very large and highly diversified set which may include not only arm movements but also movements performed by the whole body. Jovanovic et al. developed an approach

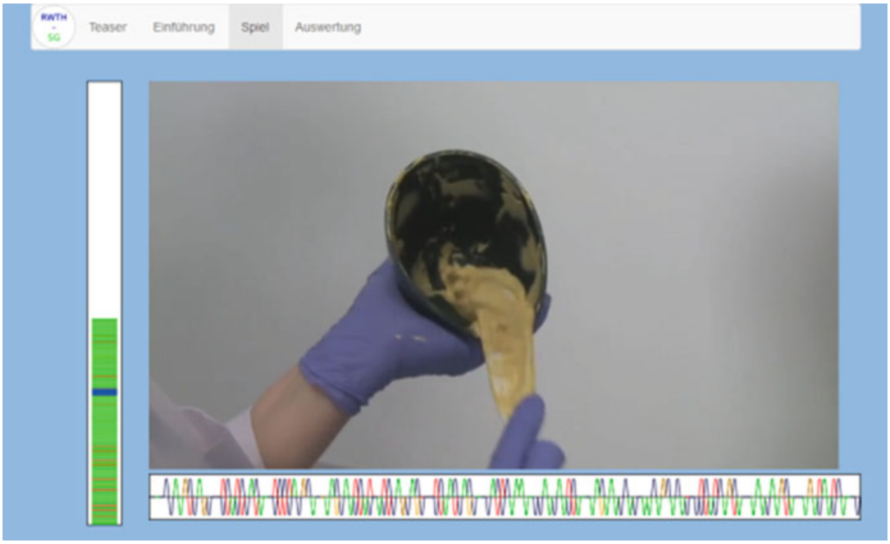

Fig. 8 Screenshot of Skills-o-mat: a serious game for alginate mixing skill training with the help of wearable surface EMG sensor

for quantification of such movements with a particular focus on providing a valuable automatic feedback in the form of a scoring for students of physiotherapy learning to perform PNF techniques (Jovanović et al. 2018). Students wear Myo devices on their left and right arms. The devices capture sEMG signals from the arm muscles, as well as acceleration, orientation, and angular velocity data, gathered by the devices' IMU. The method extracts features from the raw sensor signals and utilizes Hidden Markov Model (Rabiner 1989) to segment the particular PNF movement into sub-movements. Feedback is provided based on the data fit into the correct probability distribution in the form of an overall performance score for the entire movement. In addition, the method is also able to detect and give feedback on errors in individual sub-movements performed over time. More specifically, the authors introduce tolerance intervals for observed features in individual sub-movements and thus are able to give feedback on the performance resolved over signal feature and time (Fig. 9). Such a feedback can be further visualized with appropriate methods, in order to give a simple and understandable feedback to the student. The time and feature resolution of errors allows the algorithm to not only detect an error but even the source in time (e.g., too early/too late) and execution (e.g., wrong rotation).

6.2.2 Pottery Art Gestures

Another interesting project was described by Ververidis et al. (2016). The authors aim in preservation of immaterial heritage, such as pottery art. The proposed

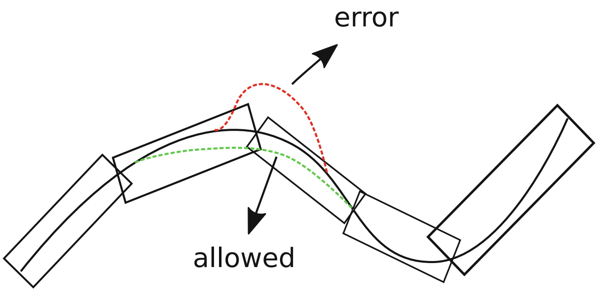

Fig. 9 Black curve represents the segmented movement, with the rectangles representing a statistical tolerance interval for the data of each segment. Green and red curves represent correspondingly a correct and erroneous movement variation

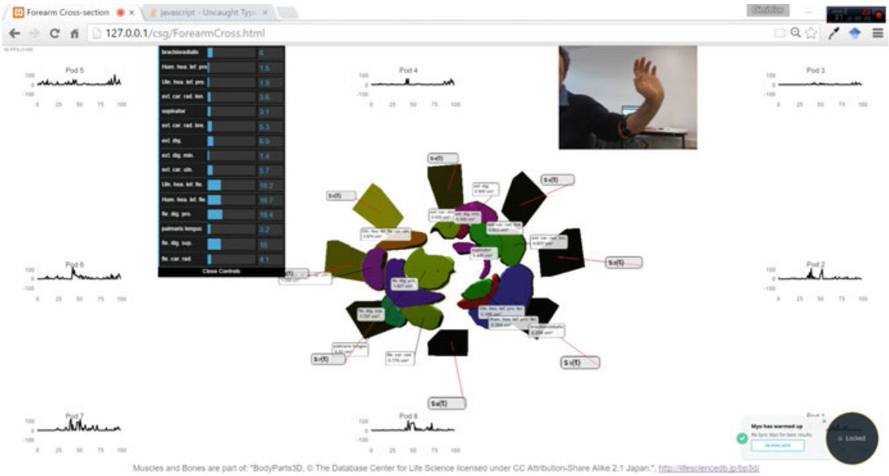

Fig. 10 A screenshot of the visualization software by Ververidis et al. (2016). In the middle of the screen, eight Myo electrodes are presented together with the relevant arm muscles (cross-sectional volume). (Created with permission from Dimitrios Ververidis n.d.)

method quantifies arm movements used in pottery and is able to capture very subtle differences. The uniqueness of the authors' approach is the focus on the forearm anatomy. The numerical features used for the gesture recognition are based on the approximated contribution of 15 individual forearm muscles. Such influence is computed based on the distance between the muscle and particular Myo electrode and the muscle volume. The authors additionally introduce a unique visualization tool, allowing to track real-time muscle activation and compare it to the EMG signal plots (Fig. 10). While wearable enhanced learning was not the primary intent of this project, the tool provides quantification and visualization which can be valuable in a variety of manual task teaching contexts.

7 Discussion

Wearable enhanced learning is a relatively novel topic. The main reason for its novelty is the fact that wearable sensors are just recently becoming comfortable, unobtrusive, and inexpensive. Solutions in wearable enhanced learning developed in the last decades now can be massively implemented with affordable high-quality sensors.

Currently, most of the computer-supported manual training on the process, outcome, and task level is done with the help of AR and VR technologies used independently or in combination with haptic simulators. While such a setup brings great benefits, particularly in medical training, there are many areas where low-cost and mobile solutions are needed since they can allow for more detailed feedback. Mobile and wearable versions of AR and VR technologies are widely present on the market, and they can often be used to show the correct task execution to the student. The main challenge therefore lies in the feedback production. The movement needs to be quantified with the help of wearable sensors, so that computer algorithms can be used to evaluate its correctness. Here, research on machine learning in motor skills in robotics can prove very useful (Peters 2007). This problem is a crossover between gesture recognition and more detailed muscle activity recognition.

sEMG- and IMU-based devices such as the Thalmic Myo have shown a great potential in filling this gap. However, further work is still needed to optimize the methodology. For instance, in the area of signal processing where a relatively low signal-to-noise ratio calls for sophisticated calibration. A deep understanding of the human musculoskeletal system and its 3D modeling may provide a better insight into the feature extraction and, again, calibration problems. Once good-quality signal is obtained and meaningful features are extracted, well-developed machine learning and statistical algorithms can be successfully employed.

However, several limitations are visible in current literature. First and foremost, validation of the proposed methods with an emphasis on the learning outcome is very limited. Most publications focus on usability or acceptability instead. In addition, the wearable device market is growing quickly, which leads to outdated methodology. This might also be a reason why only very few training solutions have been introduced to the market yet.

Other limitations in the development of wearable enhanced learning systems are related to the raw data access. Many manufacturers of good quality low-cost sensors limit this access by, for instance, using proprietary algorithms for the initial data processing. A lack of full information makes sensor validation and comparison less transparent, reproducible, and reliable.

Compatibility is another important point. Most consumer-grade wearables are meant for an independent usage. Therefore, designing an e-learning platform based on a combination of sensors requires advanced programming skills. Thus, experiments can only be conducted by experts. Some domains of research have already developed integrating software platforms, allowing to work with several wearables without diving deep into programming. For example, iMotion (iMotions:

Biometric Research, Simplified n.d.) allows to work with a number of physiological parameters such as EEG (electroencephalogram), ECG (electrocardiogram), GSR (galvanic skin response), or eye motion, collected by research- and consumer-grade devices. However, it is not aimed at wearable enhanced learning or training.

7.1 Future of the Domain

While using sensors such as sEMG armbands allows to get a good insight into the movement performance, it would be very beneficial to have a possibility to simulate real-life experiences such as force when touching a virtual object. While medical haptic simulators can do this, they lack the mobility, and the cost of such devices is high.

In the nearest future, this problem can be solved by electrical muscle stimulation (EMS) (Lopes et al. 2017; Pfeiffer and Rohs 2017). EMS is performed by external induction of muscular contraction. In order to simulate a particular sensory experience, EMS is applied to the muscles, opposite to the ones involved in the real experience. The technology can be miniaturized and incorporated into smart textiles. At the moment of writing this book chapter, we were able to find several consumer-grade devices based on EMS (NormaTec Recovery n.d.; Powerdot Smart Electric Muscle Stimulator n.d.). These devices primarily target the fitness and sports area. We believe, however, that it is just a matter of time until a large variety of muscle stimulators will be available and the new wearable enhanced learning possibilities will arise.

8 Conclusion

Computer-supported training of manual tasks is a dynamically developing area, closely following the changes on the market of wearable devices. In the last decade, impressive progress has been achieved on assessing manual tasks on different levels, particularly owing to the introduction of wearable sensors. While sensors such as IMUs were already used for some time to quantify gestures and the single movements the gestures consist of, the development of wearable sEMG sensors allowed to investigate the motion on the muscular level. The sEMG sensors allow for an even more detailed quantification and visualization of task performance. Additionally, in combination with other sensors, the setup opens a wide range of opportunities for the development e-learning.

However, for the usage of wearable devices in e-learning, better validation of long- and short-term effects on learning outcome is needed. Therefore, future work has to focus on comparing novel learning technologies to traditional teaching in repeated controlled randomized trials before widespread adoption should take place.

A very promising area of mobile wearable-supported training of manual skills is learning-on-the-job. For example, technicians would not need to know the exact layout of every machine they need to maintain but could learn specifics once they are on-site. This would allow shorter training periods or less travel costs or waiting time for specialized experts. Similarly, rarely performed tasks, for example, in medical surgery, could be practiced just in time before they would need to be performed, independently of the availability of expert supervisors.

One risk associated with this or similar approaches is the dependence on technology that is highly complex in nature. In addition, the training applications would have to ensure that no erroneous executions of tasks are trained by accident. For example, if the sensory data is not sufficient to capture a specific error, this error might not be corrected and might even be emphasized due to repeated training.

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Part V
Design of User Experience

Smart City Learning Solutions, Wearable Learning, and User Experience Design

Brenda Bannan and Jack Burbridge

1 Introduction

In the last several years, the movement toward smart cities has captivated multiple communities, organizations, and innovators from all over the world in leveraging wirelessly connected Internet of Things (IoT) wearables and other devices to attempt to improve the quality of life in cities and communities. Aligned with the evolution toward becoming a "smart" city is the quest to define what learning and design in smart cities actually involves, to include how a community may come together around a defined problem to innovate and generate solutions to improve city-based services through enhanced learning experiences of the citizens and workers who live there. The focus on enculturating multiple opportunities for innovation and a defined process to provide guidance on generating, developing, and refining smart city learning solutions incorporates many applied research and development questions and cycles. The key question for the application of a user experience-integrated design research process in the following case study was: How can ideas for smart city solutions that specifically target learning and behavior change at the city level be generated, prototyped, and tested? Additionally, we wanted to also explore the following questions: How do we advance these prototype ideas? How does UX design for wearable technology for learning differ from the process applied to other learning technology design? How do city leaders and stakeholders benefit from smart city data and services to leverage this data for learning and improvement

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of their communities? Most importantly, how does our community come together and learn through the framing of important problems and collaboratively generate targeted solutions that will solve problems in our cities and communities? This chapter attempts to address these questions through a case study example in a single city attempting to generate, design, and develop a smart city wearable learning solution prototype to improve city services leveraging a user experience design research process.

Typically, the focus of discussion related to smart cities primarily emphasizes the capabilities of new technology rather than considering the innovative capacity of the community and citizens and their valuable input in designing smart city technologies (Ratti and Claudel 2017). Recently, researchers and theorists in this area have begun to look beyond the wearable and connected devices themselves, toward the important role of identifying local problems and needs that the connected device design process could address through bottom-up design approaches which can simultaneously advance knowledge and functionality of citywide technology systems as well as the knowledge transfer and innovation among citizens (Angelidou 2017). Learning, characterized as a multifaceted reality, is often defined by the context in which it takes place, either formally or informally (Zhuang et al. 2017, UNESCO 2015), and is interpreted broadly here to mean learning that can take place anywhere, anytime from targeted feedback loops potentially enabled by a particular designed wearable solution deployed in a city services context. Learning could take place at the individual or team level in monitoring behaviors. Learning could also take place at the community or city level when citizens join together to generate and promote innovation in advancing the collective intelligence of how city systems work, function, and adapt potentially through their involvement in the co-design process of wearable learning solutions (Ratti and Claudel 2017).

Improving urban systems by employing new wireless devices and connectivity to promote the research and development of new city-based services is the current focus of the smart city movement across the world (Global City Teams Challenge 2018). Scholars from multidisciplinary fields are joining together to begin to articulate what learning may look like at a city or community level and what "smart city learning" actually may encompass (Giovannella 2014). Organizations such as the International Association of Smart Learning Environments are beginning to appear with books and publications referencing these ideas (International Conference on Smart Learning Environments 2016). Intersecting perspectives such as personalized learning within the city context (Buchem 2013) and the multiple levels and varied contexts of learning environments in smart cities (Hwang 2014, Zhuang et al. 2017) are efforts toward further defining the characteristics of these learning environments. However, the process toward becoming a "smart" city that learns and progresses from the iterative research and development efforts involving the innovation of IoT and wearable devices to solve city problems has not been fully articulated. Those involved in these efforts are often participating in co-design efforts with both stakeholders and citizens. A promising process that attempts to integrate both learning and development at a citywide level while also placing emphasis on individual citizen's perspectives and involvement is user experience (UX) design.

User experience design can incorporate investigative research cycles that may take place at the city, organization, team, and individual levels with a process-based design approach to honor cities and citizen involvement in smart citywide innovation (Rowland et al. 2015). A UX design research process was implemented in a specific case study to attempt to improve multiteam interaction, learning, and training of city-based emergency responders. This example is presented in relation to a specific city and context; however, the design research process abstracted from the effort is the focus of this chapter to move toward a process-based model that might provide enhanced guidance for communities when designing and developing wearable learning innovations at the city services level. The conclusion of the chapter presents some insights and synthesis that articulate the similarities and differences of this approach specifically for wearable technologies for learning design research in the smart cities context.

2 Case Study: Multiteam Interaction and Training of Citywide Emergency Response

Researchers and theorists have defined smart city learning environments to include diverse physical locations such as home, work, community, and museum contexts that involve a supportive digital infrastructure that adds to the ease, engagement, and effectiveness of learning no matter where it takes place that may involve informal or formal learning or both (Zhuang et al. 2017, Hwang 2014). In this case example, the specific objective was to improve learning and performance within and across multiple city teams from different organizations in varied contexts responsible for treating and transporting a patient in an emergency. To innovate toward a smart city learning solution, several of these teams participated in a live simulation training event in a real-world context from a staged car accident scene through transport of the patient 11 miles to the local hospital trauma bay (see Bannan et al., Chapter Toward Wearable Devices for Multiteam Systems Learning).

The case study specifically addressed the need for high-performance teams or coordination of multiteam systems in emergency response contexts (e.g., pre-hospital and trauma teams) in a high-fidelity real-world, live simulation. We instrumented an emergency response scenario with Internet-enabled sensor devices in our community and collected near real-time data related to each individual emergency response professional's behavior on multiple teams tracking their proximity to the patient from a car accident scene, through transport in a medic unit to the hospital trauma bay. The visualization of this data in the simulation debrief where research indicates that the most learning occurs could provide a new window into performance within and across teams (e.g., such as in the hand-off of the patient between teams) to potentially improve team learning and reflection in the simulation debriefing session (Haji et al. 2014). The ultimate goal was to improve learning and, subsequently, patient care, through informing the multiple constituent teams' performance in the multiteam system during the debriefing session immediately following the simulation.

Learning, as a multifaceted phenomenon, was addressed in this case study through the consideration of applied learning experiences and working as a team as critical components of an emergency response system. Simulation-based training can reduce errors and promote performance improvement, but it is only as effective as the learning that results with research indicating that significant learning can occur concluding a live simulation in the debriefing process (Haji et al. 2014). Facilitating reflection on action through observation of team performance in a medical simulation promotes a complex experiential learning cycle that may encourage active reflection by individuals and teams for revision of their mental models to inform their future behaviors (Sawyer and Deering 2013). This case study leveraged a UX design approach to consider the unique aspects of the context coupled with the potential of ubiquitous data collection and visualization from wearable devices to inform learning in near real-time during the live simulation debrief.

This reality-based scenario was carried out at the city services level involving personnel from multiple city-based agencies and organizations and designed to promote learning from the near real-time visualizations of the deployment of wearable, wireless sensors that continually tracked proximity of each team member across these multiple teams and contexts to the simulated patient. Learning was targeted to take place at the individual, team level but also in applying UX design to smart city solution research and development to reveal processes and insights that address systematic and similar efforts in other cities.

2.1 Identified Gap and Solution

In a city-based emergency, multiple teams including emergency operations, FEMA, Department of Homeland Security, law enforcement, EMS, fire and rescue, and hospital trauma teams must work together in a coordinated response. Despite the importance of coordination across city services and professionals, these teams rarely train or learn together. To design an effective multiteam smart city, IoT learning solution requires an enhanced understanding of the impact of cross-team interaction and learning from team members' experience of real-world interactions and as part of a more expansive citywide system. After this gap was identified, the researchers developed an IoT system to improve the capture, analysis, and visualization of mobile behavioral data from proximity sensors worn by individual team members engaged in a multiteam, live simulation context. The goal of the IoT system was to identify and uncover important individual, team, and cross-team behavioral data and patterns (e.g., response time, proximity to the patient, activity of individuals and teams, indicators across the overall multiteam system, etc.) in order to improve experiential learning during the debrief from cross-team interaction in high-fidelity simulation training. The smart city learning goal was to ultimately improve patient care, cross-team coordination, and city services teams' response time in the real-world context.

3 The User Experience (UX) Design Research Process

The applied research, development, and technological engineering of smart city learning solutions with wearable technology may incorporate a user-centered or user experience design research approach. User experience design provides a process to uncover a deep understanding of the targeted innovation, potential users, context, system, and technology as a foundation for in-depth research and development of smart learning city solutions. A shared design vision of a smart city public safety solution can be facilitated through collaboration and coordination of stakeholders such as involving those professionals involved in emergency response, including emergency managers, first responders, utilities, healthcare teams, fire and rescue, and citizens, etc. in the design research process. These stakeholders and potential end users of a smart city solution can provide important input into the iterative design resulting in a more targeted solution that incorporates quality user experience that moves toward solving identified, critical city-based problems.

Employing a UX design process for IoT or smart city solutions incorporating wearable technology involves the implementation of a flexible guiding structure or design process model that incorporates suggested questions, methods, tasks, activities, and techniques at different points across the innovation cycle to guide and manage the effort. The UX design process solicits rich contextual data to inform research and analysis of the targeted setting and users, laying the groundwork to inform the human-technology interaction design, prototyping, refinement, and evaluation of the system. There are many representations of the UX design innovation process used in multiple fields; however, it may be generally represented in four broad phases: (1) research and analysis, (2) ideation, (3) refinement, and (4) solutions. Each of these phases is aligned with guiding questions and suggested applied and empirical methodologies to apply the UX design process which are outlined below (see Fig. 1)(Table 1).

3.1 Analysis Phase: Framing the Research Problem

Multiple cycles of investigation were conducted to closely examine, generate, and evaluate best practices in emergency management, emergency response, and healthcare contexts involving the multiple teams and their cross-team interaction. User research methods were incorporated to conduct a deep dive into the identified problem and context to uncover and determine needs resulting in the conceptualization and prototyping of a customized IoT solution. Initial framing of the problem involves an iterative, cyclical, investigative approach to determine project parameters and constraints. An agile, flexible UX design approach was leveraged, aligning with the city's core capabilities and risk assessment typically undertaken by city managers and officials, to begin to determine specific needs and focus areas for smart city solutions.

Table 1 User experience (UX) design research process for smart city and wearable learning solutions in city-based emergency response

Research and analysis	Ideation	Refinement	Solution
Questions: What threats and hazards are of greatest concern for our community? What are the relevant gaps and problems in our city and specific needs aligned with mission areas (e.g., prevention, protection, mitigation, response, and recovery)? How do we characterize or frame the problem with emergency management stakeholders and community members? What are the city-based networks and systemic, cultural, and social influences on problem? What is the ecosystem of organizations, people, activities, and places relevant to the identified problem? Who is the targeted audience(s) for the smart city system? How to build alliances/working/design groups, advocacy, and trust for new ideas in this city? What information can be gleaned or adapted from research, applications, in other cities	Questions: How to include community members in a collaborative smart city design process? What functional requirements fall from the integration of information from research and analysis? How can we generate multiple ideas based on targeted needs and requirements? What relevant behaviors, workflow, learning, or performance targets are actionable for the targeted system innovation? What are the relevant physical, contextual, or ambient interactions among people, devices, and tasks given the targeted communication, data, and/or information sharing in this context? What are functional segments of the design for relevant user tasks and how can these be integrated into a holistic system design? What types of interactions are relevant (e.g., physical, movement, gesture, biometric, sound, etc.)?	Questions: Is the enacted system usable and relevant to users, stakeholders? How can we evaluate the prototype? How can we progressively iterate from proof-of-concept to iteratively build and refine the system? What elements of the system should be refined, eliminated, or revised? What city-level ROI, measures, or metrics are applicable? What are the system levers, drivers, or outcomes that can demonstrate impact on the city problem? What city impact or system effectiveness can be determined? How to grow and scale the system?	Question: How to monitor and report on strategy and results of EM IoT solution? What factors may influence the adoption, adaptation, and diffusion of this system? How does the system mutate and evolve based on targeted use? What are incentives for sharing ideas and reuse? How does the new system influence the quality of life of citizens? What new problems or issues emerge? What policies and cultures shape citizen use or non-use of the system? What are mechanisms for sharing data, models, software, hardware, etc.? What is the business value of the system? How can we empirically investigate the impact of the system? How does social network activity change before and after the system implementation? How to scale innovation in the system?

How to connect gaps in capabilities and resources to potential threats for our city? How to identify and link pre-assessment interdependencies? What is the associated UX smart city design goal, associated users, and metrics that can define success for the system? What data streams are actionable (and in what ways) for the identified city need? Can we meaningfully integrate multiple data streams to inform the problem? What are current communication, data, and information sharing systems? What are the possible future systems based on identified needs, applicable/potential data streams, and available IoT/smart technologies? What use cases or user story maps may be conceptualized that demonstrate value of this system for our city?	How are specific requirements integrated into a holistic system to address the identified need? What analytics or data streams can align with performance, behavior, or learning to measure improvement? What is the connected device infrastructure – input and output of information flow? How can we physically model and test parts of this system and iteratively evolve the conceptual design? How do we narrow focus to generate ideas for a system proof-of-concept? What are the usability and esthetic design considerations of the system? How can we create a coherent design across devices or contexts? What are considerations for interface and visualization of actionable data (input, screens, displays, etc.)? How is the system especially applicable for this city? How can data streams be integrated and interoperable?		

(continued)

Table 1 (continued)

Research and analysis	Ideation	Refinement	Solution
Methods: THIRA or threat assessment Core capabilities analysis Analysis of smart city readiness Service ecology or ecosystem mapping Planning and strategy development Identify stakeholders and networks Needs assessment/gap analysis Problem definition Define smart city design goals, metrics and targets Personas Prioritization of needs User Experience (UX) Design Inquiry Contextual inquiry and analysis Comparative analysis Bottom up/top down work flow analysis Surveys Observation/Focus groups Interviews Benchmarking User Journeys or story-mapping Use cases Case studies	Methods: Participatory design Requirement analysis Cognitive task analysis Identify workflow, learning and/or performance targets, and outcomes Network, system flows, and feedback loops Framing and reframing problem Idea generation Modeling workflow, interactions, communications, data flow, etc. Design informing models – environment, social, and process flow models Generative design methods – sketching, storyboarding, user journey mapping, etc. User walkthroughs Heuristic evaluations Expert Panels City visits Modeling Simulation Best Practices generation Technical workshops Iterative design Engineering infrastructure diagrams with available iInternet-enabled devices and data streams Prototyping Alignment of behaviors and performance outcomes with data streams Design reviews with citizens, stakeholders	Methods: Iterative feedback on conceptual design Citizen critique Cognitive walkthroughs Iterative field testing of prototype Hardware engineering and testing In situ product testing Evaluation methods such as feasibility testing, pilot testing, usability testing, expert review, and formative evaluation Determine relevant, applied, and empirical research methods such as observation and video analysis Identify metrics and outcomes at various levels of city system Document design reviews Iterative and agile revision	Methods: City-level reporting of impact Perceived value of system Performance analysis Qualitative research Quantitative research Social network analysis

Bannan et al. (2017)

Fig. 1 Observing fire and rescue and emergency medical services workplace training

In the city context, a partnership among the local university, regional hospital, and fire and rescue department began when the university research team interacted with the hospital trauma fire and rescue teams observing live simulation training sessions in their workplace contexts. A volunteer team incorporating personnel from all these organizations along with community members and researchers representing multidisciplinary expertise in engineering, information technology, organizational psychology, human factors, and learning sciences worked together to identify a need for cross-team (or multiteam system) training to improve patient care. A potential IoT smart city learning solution was envisioned, described, and targeted to attempt to improve learning and performance within and across the multiple teams involved in the live simulation exercises. Exploring the systems, interactions, and content involved consisted of several rounds of observation and exploratory user research cycles to identify the gap of cross-team training as well as the operational coordination and processes these teams engaged in to begin to imagine solutions that would intersect with the existing systems in emergency management and response training. Connecting to the professionals' everyday problem-solving and training needs meant seeing things through their perspective (e.g., in a human-centered, user experience design process) and spending significant time in their work context to deeply understand their professional practice, capabilities, existing systems, communications, and processes of identification and mitigation of city threats, risks, and hazards (see Fig. 1).

In framing the identified problem, the design team began with investigating how emergency managers perceive their operations related to a unified coordination and response to a city emergency or disaster as well as what first responders perceive as the most critical training needs. Toward this effort, the focus became supporting a multiteam effort (e.g., including emergency operations center, EMS, fire and rescue, hospital trauma teams) to extract, treat, and transport a patient quickly to the hospital emergency department to complete and support the continuum of optimal patient care across these city service teams. The UX research methods that were incorporated included:

- Observations – of the workplace contexts, simulations, and training operations
- Research and investigation – of relevant protocols, procedures, and relevant research
- Interviews – emergency managers, 911 dispatch, fire and rescue, emergency medical services, and hospital trauma team members
- Focus groups – probing for implicit and explicit protocols, procedures, and communications of these professionals' work practices

These investigative methods helped to determine a gap or need that then provided a stated target for innovation that is articulated in a concise statement for agreement by all stakeholders. The resulting solution system product statement in the project was articulated as the following: "to engineer or reconfigure existing devices to obtain targeted sensor-based data analytics (and other relevant complimentary digital information data streams) to enhance the seamless, dynamic data collection, processing and analysis for meaningful display in near real-time to improve coordination, situation awareness, learning and ultimately, the performance of emergency response and medical teams in a multiteam system." This became the stated research and development goal of this effort.

Once the smart city solution system was targeted and described, the UX research team embarked on more detailed analysis to inform our development of the system. Multiple investigations and observations of relevant and detailed processes were conducted to determine target audience(s) and system requirements and to model usage, tasks, and information flow to inform the design of the system. Collecting qualitative data on work activities, routines, and conventions as well as the professionals' perceptions of sensory, cognitive, and physical actions involved in conducting their work provide important input for the design of smart city solutions. The contextual information generated by user experience research provides the grounding for extracting requirements.

Before designing the system, the research and development team must deeply understand the potential users' work activities in the authentic context of their work such as an emergency operations command or first responder's responsibilities in an emergency or disaster.

Additional UX research methods incorporated in this phase included the following:

- Contextual inquiry – gathering detailed information on the context, users, setting, professional activities, constraints, information flow, etc. through observations, interviews, focus groups, participatory design, and review of artifacts. For example, the research team members had the opportunity to wear the full garb of firefighting equipment and ride along in a medic transportation unit to experience the professionals' work environment.
- Contextual analysis – systematically capturing, integrating, and analyzing user research data from the above stated sources to improve understanding of the context, roles, mental models, and work practice to generate ideas for modeling and design of smart city solutions.

Immersion in the context of all the constituent teams involved in the identified multiteam system allowed for deep understanding of the challenges of the targeted work and the day-to-day experience of city emergency operations managers, emergency medical response, fire fighters, and hospital trauma team members. This analysis helped to identify the core points of interaction for data collection among the teams that could be seamlessly collected through wearable technology to inform their learning in a dynamic live simulation context. Integrating and analyzing this information through the UX design techniques described above and modeling inter-team and cross-team work tasks, information flow, and socio-emotional aspects of context allowed the targeting of cross-team behavior of these city services for wearable learning design such as proximity and biometric sensor data. This user experience research provided a strong foundation to begin to extract requirements for the design and prototyping an IoT solution system.

3.2 Ideation Phase: Generative Design

In this example use case, the refined design goal that resulted from iterative cycles of research and analysis encompassed the improvement of within-team and cross-team coordination, situation awareness, learning, and performance of the multiteam system composed of EMS, fire fighters, and hospital trauma personnel. To adequately design a socio-technical system for this purpose, we needed to draw from the data and analysis in prior stages as well as the design-informing models we generated. Integrating this information provides meaningful consolidation of these ideas into a bottom-up design approach to inform ideation or generate new ideas and requirements for design of a system that would support the goals.

Briefly described, the ideation and design process strives to uncover the system requirements to iteratively design a system to meet the user or learner's goals in supporting their work and learning. Ideation is also a phase considered in the design thinking process which provides a broad-level design process approach rather than the more specific detailed process described in our example (see, e.g., Plattner et al. 2011). Determining the functionality of the wearable learning system and the necessary human-technology interactions becomes a challenging, complicated process when involving the design of complex socio-technical systems. Adding to that challenge is working with embedded computing devices such as sensors and other Internet-enabled devices (with intelligence) that can represent ambient computing or an automatic sensing and awareness of the real-world environment and actions of people and things. This aspect is unique to wearable learning technology design with the capacity to network multiple devices, collect multiple data streams, and meaningfully integrate them for improved learning in difficult real-world conditions. Leveraging these devices to design systems to improve situation awareness in public safety contexts where the user is more aware of their surroundings, the presence of others, or their own activities to improve their reflection and experiential learning in situ is the core identified challenge for UX design work. The conceptual and progressively detailed design of these systems emerges through iterative cycles of conceptualization, prototyping, deployment, and evaluation of the system in context. The city multiteam system process incorporated the following methods in the ideation phase:

- Extracting user requirements – from prior contextual inquiry and analysis.
- Consideration of mental models – determining team members' thought processes about their work in the world.
- Conceptual design – envisioning how the system might work tied to prior information considering the ecological, emotional, and interactive aspects.
- Participatory design – users participate in the entire design process.
- Modeling types of interactions – physical, sensory, movement, speech, whole body, hearing, seeing, etc.
- Storyboard and sketch – generating ideas for conceptual design and obtaining feedback from all stakeholders.
- Iterative Improvement – leveraging cycles of feedback to improve the conceptual design.
- Detailed design – wireframe screens, interactions, and visual design.
- Prototype system – integrating capabilities or innovating new ones to construct a deployable system.
- Generating a smart city design concept as well as modeling and engineering it for the real world is an enormous task difficult to describe concisely. However, in the described use case multiteam example, the iterative design cycles continue with integrating existing sensors and information systems that represent heterogeneous data sources (e.g., biometric body worn sensors, proximity beacons, 911 dispatch, GPS, and social media digital data) to provide visualized information on inflection points between the teams such as when the patient is handed off from the EMS to the hospital trauma bay team (see Fig. 2). Through conceptual design, iterative prototyping, and deploying the conceived system in the actual context through live fidelity simulation training in a UX design and research process, improvements are continually progressing the system and its value.

Fig. 2 Patient hand-off between emergency medical services team and hospital trauma bay team

3.3 Refinement Phase: Iterative Improvement

Refining the prototype represents the hard work of bringing an idea to life, testing it through solicitation of targeted feedback, and continually improving it. These phases may be described through the following activities that occurred in this smart city learning case study:

- Progressive prototyping – implement progressive levels of fidelity going from low fidelity (conceptual, limited capabilities) toward high fidelity (realistic working system) in multiple, iterative testing cycles
- Deploy, test, and evaluate the system – to progressively and iteratively examine the design in action with participants for them to provide input into the next revision of the system
- Participatory design

To implement the refinement phase, the project team progressively and iteratively constructed and tried out several versions of the IoT system prototype with each trial informing and revising the designed system, by testing it first in the university lab context and then moving it toward higher and higher levels of real-world conditions with an ultimate trial in close to real-world conditions. The participatory design aspect involved community members as well as stakeholders from the fire and rescue, medical services, and hospital contexts, contributing directly to and greatly informing the design and deployment through planned focus groups and the test run in the real-world live simulation. The professionals involved in this exercise also constituted learners who began to think about their team-based behaviors in new ways introduced to new technology. The researchers learned directly from the professionals the nuances of their complex work and interaction as well as whether their initial design ideas need to be modified based on real-world behaviors and conditions.

3.4 Solution Phase: Evaluating Implementation and Results

The smart city wearable learning solutions generated through a UX design and research process represent the experience and knowledge of the end user with a design and prototype based on rich data from the context of use. The solutions constructed through this process have improved ecological validity and are tested in context, therefore demonstrating improved opportunities for successful deployment and to transition and scale into other environments. As stated by Kiefffer (2015), ecological validity is crucial for designing relevant and meaningful UX interventions and "... To not representatively sample on the environmental side (e.g., sensor stimuli, everyday objects or social interactions) may fail to capture relevant aspects of the real world and therefore fail to engage participants in performing the experimental task as they would have for real" (p. 151). Evaluating wearable solutions for learning in emergency response contexts involves a heightened sensitivity to real-world contexts and situational awareness that requires attention to ecological validity throughout the entire UX process. Evaluating the implementation of a wearable technology learning intervention may involve multiple research methods including applied meaningful metrics, formative UX testing, as well as empirical cycles of research. Although this project is still progressing, one could imagine the value of evaluating citywide reporting of the impact of the IoT-enhanced live simulation training with reduced system response times across the patient extraction, transport, and hospital arrival. Determining multiple formats of near real-time visualization of team-based behavior that could then be more formally analyzed in social network analyses or improvement in performance-based outcomes such as response time and efficiency of activity given the varying conditions of each simulation run. The capability of these professionals to view their own behavior in situ during the post-simulation debrief when research indicates most learning occurs in simulation may engender reflective learning cycles at the individual and team level. The example project is still progressing in the solution phase remaining a budding prototype, but through leveraging a user experience design and research process to design, develop, and deploy wearable learning solutions as described above, these types of innovative systems may have a better chance for success, progression, and implementation.

4 Unique Aspects of the UX Design Process for Wearable Technologies for Learning

Designing distributed, ambient, and pervasive interactions for wearable technologies for learning in smart city contexts requires consideration of applicable mental models as well as the type of interactions that intersect with ecological, physical, and emotional aspects of the targeted situation (Rowland et al. 2015, Hartson and Pyla 2012). The contextual analysis and participatory design process are particularly important for wearable learning design to holistically and deeply understand the user's experience to enhance and not detract or overload the authentic experience of the involved professionals once deployed with wearables. Given the inherent demands of the context of this case study, the unique aspects for UX design for wearable technology feature prominently on the front end of the design process through increased sensitivity to context, stress, affect, and physicality of the participants. These complex multifunctional systems allow for fine grain data collection of the monitoring of movements and physical states that can be modeled and visualized potentially offering learning support in near real-time (Educause 2016). It cannot be more prominently emphasized that the iterative design research process can more closely align the potential of these systems with the complexity of the work and the implicit and explicit knowledge of the professionals involved.

In the later stages of the UX design process for wearable technology for learning, considerations of the appropriate selection and fusion of the multiple information data streams (e.g., recorded time stamps for response time, proximity to the patient, activity of individuals and teams, and biometric indicators such as heart rate, blood pressure, etc.) determining the right data at the right time for the right purpose become an important user experience design determination. The participant's construction of meaning from the selection of displayed data during the simulation debrief requires an iterative human-centered or user experience design approach to get the displayed information just right in simulated high-stake situations to attempt to improve awareness and fast response in the workplace (Bernal et al. 2017). Maximizing and allocating attention to the right channels of information and human perception concluding a dynamic simulation exercise is crucial to learn to best support learning, reflection, as well as improved response time in emergency response. Wearable technology for learning allows for behavioral information at the moment of need such as in the debrief where research indicates most learning occurs in simulation with assessment provided in context. To move toward these challenging goals, the following methods should be considered that directly intersect with the unique affordances of wearable technologies for learning:

- Consideration of mental models – determining team members' thought processes about their work in the world.
- Conceptual design – envisioning how the system might work tied to prior information considering the ecological, emotional, and interactive aspects.
- Participatory design – users participate in the entire design process.
- Modeling types of interactions – physical, sensory, movement, speech, whole body, hearing, seeing, etc.

4.1 Similarities and Differences in UX Design Research Process Application

User-centered or user experience design processes are just beginning to be incorporated into workplace learning contexts with IoT and wearable systems (Bernal et al. 2017). These systems share some similarities with our described case study in attempting to leverage IoT and wearable computing to improve situation awareness, learning, and emergency fast response. However, while safety is a priority, our work targets learning and behavioral change in situ through real-time feedback, awareness, and reflection on activity among and across teams.

The UX design process for wearable technologies for learning in smart city contexts can be considered as design and iterative development of a cyber-physical social system (Cassandras 2016). These cyber-physical systems defined as the "technological infrastructure of a Smart City is based on a network of sensors and actuators embedded throughout the urban terrain, interacting with wireless mobile devices (e.g., smartphones) and having an Internet-based backbone with cloud service" (p. 156). Other, more detailed technology-based design methodologies have been proposed that include analyzing the system-level design flow through consideration of hardware, software, sensors, and the user's needs that are then modeled through the involved objects of humans, computers, or devices first in the abstract and then trialed in the real-world context (Zheng et al. 2016). While these design approaches are valid and useful, the case study UX design process described here attempts to mine for detailed nuances of user experience, mental models, emotions, and contexts to leverage the affordances of wearable technologies to target and track aspects of complex human behavior (e.g., within and across teams) autonomously to attempt to inform individual reflection on action and learning in near real-time (Schön 1983).

5 Conclusion

In summary, the applied research and development process for engineering smart city wearable learning solutions may incorporate a user-centered or user experience (UX) design research approach. This case study described an iterative, progressive, and agile design process with four phases applicable for generating, refining, and scaling emergency management IoT wearable learning solutions. Each phase focuses on different objectives, involving stakeholders and citizens as co-designers to inform the research and development. It is hoped that other smart city learning and wearable device projects to improve city services might benefit from the detailed list of guiding questions, potential methods, and description of the processes implemented in this case. Adapting this process toward different city-based services and outcomes could provide a robust framework for approaching the systematic research and development of smart city wearable learning solutions and potentially provide guidance for other cities and their citizens to embark on these complex efforts. In conclusion, the four phases of the smart city learning UX design research process applied to wearable technology applications customized for city-based emergency management solutions are summarized below:

- *Analysis* – collaborative analysis and city assessment with citizens and stakeholders to establish a common vision for smart city innovation.
- *Ideation* – establishes a co-design process with citizens and stakeholders to elicit multiple perspectives on the problem, generate multiple design ideas, and prioritize and clarify the behavioral or performance targets aligned with meaningful data streams for smart city IoT innovations.
- *Refinement* – advances the generated prototype through establishing contextual relevance and usability via lab and field testing of the prototype; progressively refining and evolving the innovation through iterative cycles of design, development, and evaluation; and establishing and expanding targeted metrics and measures to determine impact.
- *Solution* – incorporates methods to monitor and report out the initial design strategy as well as impact for learning about how the smart city solution was adopted, adapted, and diffused through the system. This phase can define incentives for use and impact on citizen's lives as well as provide impetus for empirical investigation of the use, impact, and scaling of the innovation.

As this case study evidences, generating and deploying smart city wearable learning innovations may be facilitated through the process of UX design research. The systematic process of UX design research provides an iterative and agile co-design approach to work toward the improvement of city-based services and promote learning at multiple levels in and across smart cities. The unique aspects of UX design for wearable technologies for learning include consideration of affordances related to cyber-physical social systems (e.g., emergency response) to elicit collaborative analysis and assessment in concert with those involved to observe and delineate the interplay between human behavior, smart city technologies, and team interaction. The UX design process promotes a close consideration of the capabilities of wearable embedded IoT sensors in context that collect and display data seamlessly with a specific focus on improving learning and performance.

The perpetual "human-in-the-loop" UX design and development process for cyber-physical infrastructure for smart city innovation and learning required careful consideration of the in situ human dynamics of this complex multiteam setting as well as to the design of the wearable system, data collection with information processing, and visualization evidencing significant challenges for UX design (Zheng et al. 2016). In conclusion, based on the case study presented here, key factors of wearable/IoT user experience design for learning may include:

1. Establishing a co-design process with citizens and stakeholders to consider diversity of users and communities as well as to generate multiple perspectives on the problem, design ideas, and meaningful learning targets in complex, socio-technical contexts that integrate wearable devices for learning.

2. Attempting to link to the learning theory (such as reflection in action) to promote generating contextualized knowledge in a multifaceted and complex learning context connected to wearable devices for learning.
3. Considering and uncovering wearable/IoT affordances that will add to and not detract from the current practice and context closely aligned with real-world needs, behavioral data, and patterns through specific capabilities of wearable technologies for learning such as contextual awareness, monitoring, and embedded systems design incorporated into the UX design process.
4. Designing for the physicality of human behavior in the field requires a supportive digital infrastructure that must be carefully considered striving toward ubiquitous, seamless data collection and informed visualization for wearable technologies for learning.
5. Establishing and validating targeted metrics and measures such as proximity to other team members or the patient that meaningfully reflect and intersect the human activity and the ubiquitous nature of the data collected through wearable technologies for learning.
6. Promoting a participatory approach within a UX design process is particularly important for smart city wearable technologies to imagine and generate the possibilities for improving learning across multiple groups in a complex real-world context establishing a shared vision that strives for practical and learning impact.
7. Designing wearable technologies for learning requires adherence to the human-in-the-loop and consideration of cyber-physical interaction from initial conceptualization of smart city solutions through to deployment and iterative improvement through user experience design processes.

These unique considerations to move toward a user experience design process for wearable technologies for learning require careful attention to the interplay between human interaction, context, and the incredible potential of ubiquitous computing. Smart city learning solutions, wearable learning, and user experience design can seamlessly and powerfully intersect if design research process and product are both aligned to address the steep challenge of improving learning leveraging these new systems.

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Designing Wearables with People in Mind

Vladimir Tomberg and Daniel Kotsjuba

1 Introduction

Designing the wearables is in big extent designing of human-computer interaction (HCI). However, there are different peculiarities due to the different nature of the human-computer interface in wearable computing devices compared to the traditional, screen-based computers. A wearable computer must be worn, not carried, and can be regarded as being a *part of the user* and user controllable (Randell 1996). *Wearability* is defined as an interaction between the human body and the wearable object (Gemperle et al. 1998). A user literally wears the device in the form of clothes, watches, glasses, jewelry, tattoo, or other wearable artifacts. Being seamlessly integrated into everyday life, wearable technology potentially gives people with visual and other sensory disabilities better, less conspicuous, and easier access to information and services (Wentzel et al. 2016).

History shows that the different ways of human-computer interaction were prevalent in the different times. The input devices were starting with the early Hollerith key punch devices (Bird and Di Paolo 2008) popular at the beginning of the twentieth century, continuing with keyboards, adapted from typewriting machines, following by an epoch of GUI and mouse, started by Engelbart in The Mother of All Demos (Metz 2008). Although the first, real human-computer wearable input devices were introduced in the middle of 1970s (Mann 2013), the technical limitations did not allow them to gain the market at that time. The input

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sensors were non-accurate in the sensed data quality, being too bulky for wearing, and overestimated in demands for power.

Today, many of the abovementioned issues are fully or partially solved not only for the wearable input but also for the output devices. Engineers propose for us a wide spectrum of components and techniques for integrating computing electronic components into clothes, shoes, hats, wallets, glasses, jewelry, etc.

However, research indicates that there are still serious challenges in the design of wearables. Let us look at the most successful example at the market of the wearable technology: wearable fitness trackers. According to different sources (Claveria 2015; Karapanos et al. 2016; Statt 2014), the most popular companies providing wrist-based fitness trackers like Apple, Fitbit, and Jawbone have problems: many customers eventually abandon the company's fitness trackers. The voiced reasons are different: "ugly" look, problematic software usability, and different kinds of difficulty in adapting the devices in the real-life scenarios.

The nature of user interfaces for wearables is versatile and different from the traditional, screen-based human-computer interfaces. Therefore, for designing wearables, it is not enough to just apply the usability rules. By considering the necessity of wearing devices on the body, the human factor design principles should be applied during design and evaluation phases of the wearable devices. It is important for designers to consider human factors much more, in comparison to traditional computer screens or even the younger generations of mobile devices.

The goal of this study is to supply designers, researchers, and students with a tool or a set of tools, which can be used for the quick assessment on the stage of designing prototypes for wearable computing.

In this paper, we review a hierarchical model for Universal Design (UD) principles that we propose to use for the evaluation of prototypes of the wearable devices. We describe different logical groups of the UD principles and propose tools that can be used for evaluating these groups.

2 A Hierarchical Model for UD Principles

Universal Design is a popular design framework that is used in the different areas of design and development from architecture to service design.

> Universal design attempts to make products, equipment, building interiors and exteriors, transportation systems, urban areas, as well as information technology, accessible to and usable by all without regard to gender, ethnicity, health or disability, or other factors that may be pertinent. (Preiser 2008)

In the previous studies, we outlined (Tomberg et al. 2015) how UD principles can be applied to the different themes for wearables and reviewed (Tomberg and Kelle 2016) several accessibility evaluation tools from other fields, from which criteria for evaluation of the accessibility in wearables during the design process can be borrowed.

The concept of the Universal Design was coined by Ronald L. Mace (Mace 1985), a program director of the Center for Universal Design at Carolina University. Universal Design is a concept of designing products and the built environment to be esthetic and usable to the greatest extent possible by everyone, regardless of their age, ability, or status in life (Center for Universal Design NCSU – About the Center – Ronald L. Mace 2008). The works of Mace were influenced by early ideas of UK researcher Goldsmith, reflected in the book *Designing for the Disabled* (Goldsmith 1967). Being originally focused on the issues of accessibility in buildings, Mace outlined distinction of Universal Design to the other types of design for people with special needs. Mace ideas were compiled by a team of researchers in the Center for Universal Design at North Carolina State University into design guidelines. Seven design principles applicable to the environmental accessibility were defined for the first time in the book by Connell et al. *The Universal Design File* (Connell et al. 1997). UD was defined in the book as the design of products and environments to be usable to the greatest extent possible by people of all ages and abilities.

There are two synonym terms for Universal Design: *Inclusive Design* and *design for all*. While all three terms have different origins, they have similar ideas, concepts, and goals and can be used as interchangeable ones (Coleman 1994; John Clarkson and Coleman 2013). The evangelists of the inclusive design follow the same ideas where a designer must avoid design for an average user. Moreover, the modern designers call to target the “extreme” users. A designer, lawyer, and advocate Elise Roy recently said: “What gets forgotten is that people with disabilities are great examples of extreme users. We experience the world in such a different way. They are a goldmine for helping us to think differently” (Schwab 2018).

Seven UD principles by the version of Connell et al. with the corresponding descriptions are listed in Table 1.

Table 1 Principles for Universal Design and their definitions (Connell et al. 1997)

Principle	Description
Equitable use	The design is useful and marketable to people with diverse abilities
Flexibility in use	The design accommodates a wide range of individual preferences and abilities
Simple and intuitive use	Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level
Perceptible information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities
Tolerance for error	The design minimizes hazards and the adverse consequences of accidental or unintended actions
Low physical effort	The design can be used efficiently and comfortably and with a minimum of fatigue
Size and space for approach and use	Appropriate size and space are provided for approach, reach, manipulation, and use regardless of user’s body size, posture, or mobility

This list of principles becomes a base for many works in UD area. Erlandson in his book *Universal and Accessible Design for Products, Services, and Processes* (Erlandson 2010) has slightly modified the list of principles and added the eighth one. A model of Erlandson contains the following principles: *ergonomically sound*, *perceptible*, *cognitively sound*, *flexible*, *error-managed (proofed)*, *efficient, stable and predictable*, *and equitable.*

Erlandson proposed not only the extended list of principles but also a hierarchical structure, which allows grouping of the principles among different layers and establishes hierarchical relationships between them. The principles are distributed in three main groups: *transcending principles*, *process-related principles*, and *human factors principles* (Fig. 1).

On the lower level are the *human factors principles*, which include the ergonomics, perception, and cognition (Table 2). Situated in the middle, the *process principles* deal with activities and participation. They include flexibility, error management, efficiency, and stability/predictability. The *transcending* principle deals with the *equity*, and as such, that layer is very different from the others. Equity is a value judgment. As a design community, we are stating that we desire universally designed entities to be equitable (Erlandson 2010).

In the model of Erlandson, a principle situated at the higher level places constraints on the structure or design of the lower level. "Operational laws and principles, such as the various psychometric laws, physiological principles, psychological principles, and the biochemistry of brain and neurological and neuromuscular functioning, form the basis for what and how people behave and function with

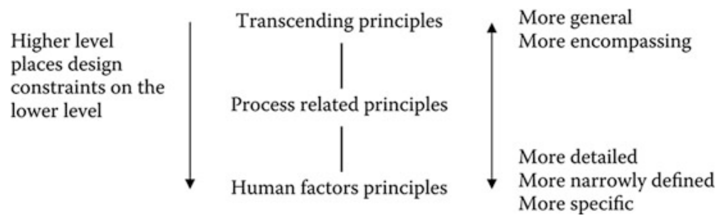

Fig. 1 The hierarchical structure of the Universal Design principles (Erlandson 2010)

Table 2 UD principles in hierarchical model of Erlandson

Levels	Principles
Transcending principle	Equity
Process principles	Flexibility
	Error management
	Efficiency
	Stability/predictability
Human factors principles	Perception
	Cognition
	Ergonomics

respect to the human factors principles. The process principles place constraints on the various human factors principles and design strategies" (Erlandson 2010).

By presenting the principles in the hierarchy, Erlandson simplifies the practical implementation of principles. He provides a categorized way of addressing them, instead of considering them all at once. By arranging principles in a specific order, Erlandson suggests the elimination or reduction of non-value-added activities (NVAA). For example, when a job requires carrying objects from one place to another, human factors principles would deal with the ergonomics of carrying, while process-related principles would deal with the elimination of carrying at all, thereby reducing NVAA-s. Therefore, dealing with process-related principles first gives a better result.

At the same time, structuring the principles and grouping by common attributes makes the model easier to understand and apply and can be considered as a way of learning for applying UD principles.

UD principles seem like a good opportunity to improve design prototypes, especially at the early stages. The whole set of requirements for an interactive system cannot be determined from the start (Dix et al. 2009). We consider the design process as an iterative activity, with the explicit goal of evolving through several design iterations. However, it is not an easy task to apply the principles themselves to the design artifacts. Though UD principles are well defined, there is still a lack of the applied tools, ready for use in a lab for different purposes.

The model of Erlandson is especially interesting because, in addition to the process-related principles, which are a typical part of the common usability evaluation tools, it explicitly adds the transcending and human factor-related layers. While those types of principles are often omitted in the common tools for human-computer interaction (HCI) evaluations, we argue that they may have a serious impact when one designs the devices that should be implemented on a human body or wearables.

In the following parts, we review and discuss the existing design and evaluation tools, which could be used together to cover all layers of the Universal Design-based hierarchical model.

3 Transcending Equity Principle

Erlandson proposes that the first principle in the hierarchical order is the equity principle. He writes that "The Transcending Equity Principle is an umbrella for all principles situated below. Equitability imposes constraints to the other design principles in that they must be applied so that a broad spectrum of users accepts the designed entities. In a most fundamental way, equitability forces the integration of the other universal design principles" (Erlandson 2010). Erlandson sees Equitability as a prominent principle that integrates other Universal Design principles. He sees it rather as a mindset that designers should be always keeping when dealing with the Universal Design framework. Erlandson noticed that equitable designed entities should provide identical means of use whenever possible and equivalent when not possible for all users. The designers should avoid segregating or stigmatizing any users in their products and processes, thus making the design appealing to all users.

A question may arise why Erlandson defines equity as a principle at all when it is given such a high level of importance. Also questionable is his attempt to provide certain specific implementation strategies (e.g., "aesthetically pleasing") that, while not being wrong, are in practice hard to define or even measure. By doing so, understanding of its actual role becomes less clear. Another question that arises is how to practically differentiate equity from other principles if it is needed to be considered in the first turn because other principles have been categorized relatively clearly.

We propose to adapt equity, on the base of the top place in Erlandson's hierarchy, as a preliminary step or a "compass" to support positioning of a project's compliance to the Universal Design principles. It should help designers to keep in mind on every step of the design process the needs of the different user groups. For example, if a wearable device gets a "negative" assessment against a Thinking Disability characteristic, then the project needs to consider the target group with such characteristics. Also, when it turns out that some user group has been left out from the beginning or misjudged, then it is always possible to go back to the "beginning" and reevaluate the characteristic accordingly. In addition, designers can choose to develop a specific solution for one target group at the time, first specifying the list of the end users and then developing and adapting solution accordingly.

In Fig. 2, all three layers of the Erlandson's model are presented as an iterative cycle. The arrows show the direction of how the layers can proceed during evaluation. After starting with transcending principle and using it with a "compass," one goes into the process-related principles where top-level principles are restricting her. Next, moving to human factors principles and being again restricted by top-level principles, she goes back to the transcending principle with new knowledge and starts a new iteration. This way equity places higher demands on designers – studying actual users and working with them as an integral part of the whole design process.

4 Equity Evaluation Principle

To our knowledge, currently, there are no specific methodologies for equity assessment for human-computer interaction. However, certain attempts have been made in other fields and subjects, to address the issue of equity assessment.

One tool that can be provided as an example is an Equity Framework for Health Technology Assessments (HTA) (Culyer and Bombard 2012). In this framework, domains of equity, adequacy, legal obligations, general principles, and embedded inequity are used to determine the degree how an evaluated concept fulfills the equity.

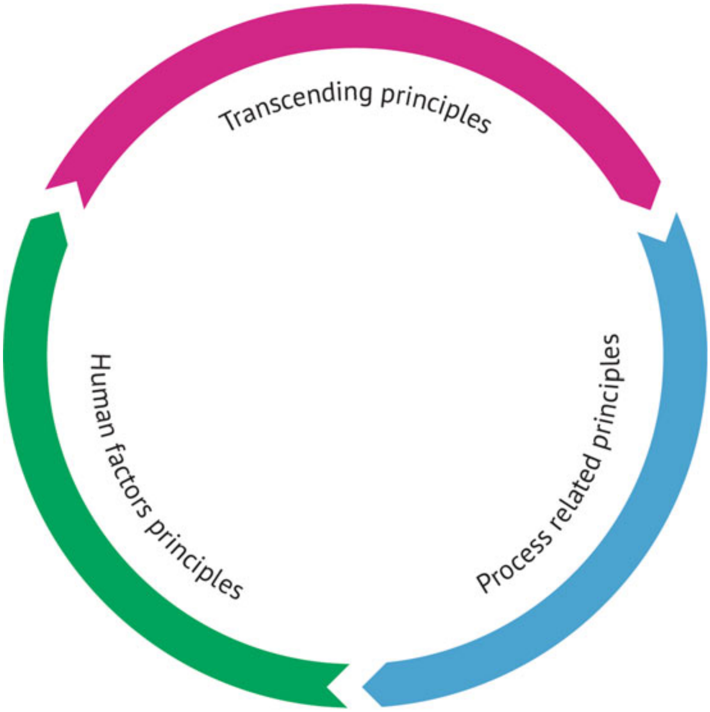

Fig. 2 Iterative workflow adapted from Erlandson model

Equity Impact Assessment (EIA) is a method for healthy policymaking proposed by Mann and Gostin in 1994 (Mann and Gostin 1994). EIA originates in Human Rights Impact Assessment (HRIA). In HRIA study, authors have discussed issues when newly designed human rights policies can uncover specific population groups. Among other human right principles, HRIA also states equity and nondiscrimination principles: "All individuals are entitled to their human rights without discrimination. This includes paying particular attention to vulnerable and marginalized individuals and groups, as well as gender. It also involves taking steps to ensure that all affected and impacted women and men, girls, and boys, are empowered to understand and participate in decisions that affect them." (Götzmann et al. 2016). The HRIA method may address some of the issues considered in a company's environmental, social, and health impact assessments (Bradlow 2016).

EIA mainly covers three areas – human rights and business, right to health, and trade agreements (MacNaughton 2015). There are other frameworks, aiming at equity assessment in different application domains. Examples of these domains can be international development (Jones 2009), patient admission (Pugh and Currie 2010), public sector (Equality and Human Rights Commission 2011), etc.

A *framework for evaluating house-level accessibility* (Omer 2006) also provides an assessment framework for equity, but, this time, for spatial equity, which is a concept that concerns architectural requirements to inform accessible building policies. This framework looks at factors for accessibility as a social construct, making assumptions to what degree social groups are included or excluded from certain spatial points of interest, such as a park or other communal elements of a city.

Another framework is related to the educational context (Brown 2006). Three different theories are combined: Adult learning theory, transformative learning theory, and critical social theory. These are matched with the pedagogical concepts of reflection, discourse, and policy. The way a framework is formed is geared at informing persons in educational leading roles, to form an equitable environment that will seek to reduce discrimination against learners.

Up to now, the most advanced works on promoting equity issues have been done in the UK. An important fundamental initiative was Equality Bill that received royal assent on April 8, 2010, becoming the Equality Act 2010 (Pugh and Currie 2010). The Equality Act includes a new public sector equity duty, replacing the separate duties on race, disability, and gender equality. The new general duty covers the following protected characteristics: *Age*; *Gender reassignment*; *Sex*; *Race – including ethnic or national origin*, *color*, *or nationality*; *Disability*; *Pregnancy and Maternity*; *Sexual orientation*; and *Religion or Belief*, including lack of belief and marriage and civil partnership, but only in respect of the requirement to have due regard to the need to eliminate discrimination (Equality and Human Rights Commission 2011).

The protected characteristics are explained in details in the UK government policy (Department of Health 2011). A variety of equity impact assessment tools based on the defined in the Equality Act 2010 protected characteristics are widely used in UK healthcare sector. Among them such organizations as NHS (Equality Impact Assessments (EIA's) n.d.; Healthcare NHS Foundation 2016), Equality and Human Rights Commission (Equality and Human Rights Commission 2011), Equality Challenge Unit (ECU) (Pugh and Currie 2010), and National Institutes for Health and Clinical Excellence (NICE) (Kelly et al. 2009). The objective of all these tools is to determine the equity of approaches used in a public health guidance.

Hereby we find it necessary to point out that Equality Act 2010 defines "equality" as an equal outcome, not equal opportunities, which is important for the subject at hand (Equality and Diversity n.d.; Smiley 2017).

The approach based on the Equality Act 2010 protected characteristics seems as a relevant one for applying to HCI, as it consists of equity-related characteristics that can affect the user experience. In our context of design for the wearable technology, each of these characteristics may be relevant in terms of raising awareness with respect to potential pitfalls that might discriminate against certain groups of users. Naturally, it is difficult to address all the different user groups at once. However, with an enhanced awareness to each of them, an optimization can be expected, and wider user group will be addressed than had been possible before.

The different characteristics can be used in a checklist that will test any design-artifact against using it for the different types of audience. For example, as we design a wearable device that will help visually impaired users to recognize items in their environment by using voice output, this will be inclusive for many of the characteristics, except people with aural disabilities. This group is excluded unless we include support for textual output or sign language support in some fashion.

Originally, the protected characteristics defined in Equality Act are used in clinical conditions and by clinical professionals, who are aware of the scope and specifics of each characteristic listed. For successful implementation of this tool, it is equally important for designers to understand the variety of each user groups' needs. For this reason, we have extended the list with more detailed characteristics (Table 3). We have added subcategories "Child, Teenager, Adult, Senior" for Age and "Vision, Hearing, Thinking, Reach and Dexterity, Mobility" for Disability and Right- and Left-handed, so that it would be easier for designers to consider the specific needs of each user group and the assessment would be more accurate. Each of the protected characteristics is assessed how they are affected by the wearable product, while the result should be only neutral or positive checkboxes. We also propose that the list of characteristics can be modified or adjusted depending on the subject at hand.

Table 3 Adapted checklist from the tools based on the definitions in the Equality Act 2010 protected characteristics. The extensions are marked by an italic font

Protected characteristics	Impact
Age	
Child	Positive/negative/neutral
Teenager	Positive/negative/neutral
Adult	Positive/negative/neutral
Senior	Positive/negative/neutral
Disability	
Vision	Positive/negative/neutral
Hearing	Positive/negative/neutral
Thinking	Positive/negative/neutral
Reach and dexterity	Positive/negative/neutral
Mobility	Positive/negative/neutral
Left-handed	Positive/negative/neutral
Right-handed	Positive/negative/neutral
Gender reassignment	Positive/negative/neutral
Marriage and civil partnership	Positive/negative/neutral
Pregnancy	Positive/negative/neutral
Maternity	Positive/negative/neutral
Race	Positive/negative/neutral
Religion or belief	Positive/negative/neutral
Sex	Positive/negative/neutral
Sexual orientation	Positive/negative/neutral
Disadvantaged groups	Positive/negative/neutral

Table 3 shows the extended list of protected characteristics that we propose to start with. The list can be adjusted for the specific design scenarios. For example, some main categories can be expanded with subcategories as we have done that for Age and Disability characteristics. In other cases, different characteristics can be explored in detail, depending on specific design requirements. It is important for designers to consider the list as broadly as possible, to eliminate chances of excluding any important user groups.

For the disability characteristics, we have avoided using WHO ICF[1] classification, because of its complexity and emphasizing first the disabilities that directly influence user interactions. Actually, the same human functions will be in more details introduced in the lowest layer of our tool. However, the lower layer addresses the specific human functions and limitations. At the top level, we are trying to focus on the human factors from the equity point of view.

In the context of the design of wearables for learning, evaluation of the design against of equity principles should make designers think about the diversity of their target audience to avoid chances of inequality in rights for learning that can be by mistake proposed by design.

The specific examples how equity impact assessment can be implemented in design are provided in the Evaluation section.

5 Process-Related Principles

Erlandson defines a process as a collection of related tasks or activities that lead to a particular result. Being situated in the middle of Erlandson's model, the process-related principles are constrained by the transcending principles and at the same time provide the constraints to the human factors principles. The process-related principles are aimed primarily at reducing NVAA-s (as mentioned in Sect. 2) and thereby deal with flexibility, error management, efficiency, and stability or predictability. Those principles traditionally are associated with the usability of a product.

Usability is a concept strongly related to the user interaction processes. Usability testing, according to Dumas and Redish (Dumas and Redish 1999), among other things, aims to give the users real tasks to accomplish. That calls up Erlandson's description of the process as a collection of tasks or activities that lead to a particular result.

Heuristic evaluations originally involved a small set of evaluators examining each element of a system to identify potential usability problems (Petrie and Bevan

[1] International Classification of Functioning, Disability, and Health (ICF): http://www.who.int/classifications/icf/en/

2009). Usability heuristics are used for evaluation of a high range of concepts, from general to specific, which can include, for example, technologies (Al-Salhie et al. 2015), devices (Alsumait and Al-Osaimi 2010), applications (Inostroza et al. 2013), or even more complex concepts like patient safety (Zhang et al. 2003). Nielsen (Nielsen 1994; Nielsen 1995) proposed one of the popular high-level guidelines (or heuristics) for usability. Usability and user experience practitioners widely adopt Nielsen's tool: it is easy to learn and use, and it provides fast and effective results even being used by novices.

As the name of Nielsen's tool states, *ten usability heuristics for user interface design* consist of ten following components: Visibility of system status, Match between system and the real world; User control and freedom; Consistency and standards; Error prevention; Recognition rather than recall; Flexibility and efficiency of use; Aesthetic and minimalist design; Help users recognize, diagnose, and recover from errors; and Help and documentation.

We have mapped Erlandson's process-related principles to Nielsen's heuristics and have found the following matches (See Table 4).

As it is shown in the table, the usability heuristics cover all UD process-related principles. A few of remaining heuristics are hard to specifically match with any UD principle. Including or excluding these heuristics from the evaluation can depend on the nature of the evaluated design artifact. For example, in the case of wearable devices, the heuristic *Match* between *system and the real world*, *Recognition rather than recall*, and *Aesthetic and minimalist design* can be sometimes relevant. At the same time, the *Help and documentation* heuristic can be less relevant for the wearables compared to the web-based user interfaces.

Heuristic evaluation can be adapted in many ways. Rather than inspecting individual elements, it is often carried out by asking the evaluator to step through typical user tasks. This can combine heuristic evaluation with some of the benefits of a cognitive walkthrough (Fisk et al. 2009).

Considering design for wearables, usability principles are the most obvious that is followed by designers. Applied on the early phases of the design process, they are crucial for saving time and resources during the development phases.

Table 4 Match between process-related principles and usability heuristics

Process-related UD principles	Usability heuristics
Flexibility	Flexibility and efficiency of use
Error management	Error prevention
	Help users recognize, diagnose, and recover from errors
Efficiency	Flexibility and efficiency of use
	User control and freedom
Stability/predictability	Consistency and standards

6 Human Factors Principles

The *human factors principles* are situated at the lowest level of Erlandson's model. They include ergonomics, perception, and cognition principles.

The human factors discipline studies the characteristics of people and their interactions with products, environments, and equipment when they perform tasks and activities. The goal of human factors is an error-free, productive, safe, comfortable, and enjoyable human-system interaction. By considering human factors, engineers and designers should ensure that human-system and human-environment interactions will be safe, efficient, and effective (Fisk et al. 2009). Human factors engineers are called upon when a *human element* is an important part of an interaction with a device, system, or process (Phillips et al. 2006). That reason well corresponds to the case for wearable computing devices, as there the human elements are real parts of interaction with the system.

Dong et al. (Dong et al. 2015) reviewed six design tools, which they have recommended for use by professional designers and students to include inclusiveness into the design process. An *Inclusive Design Toolkit* (IDT) reviewed in that study is specifically focused on human abilities, which are directly related to Erlandson's *human factors principles*.

The Inclusive Design Toolkit is a well-known tool for the assessment of human factors. The main goal of the tool is to assess design artifact against different human abilities and to provide a level of inclusiveness of that artifact on the basis of the UK population data from 1997. IDT is developed in Cambridge University and available at the website of the Engineering Design Centre http://www.inclusivedesigntoolkit.com. The website contains guidance and resources, which reflect 12 years of inclusive design research, conducted by three successive inclusive design research consortia. In 2017, IDT received an update: the number of human characteristics was reduced from seven to five, probably for simplifying the assessment process.

According to Dong et al. (Dong et al. 2015), professional designers liked the main features of IDT including interactivity, navigation, case studies, usefulness for business cases, easy accessibility on the web, and free cost. In turn, design students appreciate features like comprehensiveness, accessibility, free of cost, nice information architecture, clear instructions, useful user capability data, well-structured contents, and good illustrations. Both professionals and students noticed that the toolkit can be used for research or design (in both initial and final stages).

IDT focuses on product interactions, which place demands on the users' capabilities. If any of users' demands are higher than their capabilities, users may be excluded from using a product. For example, a visual product with very small text requires a high level of vision capability. People with age-related long-sightedness will be excluded from its use.

IDT proposes to make an initial assessment by rating the demand on each capability on a ten-step scale from low to high (Fig. 3). To do that, the following various factors should be considered (Clarkson et al. n.d.):

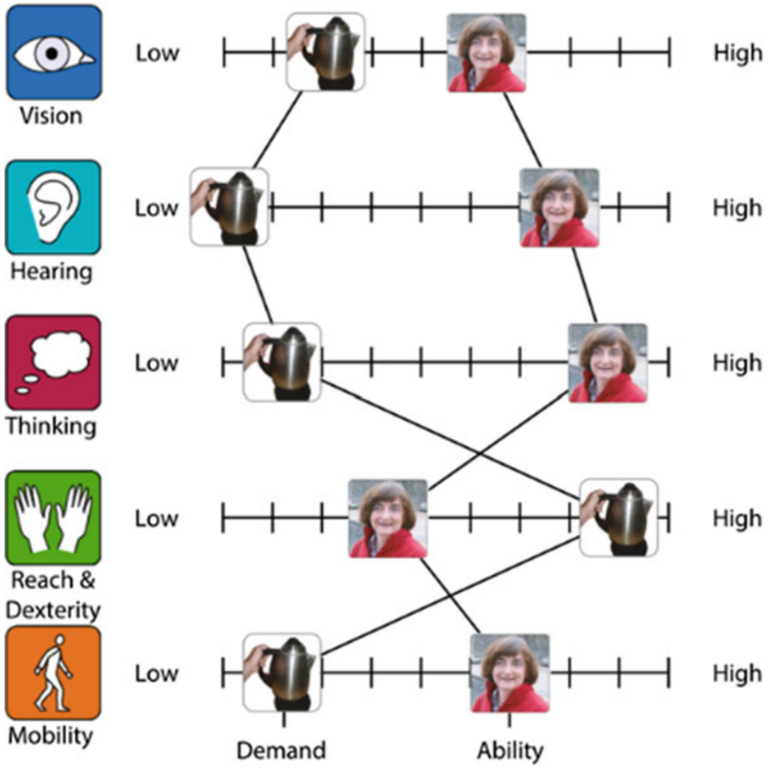

Fig. 3 Scale for the level of demand that a product places on various capabilities and human abilities of a persona aimed at using the product (Clarkson et al. n.d.)

- For *vision* – the size, shape, contrast, color, and placement of graphical and text elements.
- For *hearing* – the volume, pitch, clarity, and location of sounds produced by the product.
- For *thinking* – how much demand the product places on a user's memory, how much it helps the user to interpret its interface, how much attention it demands, and how much prior experience it assumes.
- For *reach and dexterity* – the forces, movements, and types of grip required to use the product. The demands will increase if tasks should be performed with the hands reached above the head or below the waist.
- For *mobility* – whether the product requires the user to move around. If designing an environment or service, consider whether it provides suitable features to assist balance and support mobility aids.

We have used the same factors also in the adapted checklist of protected characteristics in equity principle (see Sect. 4). The difference is that in the human factors assessment phase, these factors are being examined in detail and thoroughly, while in the equity phase, they are considered concisely.

The human factors defined in IDT are well aligned with Erlandson's human factors principles. The vision and hearing allow checking the design artifact against the perception; the thinking, against the cognition; and the reach, dexterity, and mobility, against the ergonomics.

The scales for demand in each of the five categories range from low to high (Fig. 3), where low and high provide a relative measure when one product or scale is compared to another (Stephanidis 2009).

Although the scale measurements may look crude, they are easy to use as an initial tool and can provide an effective visual comparison between alternative products or concepts. This can be useful for initially setting up the design requirements, as well as for evaluation working prototypes in the following design stages.

Using the IDT scale is especially useful when designers develop a set of personas, based on the actual encounters with target user groups with the different abilities. In that case, the user demands of the design artifact can be mapped on the abilities of the personas on the same scales.

Many people experience more than one capability loss in the form of multiple minor impairments. For this reason, estimating the number of people who would be excluded from using a product requires a single data source that covers all the capabilities required for cycles of product interaction (Stephanidis 2009). IDT proposes for that a separate tool, which is called *Exclusion calculator*[2]. The calculator can be used to estimate the proportion of the population that would be unable to perform specific tasks that require a specific level of demands. The process of estimating exclusion highlights the causes of frustration and exclusion and prioritizes these on a population basis (Waller et al. 2015).

Applying the human factors principles seems as one of the most distinctive design practices compared to the other fields of design. A good example is a computer display: the displays have the same sets of standard sizes, with somewhat different pixel resolutions for everyone. The displays do not need to adapt to the end users with different body compositions or different perception abilities. Just the opposite, the end users adapt to them. However, that does not work, when one has to wear a part of human-computer interaction hardware on a body. In such case, designers have to consider personal differences among users at the first place. The resulting wearable product has to be tailored to the user's needs either have a possibility or to adapt to the diversity of the users.

7 The Tool

Below, the questions from the UD-based tool are presented.

[2] http://calc.inclusivedesigntoolkit.com/

Universal Design evaluation tool
The tool is divided into five sections: background data, equity-related questions, process-related questions, human factors-related questions, and finalizing questions
Background data
Please enter the title of your project
Please provide a short description of your project
What is your field of study/occupation?
Do you have previous experience in design?
How many years of design experience you have?
Please enter your age
Equity-related questions
Please select *positive/negative/neutral* and make comments on your choice
What kind of impact your product may have on Age of the users?
What kind of impact your product may have on any Disability of the users? Consider please Vision, Hearing, Attention, Memory, Reach and Stretch, Dexterity, and Locomotion abilities
What kind of impact your product may have on Gender reassignment of the users?
What kind of impact your product may have on Marriage and civil partnership of the users?
What kind of impact your product may have on Pregnancy and Maternity of the users?
What kind of impact your product may have on Race of the users?
What kind of impact your product may have on Religion or Belief of the users?
What kind of impact your product may have on Sex of the users?
What kind of impact your product may have a Sexual orientation of the users? (Disadvantaged groups are groups of persons that experience a higher risk of poverty, social exclusion, discrimination, and violence than the general population. Disadvantaged groups include, but are not limited to, ethnic minorities, migrants, people with disabilities, isolated elderly people, and children)
Process-related questions.
Please select *Yes/No/N.A.* and make comments on your choice
Has your product error-prevention functionality?
Does your product help users to recognize, diagnose, and recover from errors?
Is your product flexible and efficient of use?
Does your product provide enough user control and freedom for both first-time and experienced users?
Does your product follow the standards accepted in the same field? Is that consistent enough?
Human factors-related questions
Please rank the user abilities for your target persona. Use a four-step scale from “Zero ability” to “High ability”
Vision ability
Hearing ability
Thinking ability
Reach and dexterity abilities
Mobility ability

Please rank the user abilities required for your product. Use a four-step scale from "No Demand" to "High Demand"
Vision ability
Hearing ability
Thinking ability (memory, attention)
Reach and dexterity abilities
Mobility ability
Is there any product demand above that is ranked higher than the persona's user ability? Yes/No
If yes, please describe what the product demands are higher than your persona's user abilities.
What design changes may be done to avoid that issue?
Finalizing questions
Please summarize what the design issues were identified?
What kind of solutions do you see for solving those issues?
How useful was this assessment tool for you?
What would you like to improve?

8 Evaluation

The first evaluation of the tool was conducted on a basis of a 2-week Experimental Interaction Design course at Tallinn University. In that course, students learn about the iterative co-design process including ideation, low-fidelity prototyping, evaluation of the prototypes, high-fidelity prototyping, and evaluation of Hi-Fi prototypes. The UD-based tool was used for evaluating low-fidelity prototypes. Thirteen students from China, South Korea, Japan, Germany, Belorussia, and Estonia were self-organized in four design teams, and each team worked on their own design idea for wearable devices. Three of the students had a limited (less than 1 year) experience in product design, art design, and brainstorming. The median age of the students was 23 years. The theme of the workshop was "Designing wearables for health and wellbeing."

The design teams were working on their prototypes for 2 weeks, 4 hours per a day. The first week was implemented in Interaction Design lab, where teams focused on the definition of a problem, ideating, user modeling, scenarios, and low-fidelity paper prototypes (Fig. 4).

Then students had to conduct an evaluation by using the UD-based tool. On the second week, students were moved to the hardware lab, where on the basis of their adjusted low-fidelity prototypes, they have implemented the high-fidelity prototypes using sensors and controllers (Fig. 5).

For the evaluation, a separate, 1-hour session was allocated. All students have used the computer lab for accessing online tool implemented on the basis of LimeSurvey engine. Though students worked in teams, they conducted the evaluation individually. That was made with an intention to see how different their grades will be.

Fig. 4 The team of students works on a prototype of wearable solution for a posture tracking

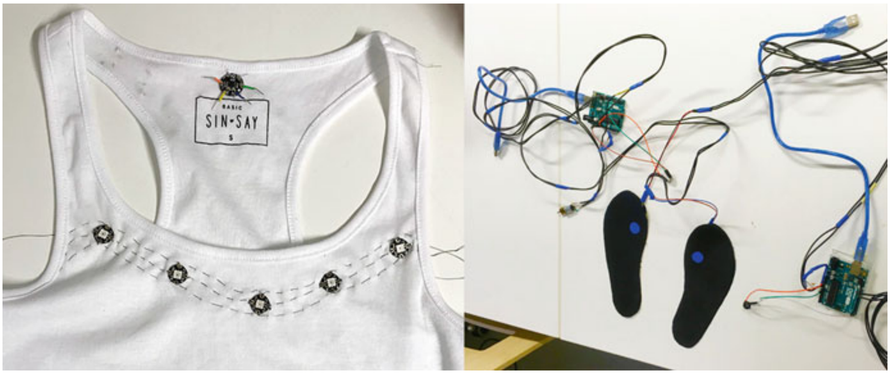

Fig. 5 High-fidelity prototypes “Balerina’s back” and “Smart insoles”

First, the students were asked to make a brief description of their projects. After asking what kind of impact the product may have on each of the protected characteristics, students were prompted by the questionnaire to comment their choices. The *Age*, *Disability*, *Pregnancy*, and *Maternity* characteristics received the greatest attention of the students. There are some comments they have left:

The Race, Religion or Belief, and Sexual orientation characteristics were mostly ranked as receiving the neutral impact.

Age	"Elderly people may have a more difficult time working with the product (for fitness) because it requires adjusting the balance while moving and exercising. However, elderly people would also benefit from its balance monitoring and feedback function in their daily lives since they may not have great balance anymore and may be susceptible to falling as a result"
Disability	"Some group of disabled people may consider our product to be difficult to use due to the requirement of the vision ability and hearing ability. However, we are trying to insert the vibration signal to make up for that"
Pregnancy and Maternity	"It is also possible to them if modulate electromagnetic or something bad to a baby"

Next, the students have assessed prototypes against of the set of Usability Heuristics. This part was well commented: the students have found a variety of the process-related problems.

In the following part of the questionnaire, the students have ranked user's (persona) human abilities like vision, hearing, thinking, reach and dexterity, and mobility, required by product and the same abilities for the product demands. They had an option to compare the results of abilities and demands and to analyze if there is any demand that is ranked higher than the persona's user ability. The students answered "No" 12 times and "Yes" one time. That means, one student found the product demands higher than the expected user abilities.

After answering all questions, students were asked to answer three concluding questions. The first question was "Please summarize what the design issues were identified?". There are some answers from the students:

Answer	Addressed principles
"I need to consider groups of different ages and disabilities"	Equity-related principles
"Pregnancy women can't use it. Pure people can't use it. Users have to remember to wear underwear and accessory, it takes more time"	Equity- and process-related principles
"In case we are designing a product for children, they would easily get bored of the simple interactions, so we need to come out a long-term motivation system"	Equity-related principles
"So far, we haven't considered the error prevention functionality. It will be good to have that function reconsider for our projects. And we will try to consider including the benefits of using the product for the disadvantaged groups as well"	Equity and process-related principles
"We have not considered children with disabilities in the design stage, and after evaluating I have realized the design may have a positive impact on children with disabilities as it's easy to use and understand but still we have to discuss and review disabilities like deaf, blind and dexterity"	Equity and human factor principles

The second concluding question was: "What kind of solutions do you see for solving those issues?". Here are some students' answers:

Answer	Addressed principles
"To make a watch that young and the old can both use easily. Reduce complexity and make it simpler"	Process-related principles
"Orient to our user group excluding poor people and pregnant women. Add for the first a vibration for underwear and changing non-stop color if a user uses only one part of it (for example wear one underwear and forget about ring) - a signal for connection underwear with the accessory on your body. Notification on phone for the reminder"	Equity and process-related principles
"We have to discuss and find solutions, but there are many options for us, we actually just have to make decisions"	(Indicates an importance of discussing the found issues in a team)
"Do further research and personas"	Human-factors principles

The last concluding question was related to the tool itself. We asked the workshop participants: "How useful was this assessment tool for you? What would you like to improve?" The overall feedback was positive:

- "It helped me think about the view of our target for the product."
- "Tools helps me think about movements that I missed. It's useful."
- "This assessment tool seems to be a lot more helpful than I expected it to be before trying it. It makes you rethink and question your ideas and helps you verbalize your doubts."
- "Already the task of describing briefly the product was a good task", and "It was useful."

The students also have proposed several aspects that could be improved in the tool.

Answer	Revealed issue
"We can't measure people who have diseases. (This says only disorder)"	That one shows an issue with "not enough" – "too many" questions. There is always a trade-off between a level of deepness and demanded efforts required from a user of such tools
"In my opinion, some multiple-choice questions' wording could be improved because some of them are not very clear for first-time-users, but overall it is a very helpful tool"	That comment shows that we must supply the tool with detailed explanations and think about an adaptable version of the tool, that could consider the level of the designer

To summarize, the evaluation has shown that use of the tool has made students to examine their wearable prototypes from different perspectives and has contributed to the deeper analysis of the target audience. The students have made the evaluation individually. After finishing that, they had an option to discuss their finding in the design teams and exchange their opinions and ideas. Finally, the students reported about improvements they have made in the design of prototypes.

9 Conclusion

In this study, we have reviewed the layered UD model of Erlandson and proposed a set of evaluation tools that cover all the layers of the model (Table 5). Initially, the target for the new combined tool was the wearable technology. However, as we have understood later, the same tool can be used for other types of design projects that are different in ways for interaction compared to the traditional screen-based devices.

The proposed UD-based tool can be used as in the early design stages, like defining business cases and initial scenarios, as well as for the late evaluation of the high-fidelity prototypes. In both cases, the tool may help to have more attention to the users with different abilities and to introduce more empathy in the design [38].

On the basis of the tools mentioned above, we have created an interactive online questionnaire aiming to support the design and evaluation of human-computer interactions. The proposed tool may be useful for the introduction of Universal Design principles to the designers of wearables but can be applied to other types of technologies as well. However, the design tools are dependent on the media they are intended to evaluate. In a case of the wearable user interfaces, we have many aspects that can be not relevant in the traditional, screen-based user interfaces. Wearable computing causes additional challenges for designers because of higher diversity in abilities and limitations of the end users.

Considering the practical usage of the tool, we propose to start the evaluation in a top-down manner, from general to specific. The protected characteristics defined in the Equality Act 2010 are proposed as a basis for the assessment of equity. It can focus the attention of the designers to the specific groups of the end users that could be otherwise excluded from the design. Precise determination of such groups should help to avoid crucial errors in the initial design phases.

When the equity assessment is finished and the design is adjusted in accordance with results of the first-step evaluation, the usability assessment step is proposed to be conducted by using the Nielsen's usability heuristics evaluation method. That should help to ensure that the process-related principles are addressed in the design.

Table 5 The composition of the evaluation tools with corresponding layers of DU principles

Groups of principles	Tools for evaluation
Transcending principles	A tool based on the protected characteristics defined in the Equality Act 2010
Process-related principles	Nielsen's Usability Heuristics
Human factors principles	Inclusive Design Toolkit

After finalizing the usability checking and making sure that process-related issues are solved, the demands for human factors can be evaluated. For that purpose, based on the Inclusive Design Toolkit, a set of questions can be used. After measuring the product demands, the set of prepared early personas can be used again, to check their abilities against measured demands.

Considering the practical implementation, the tool still requires additional development. The tool requires more testing in the labs. The first evaluation shows that the designers found the tool as useful and found ways for improving their prototypes by addressing equity, process, and human factors-related issues. We see the requirements for improving documentation of the tool and adding possibilities to use tool for internal communications inside of the design team. We also think that a mobile implementation of the tool may be very useful. A possibility to use the tool on mobile devices will allow the designers to quickly test their design of the wearable devices in the field.

For sure, the tool proposed in this study is far from the final stage. We see different ways for extension of that by examining other evaluation frameworks. The practical design workshops show us that the quality of design for wearables is in a high degree dependent on awareness on the technical limitations. We think there is an empty niche in the field of technology awareness among designers.

The final goal is to develop an efficient, unified tool, which can help to evaluate design ideas or prototypes of students and professional designers.

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Experience Capturing with Wearable Technology in the WEKIT Project

Puneet Sharma, Roland Klemke, and Fridolin Wild

1 Introduction

For the daily smooth operations of an organization, experienced workers are vital at every level. By sharing their knowledge, experience, expertise of procedures, and best practices with colleagues, trainees, managers, and bosses, they build, maintain, and support the different functions of an organization. In addition, a number of studies (Mcdaniel et al. 1988; Myers et al. 2004) suggest that there exists positive correlation between job performance and job experience for both low- and high-complexity tasks. Industries are fully aware of that and are trying new ways to capture, support, and preserve the experience of an expert (Panopto 2017).

In order to address capturing, supporting, and sustaining the knowledge of experts, WEKIT (2017) is a European research and innovation project formulated with the aim to develop and test within 3 years a novel way of industrial training enabled by augmented reality and wearable technology. The WEKIT industrial learning methodology comprises of capturing experience of an expert and reenacting the experience for training novices, with the former being the focus of this article, while the accompanying article (Limbu et al. 2018) reports on the underlying pedagogical framework and methodology. The rest of the paper is structured as follows: first, we briefly describe the state-of-the-art experience-capturing systems. Second, we outline the different use cases associated with our project. Third, we

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explain the different experience-capturing mechanisms and provide a mapping of such mechanisms to low-level sensors. Fourth, we discuss our proposed framework for experience capturing. Finally, we discuss the challenges and considerations associated with the proposed system and outline future research directions.

2 Background

Tsuchikawa et al. (2005) proposed a compact wearable computer unit for capturing human-to-human and human-to-object interaction using microphones, digital cameras, and infrared LED tags and their tracking. The authors relegated the analysis and evaluation of the captured data to a later stage.

Ros et al. (2017) captured stereoscopic point of view of surgeons in various neurosurgical procedures. For capturing, the authors used a specially designed system that consisted of GoPro cameras and LEDs for increasing brightness in the region of interest. The recorded data was enriched and played to other surgeons and practitioners on a VR headset. The results suggest that a majority of the participants agreed to the pedagogical value (mean quote 4/5) of the proposed system.

Hou et al. (2012) proposed a system for logging, recalling, and evaluating the learning log by passive capture of images associated with a language learning activity. In order to capture images, the authors used SenseCam (2017), a wearable camera that takes photos automatically. The authors suggest that their system captures too many images and many duplicates with poor contrast, and the capture can be improved by using image processing algorithms.

Other types of sensors include touch sensor proposed by Nakamura et al. (2018) which uses touch element worn on index finger for capturing visuo-tactile experiences. Heinz et al. (2006) proposed a set of body-worn gyroscopes and acceleration sensors to add ambient intelligence and context awareness to tasks such as martial arts training. The authors suggest that pattern recognition methods can be used to distinguish between different levels of expertise and the quality of movements associated with certain tasks.

The TellMe project (Bianchi et al. 2016) developed a new learning methodology for manufacturing environments, namely, eMeMO, a process model that iteratively refines the actual training experience using steps of enquiry, (re-)mixing learning activities, matching needs to learning resources, and optimizing through recommendations. Smart glasses and tablets were used for delivering learning content, also in augmented reality, for three different use cases (aviation, textiles, furniture).

Based on the state-of-the-art experience-capturing systems as shown in Table 1, it is clear that different prototypes are designed with diverse objectives, which means that they use different types of sensors. There is a need for a new experience-capturing system that can encompass different objectives across various domains, in other words, a generic prototype that can be used for experience capturing and training for various training scenarios (Fig. 1).

Table 1 Sensors used for experience capturing

Experience capturing system/prototype	Microphone	Camera	Wristband	Posture	Others
Tsuchikawa et al. (2005)	✓	✓	✗	✗	✗
Heinz et al. (2006)	✗	✗	✗	✗	✓
Hou et al. (2012)	✗	✓	✗	✗	✗
Ros et al. (2017)	✗	✓	✗	✗	✗
Nakamura et al. (2018)	✗	✗	✗	✗	✓
TellMe (2017)	✓	✓	✗	✗	✗

Fig. 1 The three use cases in the WEKIT project (2017)

3 Use Cases

The WEKIT project (2017) comprises of three use cases: aircraft maintenance (for Lufttransport), bioimaging (for Ebit), and astronaut training (for Altec). In aircraft maintenance (WEKIT 2017), the objective is to develop a process for safe and efficient aircraft maintenance for tasks such as preflight inspections, engine rigging, helicopter engine check, and communication and safety via shared mental modeling during shift handover. As an example in engine rigging procedure (Nergard et al. 2016), several steps are required for the maintenance of an installed engine in the different stages of ground run such as before the ground run, during, and after. Here ground run means checking the functionality of aircraft engines while on the ground. For instance, in Fig. 2, we can see a few instructions associated with setup of propeller levers in before the ground run stage. We can observe that it is a complex task; this means that for providing training associated with such intricate procedures, the information has to be presented to the user in a stepwise manner, it should be reliable and relevant to the task at hand, user's attention needs to be guided to correct components in a timely manner, and the user needs regular feedback to perform the task in a continuous manner.

In bioimaging (WEKIT 2017), the aim is to use healthcare IT systems for the workflow management of the radiology and cardiology diagnostic process for tasks such as structured reporting and image in situ inspection. In astronaut training (WEKIT 2017), the objective is to find effective ways for trainers and operational managers to communicate and understand performance on activities such that it reduces the numbers of mistakes on maintenance and training activities,

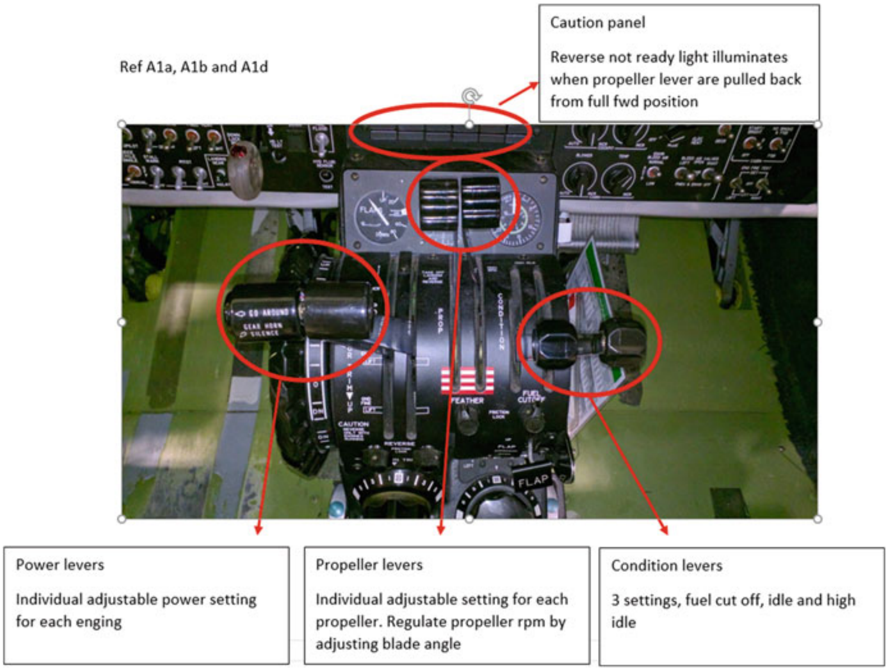

Fig. 2 Engine rigging instructions in the cockpit of Beechcraft B200 aircraft at Lufttransport (Nergard et al. 2016)

reduces the time needed for training, and also leads to faster recovery from mistakes in a safe manner.

The key objective that is common across the three use cases is improving safety and efficiency at the same time. Karanikas et al. (2017) suggests that there is a fine balance between safety and efficiency; furthermore, the experience obtained by doing own tasks and that transferred by experts to trainees are the key factors for improving safety and efficiency. In order to improve safety associated with critical tasks and estimate performance, there is a strong need for workers to be aware of their physical and mental states such as fatigue, attention, and stress levels.

4 Mapping Experience-Capturing Mechanisms

In their article, Limbu et al. (2018) formalize the experience-capturing mechanisms as transfer mechanisms where each transfer mechanism is defined as an instructional strategy or method that makes use of augmented reality and wearable technology for training purposes. The transfer mechanisms proposed by the authors (Limbu et al. 2018) include augmented paths, augmented mirror, highlight object of interest, directed focus, point-of-view video, think aloud protocol, cues and clues, annotations, object enrichment, contextual information, 3D models and animation, interactive virtual objects, haptic feedback, X-ray vision, and feedback.

In this section, we will discuss the different transfer mechanisms, associated sensors, their requirements, complexity of integration, and other considerations. Here, we define the complexity of integration as the difficulty associated with integration of a particular sensor hardware and software pertaining to a transfer mechanism. For instance, Microsoft HoloLens (2017) compromises of smart glasses with built-in integrated microphone array, a depth camera, ambient light sensor, and inertial measurement unit. This means that the complexity of integration associated with including microphone as a sensor with smart glasses will be low. On the other hand, including external biosignal sensors such as galvanic skin response with smart glasses will be high.

Augmented paths overlay virtual information over the physical world in a way that allows the trainee to follow motions of an expert accurately (Limbu et al. 2018). For this, we need to track the position of the person in the environment by employing inertial measurement units and provide a virtual visualization of the correct path. Furthermore, the guided path can be enriched by haptic feedback (discussed later). As shown in Table 2, the sensors pertaining to this transfer mechanism include smart or augmented reality glasses and inertial measurement units. A few key products that can be used include Moverio BT-200/2000 (2017), Microsoft HoloLens (2017), Sony SmartEyeglass (2017), Glass (2017), Meta 2 (2017), Vuzix M-100 (2017), Optinvent Ora-2 (2017), and ODG R7 (2017). As this transfer mechanism involves capturing and visualization of paths taken by an expert in the environment, the complexity of integration is low.

An *augmented mirror* is specified as a display with which the apprentice can track the own body movement (like in a dance room Limbu et al. 2018). For this, we need to track the posture of the person in the environment and show in the replay a virtual representation of the person performing a task. The posture can be estimated by using a set of inertial measurement units (IMUs), which are usually a combination of accelerometers, gyroscopes, and sometimes magnetometers. The IMUs can be placed across the body of the person and the captured information can be replayed on a smart glass. There are several possible products that can be used for IMUs; it is important to use a sensor with high degree of accuracy; furthermore, signal processing algorithms are needed to estimate the correct posture. The data from IMUs should be integrated with the visualization on smart glasses which can be technically challenging; and hence the complexity of integration is high.

Highlight object of interest is a transfer mechanism which indicates to the trainee what and where an expert looked during execution of a task (Limbu et al. 2018). This requires recording the gaze direction of an expert, e.g., recorded with an IMU or with an eye tracker integrated or mounted on a pair of smart glasses. For this, we need eye trackers that can be used along with smart glasses. A few key products include Pupil Labs binocular mounts (2017), SMI AR tracking (2017), and Tobii Pro Glasses 2 (2017). IMUs are built in, for example, into the Microsoft HoloLens but alternatively can be provided in the same way as for the augmented

Table 2 Mapping capturing mechanisms to sensors

Transfer mechanisms	Sensors	Key products	Complexity of integration
Augmented paths	Smart/AR glasses, and inertial measurement units	Moverio BT-200/2000 (2017), Microsoft HoloLens (2017), Sony SmartEyeglass (2017), Glass (2017), Meta 2 (2017), Vuzix M-100 (2017), Optinvent Ora-2 (2017), and ODG R7 (2017)	Low
Augmented mirror	Inertial measurement units (IMUs)	Several	High
Highlight object of interest	IMU or Eye tracking mount	Pupil Labs binocular mounts (2017), SMI AR tracking (2017), Tobii Pro Glasses 2 (2017)	Moderate (for IMU) to High (for eye tracker)
Directed focus	IMU or Eye tracking mount	Pupil Labs binocular mounts (2017), SMI AR tracking (2017), Tobii Pro Glasses 2 (2017)	Moderate (for IMU) to High (for eye tracker)
Point-of-view video	Head-mounted camera	Several hardware products including the possibility to use built-in integrated cameras on smart glasses	Low
Think aloud Protocol	Microphone	Several hardware products including the possibility to use built-in microphone on smart glasses	Low
Cues and clues	Head-mounted camera, smart glasses, microphone	Several	Low
Text annotations	Smart glasses	Several	Low
Object enrichment	Head mounted camera, smart glasses	Several	High
Contextual information	Smart glasses	Several	Low
3D models and animation	Smart glasses, armbands	Myo (2017)	Moderate
Interactive virtual objects	Smart glasses	Several	Moderate
Haptic feedback	Vibration motors	Several	Low
X-ray vision	Smart glasses	Several	Moderate
Feedback including awareness of mental and physical state	Galvanic skin response (GSR) band, smart armband, IMUs	Emphatica E4 wristband (2017) (GSR, heart rate variability)	High

mirror. Depending on the choice of sensor used for this transfer mechanism, the complexity can vary from moderate (for IMU) to high (for eye tracker). For instance, gaze estimation using eye tracking mount requires processing the video feeds by employing computer vision algorithms which accounts for high complexity of integration.

Directed focus provides a visual aid for locating objects outside the view of the trainee (Limbu et al. 2018). This mechanism requires recording the gaze of an expert during a procedure and later by using visualizations such as direction arrows to steer the focus of a trainee toward the correct target location. The same hardware configuration as for the object highlights described before can be used.

Point of view video is characterized as a mechanism that provides a recording from the head-worn camera point of view of the trainee/expert (Limbu et al. 2018); this type of information may not be available when captured from a third person perspective. For this, we need a point of view or head-mounted camera and interaction mechanisms for initiating, stopping, and zooming in the videos. Several hardware products are available including the possibility to use built-in integrated cameras on smart glasses.

Think aloud protocol involves making experts verbally describe actions and thoughts as they perform a task or provide an explanation. This information is associated with the mental processes of the expert (Limbu et al. 2018) and can be captured by using a microphone. For quality information, it is important to reduce audible noise from the environment during recording. Several hardware products are available including the possibility to use built-in microphone on smart glasses.

Cues and clues are pivots that trigger solution search (Limbu et al. 2018). This can be achieved by taking a picture, recording video, audio, or writing a text associated with a procedure. For this, we need sensors such as head-mounted camera, smart glasses, and microphone.

Text annotations expressed as tagging the objects in real world with virtual information (Limbu et al. 2018). For this, the user should be able to manually tag objects with relevant text information and in the replay see that text. It requires smart glasses for which several products have already been discussed before.

Object enrichment is a way of providing information about the physical object in the environment (Limbu et al. 2018). For this, the system should be able to recognize the object of interest in the environment. This object can be recognized by either using computer vision techniques or by employing a combination of infrared tags and image processing algorithms as proposed in the study by Koyama et al. (2016). Owing to these factors, the complexity of integration is high for this transfer mechanism. For recording and displaying information, head-mounted camera and smart glasses, respectively, can be used.

Contextual information is defined as providing input about a procedure depending on the context, i.e., trainee, expert, experience of the user, and the complexity of task (Limbu et al. 2018). This is mainly linked with using smart glasses for presenting relevant information. The contextual information should frame the user's activity at hand in the context of the overall user process and help the user to understand the current activity.

3D models and animation enable easy interpretation of complex models and tasks which may require high spatial processing ability (Limbu et al. 2018). For this, we need to create 3D models of objects of interest, their animation and interaction mechanisms using gestures. For displaying we can use smart glasses, and for interaction we can employ gesture-based armbands such as Myo (2017). As this transfer mechanism involves use of gestures for interaction with 3D models, the complexity of integration can be moderate.

Interactive virtual objects can be characterized as manipulating to practice on virtual objects with physical interactions, i.e., virtual objects move realistically in real-world space (Limbu et al. 2018). For this we need realistic 3D models of objects which can be viewed on smart glasses, and the interactions between real and virtual objects in the environment can be observed visually and via haptic feedback. Smart glasses such as Microsoft HoloLens (2017) map the space around the user in terms of 3D mesh surfaces that can be used for collision detection between the 3D models and the real world. Owing to these factors, the complexity of integration for this transfer mechanism is moderate.

Haptic feedback defined as providing feedback relating to the perception and manipulation of objects (Limbu et al. 2018). For this we need vibration motors that can provide a feedback to the user based on his or her actions. The complexity of integration for this transfer mechanism is low.

X-ray vision is expressed as a mechanism for visualizing the internal process or mechanism not visible to the eye (Limbu et al. 2018). For this we need simulation of the visualization of process or phenomenon associated with an object of interest. Computer vision algorithms are needed to identify the object of interest and correct visualization (over smart glasses) of the internal process or mechanisms. Due to these factors, the complexity integration for this transfer mechanism is moderate.

Feedback is described as providing summative and formative feedback (Limbu et al. 2018). It involves outlining the errors made by the test candidate based on an expert's data and providing an assessment of the overall performance of the candidate.

Special status thereby should be given to fostering reflection and awareness of mental and physical states of the user of a system. For this we need biophysiological signals such as heart rate variability, number of steps taken for a task, fatigue levels, and posture. The sensors include galvanic skin response (GSR) band for measuring emotional and sympathetic responses (Critchley 2002), smart armband (for heart rate variability), and IMUs (for posture). Owing to sensors such as heart rate and GSR and the associated challenges with estimating the mental and physical states of a person, the complexity of integration for this transfer mechanism is high.

The mapping from transfer mechanisms to sensors is not injective. For instance, a transfer function such as augmented paths requires both smart glasses and IMUs which means that we need multiple sensors. On the other hand, smart glasses (such as Microsoft HoloLens 2017) are equipped with a number of integrated sensors, which enable it to capture various transfer mechanisms. Some transfer mechanisms (e.g., contextual information, text annotations, 3D models and animation, and interactive virtual objects) need highly processed information provided by subroutines or software libraries of an API. Some transfer mechanisms (such as X-ray vision and object enrichment) are computationally expensive and can be impractical based on the current state of the art of wearable devices.

5 Proposed Framework

In this section, we described our proposed framework for experience capturing along with a detailed schematic. Later, we discuss the different considerations associated with the proposed prototype and possible future directions.

The proposed framework (as shown in Fig. 5) comprises of smart glasses with built-in integrated sensors. In addition, we need external sensors that are not part of the smart glasses. In order to collect, record, and store all the necessary data from the smart glasses and external sensors, we define a sensor processing unit (SPU) that can request, process, and store data from various sensors. Here the role of SPU can be performed by a stick PC such as Intel Compute Stick (2017) or similar platforms. The external sensors and the SPU can be provided power via a power bank. As an example, we can use Microsoft HoloLens (2017) and its built-in sensors for smart glasses. The proposed framework is modular which means that the different components of the system can be replaced by products from different vendors. Furthermore, this framework enables extension of the prototype by adding a number of external sensors and assigns the associated data processing to the SPU.

For the first wave of trials for the three industrial training scenarios (aircraft, bioimaging, astronaut), we used Microsoft HoloLens (2017) as the core system for experience capturing. While HoloLens (2017) can address a number of transfer mechanisms (as shown in Table 3 and Figs. 3 and 4), it cannot map all the transfer mechanisms. To this end, we plan to integrate Microsoft HoloLens (2017) with a number of other external sensors before the second wave of trials. In doing so, we can enrich the experience-capturing prototype with a number of different transfer mechanisms (as outlined in Table 3). For instance, using Myo (2017) we can use arm and hand gestures for interaction and hence support 3D models and animation. By employing IMUs and sensors for heart rate variability and GSR, we can address awareness of the mental and physical state of the user and support the *feedback* mechanism.

As shown in Fig. 5, we plan to use two IMUs on the back of the user to estimate the posture of the person, and this information will be combined with the integrated IMU in the smart glasses to estimate the head position. The posture estimation and the associated visualization can be improved by using more than two IMUs and also placing IMUs on different parts of the body such as arms and legs; however, this can reduce the wearability of the prototype and increase the hardware complexity of the system. Vibration motors can be used for haptic feedback mechanism.

Finally, eye tracking mounts can support mechanisms such as highlight object of interest and directed focus. As shown in a proposed schematic diagram (please see Fig. 5), smart glasses can be worn on the head along with eye tracking mount, IMUs

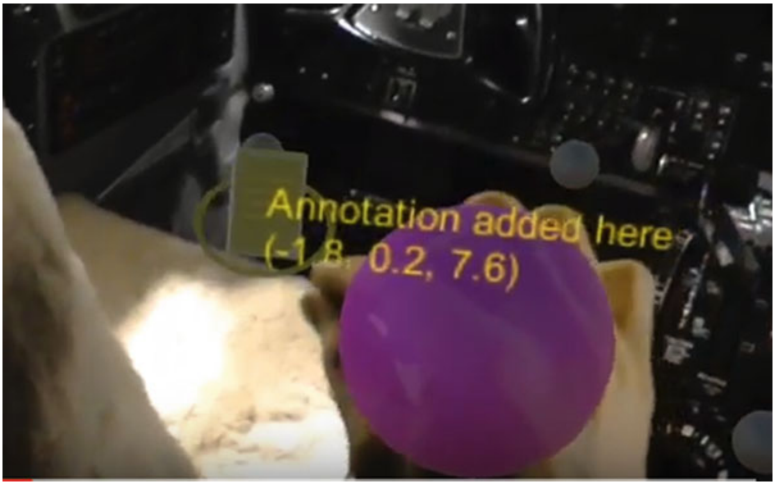

Fig. 3 Annotations using the WEKIT prototype. Here we can see an expert annotating an object in the cockpit of Beechcraft B200 aircraft at Lufttransport. This image is captured from the point of view of the user wearing the prototype

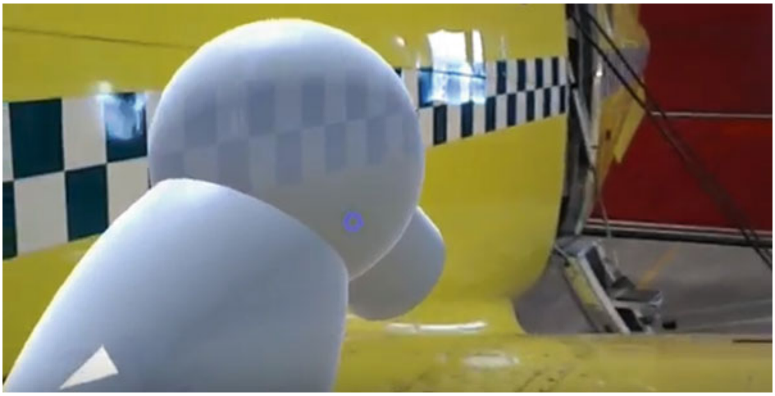

Fig. 4 Animations using the WEKIT prototype. Here we can see an animation of an expert in the form of a crude avatar outside Beechcraft B200 aircraft at Lufttransport

can be placed on the back of the user, heart rate variability can be measured by using an ear clip-based sensor (such as 2017), Myo (2017) armband can be placed on an arm, vibration motors can be placed on both arms, and finally power bank, SPU, and micro-controller for external sensors can be placed in the front.

The different transfer mechanisms described before have been realized in a lab setting, and they will be tested for the different use cases.

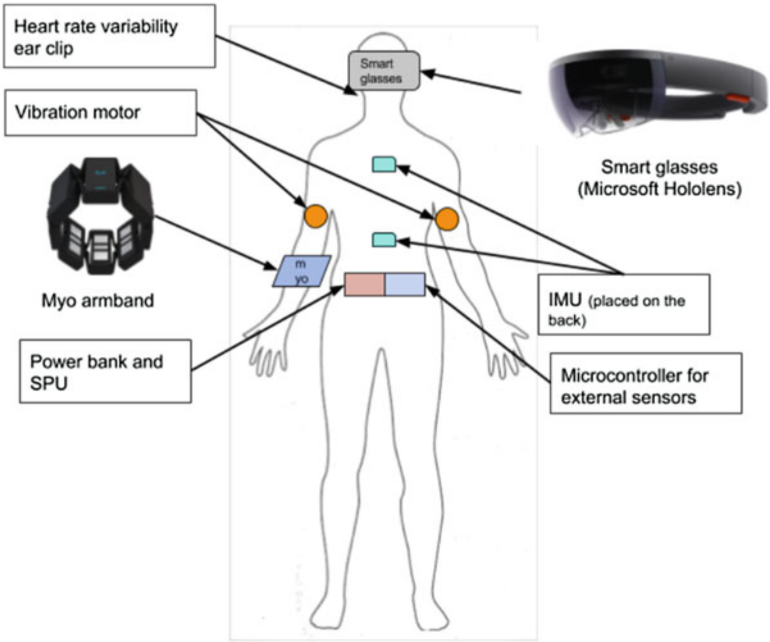

Fig. 5 Smart glasses can be worn on the head, IMUs can be placed on the back of the user, heart rate variability can be measured by using an ear clip-based sensor (such as 2017), Myo (2017) armband can be placed on an arm, vibration motors can be placed on both arms, and finally power bank, SPU, and microcontroller for external sensors can be placed in the front

Table 3 Overview of sensors in the proposed WEKIT prototype

Sensors	Transfer mechanisms
Microsoft HoloLens (2017) and built-in integrated sensors	Augmented paths, point-of-view video, think aloud protocol, cues and clues, text annotations, object enrichment, contextual information, 3D models and animation, interactive virtual objects, and X-ray vision
Myo (2017)	3D models and animation
IMUs, heart rate variability and GSR	Augmented mirror, and feedback
Vibration motors	Haptic feedback
Eye tracking mount	Highlight object of interest and directed focus

5.1 Discussion

For the proposed WEKIT experience-capturing system, we need the following considerations.

In addition to the smart glasses, all external sensors used in the proposed prototype should be wearable, which means that the external sensors should be placed on specific locations on the body of the user such that it does not interfere with the regular work-related tasks especially in use cases (such as aircraft maintenance and astronaut training) which require both the trainee and the trainer to move, bend, lean, and sit in the work environment.

All external sensors should be compact in size and lightweight; in other words, they should have an ergonomic design. For integration of all the sensors and the power bank in a wearable form, we will need a vest or similar garment that can hold all the components together. Furthermore, this garment should have a modular design to include or exclude different sensors on the basis of requirements and needs of the different activities associated with training.

In order to reduce the overall cost of the prototype, the external sensors such as heart rate variability, IMUs, and GSR can be implemented using open microcontroller platforms such as Raspberry (2017) and Arduino (2017). Both Raspberry (2017) and Arduino (2017) have a range of low-power microcontrollers such as Pi Zero (2017) and ESP32 (2017), respectively, with supported sensors that can be added in a modular fashion to the WEKIT prototype.

To transfer data across different units of the WEKIT system, different units can employ wired or wireless communication standards. Among the short-range wireless communication standards, Wi-Fi (IEEE 802.11) (2017), Bluetooth (2017), and ZigBee (2017) are more common, while in short-range wired communication, Universal Serial Bus (USB 2.0 and higher variants) (2017) is typically used. A test site containing machinery such as stators, rotors, gears, fans, and electrical and magnetic resonance imaging (MRI) machines can have significant levels of electrical noise. This electrical noise can interfere with wireless communication of data across different units. To this end, we can either use a robust wireless communication standard or employ a hybrid of both wireless and wired communication, such that the latter can be used for the noise-prone units of the system. In addition, the choice of communication standard is also influenced by the bandwidth requirements of the different units of the system.

The WEKIT prototype comprises of smart glasses and various other sensors that can collect a wealth of data. With this vast amount of data associated with a single user, there is also a strong need to take into account the privacy and security of the collected data. As suggested in a study by Roesner et al. (2014), there are several challenges associated with using multiple applications, several communication standards, multiple output devices, and sensors that are always recording. In order to address these issues, we can employ encryption of data, password protection of sensitive data, and data security layer in the software architecture of the proposed system.

5.2 Future Directions

In the future, the design of the WEKIT prototype can be enhanced including interaction buttons on the clothing textile itself (Stoppa and Chiolerio 2014). According to Stoppa and Chiolerio (2014), it can be achieved by employing conductive fibers (conductive fiber twisted with normal fibers), treated conductive fibers, conductive fabrics (using twisted metal wire, metal coating, or metal multifilament fibers), embroidery stitching patterns using conductive threads on regular fabrics, and conductive inks. Other approaches include creating graphical user interface like widgets with conductive embroidery (Gilliland et al. 2010).

Activity recognition using sensors aims to monitor the actions and goals of an individual on the basis of sensors such as accelerometers and gyroscopes (Ravi et al. 2005). Activity recognition can be used to enrich context awareness of the proposed learning prototype by estimating factors such as correct posture and gait, correct application of force for performing a task, and the task itself. For example, in a study by Ravi et al. (2005), their machine learning algorithm is able to distinguish between eight different sets of activities on the basis of accelerometer data alone. In the WEKIT prototype, a number of sensors, such as IMUs, heart rate variability, and GSR, have been proposed. In the future, the data associated with different sensors can be analyzed by using machine learning algorithms to refine and support the context awareness and wider aspects of experience capturing.

6 Conclusion

In this paper, we focus on capturing an expert's experiences using augmented reality and wearable technology. For this, first, we outline a set of high-level tasks that support the transfer of experience from an expert to a trainee. Next, we describe a mapping strategy to associate each task with one or more low-level functions such as gaze, voice, video, body posture, hand/arm gestures, biosignals, fatigue levels, haptic feedback, and location of the user in the environment. These low-level functions are then decomposed to their associated state-of-the-art sensors. Based on the requirements and constraints associated with the use cases from three different industrial partners, we propose a set of sensors for the experience-capturing prototype. In the end, we discuss the attributes and features of the proposed prototype, along with its key challenges, constraints, and possible future directions.

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Wearables for Older Adults: Requirements, Design, and User Experience

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1 Demographic Change and Digital Health Technologies: An Introduction

Our society is getting older. Current forecasts show that the process of population aging is continuing in most countries, both industrial and developing. In this context, it is expected that the proportion of people aged 60 and older will increase by 56% between 2015 and 2030. This means that while by 2015, every eighth person worldwide was 60 years or older, by 2030, it will be every sixth person. Furthermore, by 2030, there will be more people aged 60 and older than those aged 10–24 (United Nations 2015).

As a result of this demographic change, a progressive structural change is taking place that affects various areas of society, such as the working world, infrastructure, social security systems, and the healthcare sector. Major challenges in the healthcare sector especially include the growing need for care and changes in social care needs. On the one hand, these result from an increase in chronic degenerative and age-related diseases. On the other hand, they are linked to changing social and natural (and other external) environmental influences and the associated changes in the health behavior of the population (Fischer and Krämer 2016). Furthermore, as people's life expectancy increases, new lifestyles of aging are emerging, with healthy aging as the center of attention (Bundesministerium des Inneren 2015). For many older people, maintaining their own health is a highly complex and long-term

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task in life. Many healthcare institutions and professions are involved in this task, but increasingly, the elderly themselves and their relatives are becoming involved. The importance of people's active participation in the treatment process, as well as their ability to deal competently with health-related questions, plays a central role in the face of increasing healthcare issues. Therefore, an essential task in societal healthcare is to improve its ability to autonomously and independently manage its health, i.e., educating and promoting general social, mental, physical, and disease-related competencies.

In this context, great expectations are associated with the advent and rapid diffusion of digital technologies in the healthcare sector. Digital technologies are expected to contribute to higher quality and efficiency in disease prevention and medical care, enable better economic efficiency of service delivery, help focus more strongly on the needs of patients, increase access to health-promoting services, and strengthen the individual responsibility of citizens in health issues (Kramer and Lucht 2015). Electronic health, or eHealth, has become the generic term for these technologies in healthcare. Although no standardized definition has been agreed upon, in the international context, reference is often made to Eysenbach's broad definition (2001), which describes eHealth as

> An emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the internet and related technologies. In a broader sense the term characterizes not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care locally, regionally, and worldwide by using information and communication technology. (p. 1)

With regard to the expected outcomes of eHealth solutions and services, the term also refers to the improvement of quality, accessibility, cost-effectiveness, and efficiency of healthcare and disease treatment through health-related products and services based on information and communication technology (ICT) (Oh et al. 2005). Of particular importance in the field of electronic healthcare is the segment of mobile health, or mHealth technologies. These are "[...] medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (World Health Organization 2011). Furthermore, digital applications (apps) are added to the field of mHealth services, "[...] such as lifestyle and wellbeing apps that may connect to medical devices or sensors (e.g. bracelets or watches) as well as personal guidance systems, health information and medication reminders provided by sms and telemedicine provided wirelessly" (European Commission 2014). Looking at the growing importance of mHealth services from a health economic perspective, by 2025, global market revenue is forecasted to reach USD 1184 billion (Transparency Market Research 2018). It seems remarkable that market growth is primarily determined by the second health market, such as consumers and start-up companies, rather than by the main players in the first health market (European Commission 2014; Scheel 2013). The sustained growth momentum is largely attributed to the proliferation of smartphones and tablets, as well as the ongoing expansion of the mobile network (European Commission 2014).

The great potential of mHealth solutions lies in the ability to use sensors (e.g., wearables) and mobile apps to collect and evaluate significant amounts of medical and physiological data, as well as activity and environmental data. These could be used for evidence-based care practice and research and for providing patients with access to their health information at any time and place (European Commission 2014). In addition, the combination of mobile communication technologies with medical devices and the health and social care sectors is expected to open up many opportunities for new business models. While currently the most attractive market segments are still in the areas of well-being, lifestyle, and fitness applications, app providers expect the market potential to increase in the future for the applications of therapy monitoring and follow-up (53.2%), counseling and coaching (38.2%), and diagnosis (31.7%). Target groups of mHealth services include patients with acute illnesses or those who are chronically sick, persons who are interested in health and fitness, physicians, caring professions, insurers, and other groups (Kramer and Lucht 2015).

For the target group of patients, significant potential is seen in the possibilities of raising awareness of health issues and increasing responsibility for one's own health. The possibilities of mHealth technologies, such as providing easier access to understandable health information, enabling autonomous identification and transmission of health-related data, or prompting self-motivation to comply with diet plans or take medication through memory systems, is expected to promote awareness of one's own health and enable greater participation in medical decisions (European Commission 2014). This should allow patients to take a more participative role in the treatment process. For the group of chronically ill patients, in particular, mHealth services are expected to help to reduce physical and psychological efforts in comprehensive ambulant or stationary check-ups through monitoring and remote counseling (Endl et al. 2015). Despite the considerable potential of mHealth services as complementary forms of healthcare, there are several barriers to their deployment, such as the complex regulation of the healthcare industry, the industry's reluctance to embrace innovation, insufficient evidence regarding the medical and economic benefits of mHealth services, a preference for diagnostic and therapeutic measures for prevention and education, and, historically, unclear legal framework conditions for estimating potential risks (Scheel 2013).

2 Wearables and Apps in Healthcare

Wearable technologies are becoming increasingly important in the area of mHealth services. Wearables are small electronic devices worn on the human body, in which different sensors for measuring physiological and physical data are installed. Depending on the complexity of the installed sensors, wearable computing devices can record geographic location and acceleration vital-sign data, such as heart rate,

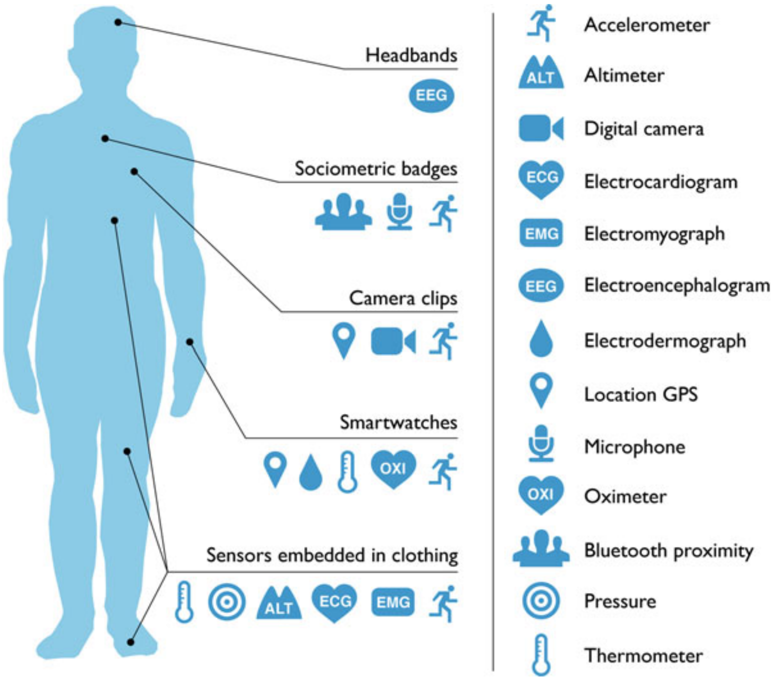

Fig. 1 Overview of possible measuring points and measurement variables of consumer wearables (Piwek et al. 2016)

heart rate variability, skin conductance, oxygen saturation, blood glucose level, and blood pressure; the devices can also execute complex measuring methods such as electrocardiograms (ECGs), electromyograms (EMGs), or electroencephalograms (EEGs) (Mischak 2017; Piwek et al. 2016; Schumacher 2016).

Wearables are often worn on the wrist (as wristwear, e.g., smart watches and fitness bracelets), on the head (as eyewear, e.g., Google Glass, or as earwear, e.g., smart headphones), in everyday clothing (as smart clothing), or on the skin (as smart plasters) (Mischak 2017; Moll et al. 2017; Piwek et al. 2016). Figure 1 provides an overview of measurement points and variables in the area of consumer wearables.

Furthermore, wearable computing devices have different interfaces such as Bluetooth, near-field communication (NFC), or Wi-Fi, which allow transmission of the measured sensor data to most Internet-enabled devices, such as smartphones and tablets (Moll et al. 2017; Schumacher 2016). On these devices, the transmitted (raw) data are aggregated and processed by specific applications (Moll et al. 2017). Some wearable devices focus on specific functions with a limited set of features, such as fitness and activity trackers. Others, like Google Glass, are complex and multifunctional systems. A further key characteristic of wearable computing devices is to provide users with contextual support without restricting their attention or mobility (Bliem-Ritz 2014). In contrast, the operation of conventional mobile systems requires that the users interact either with the system or with the environment, as they must focus on the interface. Wearables instead enable the users to interact simultaneously with the system and the environment (Lukowicz et al. 2004). Additionally, these technologies should empower their users to have more autonomy and control over a specific theme (Moll et al. 2017; Schumacher 2016).

Schwartz and Baca (2016) distinguish three types of wearable technologies. The first type consists of wearables developed for the general public, which Schwartz and Baca refer to as "common" or "commercial." Another type, which is mainly used in the scientific field, includes "advanced" or "high-quality" wearables. Finally, the third type consists of "experimental" wearables, which are still largely in the development stage. Differences between the three types mainly exist with regard to the access possibilities of raw data, the resolution of data, the algorithms used, the validity of the data, and, finally, the price (Schwartz and Baca 2016).

The market potential of wearable technologies is generally rated as high (Growth from Knowledge [GfK] 2017; International Data Corporation [IDC] 2018; PricewaterhouseCoopers AG Wirtschaftsprüfungsgesellschaft [PwC] 2015). According to the International Data Corporation's World Quarterly Wearable Device Tracker, global sales in 2018 will increase to 15.1%, or 132.9 million units (IDC 2018). In addition, it is estimated that the compound annual growth rate (CAGR) of the total market will reach 13.4% over the next 5 years. In this context, it is expected that 219.4 million devices will be sold in 2022 (IDC 2018). According to PricewaterhouseCoopers (2015), the United States and South Korea are leading with regard to the use of wearable technologies. Furthermore, the strongest demand can be observed in the emerging markets in Asia, Central and Eastern Europe, and Latin America (GfK 2017).

The fitness movement, in which a growing interest in new possibilities of self-measurement has emerged, has been notably responsible for the great popularity of wearable technologies. The credo of the so-called quantified self-community self-knowledge through numbers illustrates the central assumption of being able to gain insight into one's own way of life and to trigger behavioral changes by recording and evaluating body and behavior-related data. Continuous self-measurement should thus create an awareness of health-promoting behavior and should empower users to make constructive decisions in relation to their own behaviors (Schumacher 2016). In this context, wearables are used specifically for activities of self-measurement, self-control, and self-optimization. With the aim of improving lifestyle and health development, activity, nutrition, and sleep are core areas of self-measurement in the end consumer area. In addition to the continuous logging, analysis, and visualization of individual data, users' external motivation to develop an active and healthy lifestyle is a central function of the wearables and the mobile applications connected to them (Schumacher 2016).

Another area of rising importance for wearable technologies is the industrial context. Potential application fields include logistics, production and maintenance, and repair (Rügge 2008; Seyrkammer 2015). In the context of pilot projects, there have been evaluations of different application scenarios, such as the optimization of inspection on the basis of smart glasses or multimedia expert consultations (Seyrkammer 2015). An additional focus on the use of wearable technologies pertains to the area of workplace health promotion, in which companies hope to reduce the costs of illness and increase productivity. In the United States, in particular, different companies use wearables and fitness apps to motivate their employees to be more active and offering them different beneficial systems (Moll et al. 2017).

The importance for the healthcare sector of mHealth solutions, in general, and wearable technologies, in particular, lies primarily in direct access to health-related data, which was previously insufficient or not available at all. In this regard, the "[integration] of vital-sign data, health-related behavioral data, and environmental-exposure data with clinical and genetic data" (Amft 2018) promotes insight into the development of certain diseases and how the development correlates with patients' everyday life activities and lifestyles (Genaro Motti and Caine 2015; Lukowicz et al. 2004). Additionally, the use of wearable technologies in the treatment process offers the opportunity for remote monitoring of a patient's health status. As a result, hazards and emergencies could be detected at an early stage so that hospital stays could be reduced and readmission rates decreased. Preventive and diagnostic healthcare services could be provided, and established treatments could be optimized by the individualization of these services (Malwade et al. 2018). Furthermore, these insights could be used to establish individualized education programs both for prevention and therapy. In sum, wearable computing solutions could enable more personalized healthcare and could organize the entire care process more efficiently, which would lead to cost saving. Relevant fields of application for wearable technologies are primarily prevention, diagnosis, and rehabilitation. According to Genaro Motti and Caine (2015), wearables are used as assistive technologies for the expansion of the human senses, as prosthetics for the replacement of organs or extremities and as medical devices for the monitoring of specific diseases. In addition, the two authors name five fields of application that particularly benefit from the potential of wearable technologies. The first field of application is chronic disease. Examples of the use of wearable solutions are glucose measurement and control of insulin pumps in diabetes mellitus and tremor measurement in Parkinson's disease. Another field of application concerns mental health. Wearable solutions are used in situations such as monitoring the behavior of autistic children or for stress management. The third field concerns the use of wearables as assistive technologies to expand the human senses of people with certain impairments or disabilities. Examples include navigation for people with visual disabilities, the increase of color contrasts for people with color blindness, and the extension of acoustic feedback for people with auditory disabilities. A fourth field of application is the monitoring of specific diseases. Examples include recording the drinking habits of alcoholic patients, monitoring high-risk cardiac/respiratory patients, and monitoring the eating and activity behaviors of overweight patients. Finally, the fifth promising field of application for wearable technologies is support for health-related behavioral changes. Although different limitations in the current development of wearables do not yet successfully enable support for behavioral changes, there is still great potential. One of the core opportunities for wearable technologies is to provide objective data, which means that there would be no need for self-reported data that might be biased. In addition, it means that sensors would automatically gather the data, so that in principle there would be no interruption in the data history. Besides data collection, another core opportunity for wearables is providing analysis and visualization of different entities of health-related behavioral data. In connection with personalized feedback and advice functions, wearables can provide support in the process of health-relevant behavioral changes; this can be done by alerting the user if target parameters are not reached and drawing attention to the underlying causes (Genaro Motti and Caine 2015; Kelders and Howard 2018).

Despite the diverse potential of wearable technologies in healthcare, their use should be accompanied by a trained expert (Genaro Motti and Caine 2015; Schwartz and Baca 2016). The integration of these technologies into the healthcare system requires the provision of necessary skills for health and disease management, as well as related media skills (Kramer and Lucht 2015). Current target groups of mHealth solutions focus predominantly on the needs and skills of younger people who are familiar with intelligent technologies and are already using them regularly in their everyday lives. These technologies are also important for older adults, who place special demands on the design, usability, and performance of wearable technologies. In addition to these requirements, which will be described in more detail below, the main challenges for the use of wearables in the healthcare sector are technical requirements and data security (Bienhaus 2016; Schwartz and Baca 2016). An important issue in this context is the validity of the data, which is related to the access possibilities of raw data, the resolution of data, and the algorithms used (Schwartz and Baca 2016). Most current commercial wearables on the market are lifestyle and fitness products that are not comprehensively calibrated and specific like medical-grade devices (Chiauzzi et al. 2015). Further, interoperability and standardization of data collection, processing, and analysis are crucial for the use of wearable technologies in the healthcare sector to enable the transferability and comparability of measurement results. Many manufacturers use their own proprietary protocols, which leads to the development of fragmented software environments in which information can only be exchanged between the technical devices to a limited extent, or not at all (Dimitrov 2016). Another challenge, which also represents one of the biggest deployment barriers, is data security. User data are often stored on the manufacturers' cloud servers, so further use by third parties or for advertising purposes cannot be excluded (Kelders and Howard 2018). An additional issue in this context concerns the complex relationship between users and processers of personal data, "[...] as datasets are combined, transferred, shared, or sold" (Banerjee et al. 2018). Since consent notices often do not reveal the identity of third parties and are written in voluminous detail so that users cannot understand them, no truly informed consent can be given for the use of personal data. Another serious problem concerns the use of health-related data for new business models, in which gathering data as proof of a healthy lifestyle is connected to specific beneficial programs. Although at first glance these business models seem to promise interventions to increase health promotion, experts already warn against the possibility of group-specific discrimination and barriers to healthcare (Banerjee et al. 2018; Moll et al. 2017).

The following section will continue to examine the presentation of design and usability requirements for the use of wearable technologies in the healthcare of older adults. As already mentioned, these elements are central to enable users to take measures for health-promoting behavioral changes on the basis of wearable computing devices.

3 Wearables in Healthcare of Older Adults: Usage and Recommendations

According to the results of one survey, 31% of Germans aged 14 and older are using wearables, with a clear preference for fitness trackers (18%), fitness apps on a smartphone (13%), and smartwatches (6%). Within the group of wearable device users, popular health-related data that are tracked by users are temperature (99%), body weight (75%), number of daily steps (62%), and distance (57%) (Bitkom 2016a). Another study by Bitkom Research showed that about one fifth (18%) of Germans aged 14 and older would definitely like to use a smartwatch in the future, while more than a quarter (28%) could at least imagine using one (Bitkom 2016b). However, another survey conducted by the Federal Ministry of Justice and Consumer Protection found that consumers expressed concerns about incorrect measurements (32%), incorrect health advice, and the use of their data by third parties (39%) (Bitkom 2016a).

With regard to the use of wearables, it can be stated that the majority of users of fitness trackers or health applications (65%) primarily want to improve their health. In addition, users are interested in increasing their activity (36%), learning more about their health (26%), or optimizing their training (15%), while only 3% use wearables to promote their recovery in the case of illness (Bitkom 2016a). A study that aimed to explore users' experiences with activity trackers found that users find activity trackers appealing and useful tools for increasing physical activity levels and adopting healthier lifestyles (Maher et al. 2017).

The simplest form of wearables is a pedometer, mostly worn at the wrist. A key functionality of the pedometer is to motivate users to increase their physical activity by showing the number of daily steps. The positive effect of simple self-monitoring has been evidenced by studies that investigated the use of pedometers among older people (Ransdell et al. 2004), such as a study of 29 adults aged 60 and older. The number of daily steps increased significantly from 7564 to 8897 (+18%) when wearing a pedometer (Steinert et al. 2016). With regard to learning, the aim of the study was to achieve a change in behavior through a very simple technology. This behavioral change was related to the amount of physical activity in everyday life. The goal was achieved by increasing the number of daily steps of the older adults. However, it was not examined whether this behavioral change would continue in the long term.

The fMOOC project, a wearable-enhanced fitness program for older adults, developed the combination of fitness trackers and gamification elements. The aim of the project was to combine insights from creativity, learning, and health theories to enhance healthy aging. Wearables and mobile technologies constituted key elements of the wearable-enhanced learning environment within the fMOOC project (Buchem et al. 2014).

To identify older adults' requirements for training with wearable fitness trackers, a comparative study with five different fitness trackers was conducted among 20 older adults (PrefMOOC study). This study showed that the operation of the appropriate smartphone application, the comprehensibility of data, and the ability to display data on the wristband were the most important elements in buying a fitness-tracking device. In contrast, price, design, and label were less important for older adults in the study. However, all tested devices in the study showed marginal usability (37.5–66.25 points on the 1–100 reaching System Usability Scale). In particular, the older participants rated poorly the manner of attachment and synchronization between the wristband and the appropriate application (Steinert et al. 2018b).

In another study of 92 older adults (average age 65 years), the participants tested 7 activity-tracking devices, including Fitbit, Withings, and Jawbone, for 6 weeks. Within this study, four frustrating factors were identified: inaccuracies in reported data, challenges in finding and using instructions, device malfunctions (especially with syncing), and discomfort when putting on or wearing the device (American Association of Retired Persons [AARP] 2015). Considering these frustrating factors, the authors formulated specific recommendations for consumers aged 50 and older. Detailed and easily understandable instructions, as well as explanations of how the activity-tracking device collects activity and sleep data, should be provided. Furthermore, the authors recommended ensuring robust syncing capabilities, greater comfort while wearing the device, and notifications according to the specific target group. As the PrefMOOC study also mentioned, a small screen for displaying instant data and interoperability with additional sensors related to health-specific conditions should be provided (AARP 2015).

The best-rated wristband within the PrefMOOC study (Garmin vivofit) was part of another study within the fMOOC project. Older adults tested the training system, which combines an enhanced fitness program with a fitness-tracking device and gamification elements. With this system, older adults' fitness and subjective well-being should be improved. The aim of the project was to achieve an increase in training adherence through the combination of fitness tracker, smartphone app, training plans, and gamification elements and to maintain this adherence in comparison to simple pedometers in the long term. The older people should learn an improved health-related behavior not only in physical activity. Thus, 20 older adults (average age 69 years) used the fMOOC system for 4 weeks. Hand and leg strength, endurance, balance, physical activity, body consumption, and subjective fitness were assessed before and after the intervention. The effects of training were not only reflected in the improvement of physical performance, such as endurance and balance, but also in the quality of life of the test persons. Accordingly, the test persons stated, for example, that their sleep quality improved through regular physical training. Accordingly, the participants learned that evidence-based technically supported training can achieve further positive health-related effects than exclusively the improvement of objective physical abilities and subjectively perceived fitness. Although the duration of the study was short and the sample was small, positive effects in balancing ability and subjective well-being were found (Steinert et al. 2018a).

Besides the senior-friendly app design and the fitness-tracking device, gamification elements such as goal-setting, social support, social comparison, and reward systems motivated the users to conduct training on a regular basis. Gamification elements are often used to increase compliance and encourage user participation. Gamification elements are implemented mostly in business and education settings, but more and more health applications are using badges and points to encourage users to improve their fitness or take their medicine (Brigham 2015). In a 2018 study by Kappen, Mirza-Babaei, and Nacke, a gamified physical activity intervention was tested for 8 weeks by 30 participants aged 50 and older. The results of the study showed that users of a gamified training program exhibit more engagement and interest in performing physical activity facilitated by technology, in contrast to a non-gamified training program and a control group (Kappen et al. 2018). Moreover, motivational elements that increase enjoyment in the performance of health-related behaviors could have special advantages for patients who suffer from chronic diseases. In addition to the motivation provided by gamification elements, aspects such as the provision of feedback and visualization elements play an important role. At the same time, these motivational elements have a significant impact on the use of the wearable device itself. In this context, it has been noted that one third of wearable device users in the United States stopped using them within 6 months of first use mostly because of the lack of motivational elements (Chiauzzi et al. 2015).

One of the most striking problems in healthcare of a population is the duration and repetitiveness of interventions. In this regard, wearables offer various options to support users in the process of learning and continuously executing their health and disease management. First, wearables expand the ability to distribute and access health-related information. Second, wearables can be used to support early detection of derailment in the context of various diseases, which could prevent long-term rehabilitation measures. Third, as shown above, direct access to health-related data and the ability to track the progress of an intervention can have a positive impact on compliance with the required practices. Finally, motivational elements in the performance of a task can support patients' compliance.

The extent to which wearables can support the performance of and compliance with health-related tasks depends mainly on their complexity. In this context, wearable solutions such as smart glasses are discussed in many fields of healthcare delivery.

3.1 Smart Glasses: More Appropriate for Older Adults?

The example of Google Glass is one of the clearest illustrations of the main feature of wearable devices to provide contextual support to users without limiting their attention or mobility. Of great importance is that users can be supported by the system while performing a task. Relevant contextual information and hints regarding the performance of a task could be directly provided during the execution of the task. Smart glasses are currently evaluated primarily in the context of work-related situations, such as in the field of vocational education and training. In this setting, smart glasses have the potential to make learning content accessible to different user groups, regardless of location and time (Thomas et al. 2018). As part of the GLASSROOM project, which is funded by the Federal Ministry of Education and Research, employees should be trained and supported in a virtual reality that serves as a learning environment. Another part of this project is the design of vocational training and further training scenarios. According to Niegemann and Niegemann, there are 11 decision areas that must be taken into account when designing these scenarios: format, content structuring, learning tasks, the technical operation and development, multimedia, motivation and interaction design, time structure, graphical design and usability, and implementation (Niegemann and Niegemann 2018). Also, in the context of vocational education and training, Berkemeier, Niemöller, Metzger, and Thomas (2018) set up design principles for smart glasses. Here, the voice command is used as the main interaction pattern, to make sure that the hands are free. Further, it is mentioned that the menu structure should be kept as simple as possible. With regard to the menu guidance, the user should always have the possibility to return to the last shown step.

Based on a literature review on *Augmented Reality at the Workplace of the Future*, a total of 40 usability aspects were identified and divided into 12 categories, which should be taken into account when designing smart glasses. The 12 usability categories identified contain terms like performance, perception, preference, user interface, interaction, cognitive load, suitability, system stability, usage, ergonomics, social experience, and technology. There are overlaps within these categories due to recommendations from older users on the design of smart glasses. These include, for example, a clearly structured user interface, a high level of runtime stability, and an intuitive operation of the system, in general (Zobel et al. 2016).

Like any other technology in its infancy, user acceptance is one of the major problems concerning wearables (Meng et al. 2011). In this regard, one survey found that an alarming 83% of those purchasing intelligent devices had difficulty using them or found them too complicated to use (Björnsjö et al. 2014). The survey also showed that users struggled to set them up properly or discovered that they did not work as advertised, being unable to connect the smart glasses to the Internet (Björnsjö et al. 2014). Nevertheless, the use of a head-mounted display (HMD) such as Google Glass is becoming more popular, especially in healthcare (Kutzin et al. 2017).

To identify and address older adults' specific recommendations for Google Glass, several projects and clinical studies were conducted. For example, data of experience with Google Glass as a wearable device for the elderly were collected within the GLASSISTANT project. In this project, a virtual assistance system based on Google Glass was developed to support patients with mild cognitive impairment (MCI) and seniors in their daily lives and during leisure time. The system combines environmental data with the user's vital parameters in order to automatically offer contextual assistance, support, or additional information (Haesner et al. 2018). The aim was that the users use the system to maintain a high degree of independence in different everyday situations. To this end, the system offered support in the areas of navigation, appointment reminders, or shopping lists as well as the retrieval of misplaced objects (e.g., bowls). The focus of learning was the handling and integration of the system into everyday life. The developed system was tested in several evaluations and clinical trials, and the results showed a lack of usability for older adults. In particular, the operation of the device was difficult for older adults, even those with computer or touchpad experience. The touchpad is located on the right side of the device near the temple, so the user cannot see his or her gestures. The operation of the device by tipping or swiping with one or more fingers is less intuitive for older adults. In addition, the complex menu structure with many levels and changing sequences causes problems in operating with Google Glass. Furthermore, the time lag between the selection of a function by the user and its execution by the system affected the operation and led to a misunderstanding of the execution. The Google Glass screen was easy for the participants to handle, despite the small size of the display and the small fonts.

In the course of the field test, it became evident that the corresponding learning objectives could not be achieved in various system modules such as navigation or finding objects. The reasons for this included in particular the insufficient interoperability of all devices networked in the system, the limited battery lifetime of Google Glass (despite an additional battery), the heat development of Google Glass (as a result of which the system crashed), and the episodically breaking Internet connection of the smartphone. These fundamental technical problems caused users to be unable to train the required learning objectives, which had a negative impact on the overall usability of the system, too. Despite these considerable limitations, smart glasses offer considerable potential for the development and promotion of health-relevant behavior. For example, patients could be supported in learning complex practices or interventions with a high level of difficulty that require high repetition rates by displaying additional information and instructions on performance. In addition, patients with emotionally charged health practices, e.g., fear of stabbing themselves in the context of insulin therapy, could be supported by services such as remote expert consultation. In the future, it will also be possible to consult experts in remote patient care, such as with regard to drug therapy or the independent continuation of specific therapy programs in the home environment. Finally, the representation of memories in the user's immediate field of vision could help to promote compliance with therapy measurements.

3.2 Smartphone Applications for Learning in Connection with Wearables

Especially in the consumer field, wearables are often dependent on a smartphone app to perform certain interactions and operations. An exact number of currently available health apps cannot easily be found and depend strongly on which categories are assigned to health. However, it is often stated that the number of these applications in the two largest app stores (Google and Apple) in the categories health, fitness, and medicine is more than 100,000 (Kramer and Lucht 2015). As smartphones have a multitude of sensors and high recording capacities, they can likely be used for monitoring health-related behavior. In this context, one study suggests that many smartphone apps are as good as specialized wearable devices at tracking physical activity, for instance (Tedesco et al. 2017). According to a study by Bitkom Research, almost every second German smartphone user (45%) uses health apps. Moreover, another 45% of smartphone users can imagine using these apps in the future. The reasons given for using health apps are a general interest in improving one's fitness (74%), the enjoyment of monitoring one's own health data (51%), a general interest in learning more about one's own state of health (48%), the improvement of one's own training (42%), the enhancement of physical activity (39%), healthy eating (26%), and the support of recovery in case of illness (17%) (Bitkom 2017). A crucial element is the media skills of the patients, especially for health-related purposes. In this context, individuals show differences regarding their user behavior in terms of age and gender. As mentioned above, younger people are more likely to be familiar with smart technology such as smartphones. Although seniors consistently have lower rates of technology adoption than the younger generation, this group is more digitally connected than ever. Therefore, numerous projects, studies, and organizations are exploring the usability of these applications, especially for older adults. A general observation is that applications must be configured as motivating and user-friendly to support the use of programs in the health sectors for mobility, prevention, healthy eating, or medication reminders.

In a study that examined an application that reminded participants of healthy eating, liquid-supply, mobility, and taking medication, the results showed that a user-friendly configuration was essential for older people to guarantee long-term use. Another factor contributing to long-term use was senior schooling, consisting of written information and a technical support system (Steinert et al. 2016).

The results of several studies have shown that smartphone apps offering a reminder system have contributed to better health behaviors among older people. Participants reduced their weight (Carter et al. 2013; VanWormer et al. 2009), were more compliant in taking their medicine (Steinert et al. 2016, and increased their physical activity (Croteau 2004).

Ahmad, Rextin, and Kulsoom (2018) have identified three major aspects of usability guidelines that should be considered in smartphone apps: platform-specific guidelines (such as for IOS or Android), genre-specific guidelines, and generic guidelines. In this review, generic guidelines for smartphone applications were described extensively and referred to navigation (clear and consistent; minimize scrolling; and visible and well-defined buttons), content (brief and specific; thumbnail at each page), error handling (simple and easy error messages), input method, equitable use, cognitive load (brief and homogenous information; similar and minimal steps), and design (attractive; color contrast; consistent design) (Ahmad et al. 2018).

In summary, there are many capabilities of health apps that can support users in questions of a healthier lifestyle. One of the most important features, especially for patients suffering from chronic diseases, might be the possibility of automatically monitoring their health or disease-related conditions. Many diseases, such as diabetes mellitus, require continuous recording of specific parameters by the patient in addition to measurements as part of control examinations. Currently, this recording is often done manually. It should be noted that in the future course of the therapies, the recordings are largely incomplete, or the patients are overwhelmed with incorporating this task into their everyday life. Since users of wearables and smartphones carry their devices with them at all times, continuous long-term recording could be guaranteed. In addition, the possibility of reminders has a positive effect on permanent monitoring. In this way, the patient can be supported in making a habit of specific treatments in everyday life. Depending on the complexity of the system, advanced visualization and evaluation tools can support the patient by identifying possible behavioral patterns that influence disease or health, thus creating an awareness of personal responsibility.

4 Key Requirements for Wearable Solutions Based on User Experience and Literature

Although wearable solutions are designed and used for very different applications, comprehensive requirements for design, functionality, and embedding can be formulated. Based on the results of user experience and literature research discussed above, the following table summarizes the core areas (Table 1):

Table 1 Summary of key requirements for wearable solutions according to user experience and literature used

Dimension	*Specification*	Requirements
General system		• Accuracy of measurement results • Robust connectivity and synchronization with other devices and applications • Interoperability with additional sensors • A high level of run-time stability • Long battery run time
Human-computer interaction	*Operation*	• Robust user interface without restricting user's attention or mobility • Simple menu structure with few levels and changing sequences • Structured navigation (clear and consistent) • Minimize scrolling (visible and well-defined buttons) • Ability to display instant data on the wearable device • Real-time capabilities for the selection of a function and its execution • Intuitive operation, e.g., on the basis of an easy-to-learn set of gestures • Customizable interface (e.g., regarding cognitive or physical limitations) • Low cognitive effort in using and operating the device
	Applied information	• Easy-to-understand presentation of the measured data on information (color, brightness, contrast, and positioning) • Content (brief and specific; thumbnail at each page) • Error handling (simple and easy error messages) • Input method, equitable use, and cognitive load (brief and homogenous information; similar and minimal steps)
Extrinsic motivation		• Habit formation (goal setting, routines, reminder systems, and rewards) • Social motivation (sharing or competing for goals with others) • Goal reinforcement feedback to monitor personal progress
Ergonomy		• Highly comfortable to wear and exclusion of health risks through use of the device
Support	*Schooling*	• Target group-specific training programs to impart the necessary skills in disease management using a technical device • Training programs for medical personnel to implement measurement results in the treatment process and to impart the necessary skills to users
	Guidelines	• Platform specific guidelines (such as for IOS or Android), genre-specific guidelines and generic guidelines • Easily understandable presentation of the intended purpose and its technical implementation as well as the associated data collection
Legislative and medical standardiza-tion		• Mandatory standards for the regulation of data exchange • International medical care guidelines • Legislative framework for providers and users regulating risks of liability, registration requirements, protection of personal data, and the assumption of costs

5 Conclusion

In the face of increasing chronic and age-related diseases and a rise in problems of delivering healthcare services, there is a great need for health-related solutions that can expand and enhance health-related services. In this context, a core task is empowering people to support them in the attainment of a healthier lifestyle and the management of disease-related conditions. Therefore, empowerment not only means communication of knowledge about health-conscious living but also training and the promotion of necessary skills to integrate health-related behavioral elements into individual everyday life. This process of creating habits to promote health-related behavior is a great challenge, not only for chronically ill people. As described in the previous sections, wearable solutions offer various possibilities to support such learning processes. In summary, these consist of situation-specific availability of easily understandable health-related information and personal health data. They also consist of the development and promotion of awareness of health-related issues, which can be achieved through the continuous recording of health-related events, their contextualization with aspects of users' lifestyles, and their visualization in a way that is comprehensible to users. In addition to this sensitization, the support for permanent implementation of necessary treatments plays a decisive role. In this regard, continuous reminders, feedback on progress and failures to meet health-related targets, and further motivational elements, such as those presented in the context of gamification, play a central role. At the same time, however, this empowerment process requires continuous support by specialist physicians. Therefore, training programs are needed to address patient-centered questions about the usefulness and integration of their self-measured health data during the treatment process. These programs should take into account that there are great differences between patients' health literacy and numeric skills, which are important for the comprehension and utilization of health-related information based on wearable solutions (Chiauzzi et al. 2015; Kramer and Lucht 2015). Finally, these educational programs must also focus on differences in media skills, which, in this case, means the ability to use specific technology for health-related purposes.

In order to successfully integrate digital health technologies into the healthcare sector, many obstacles still have to be removed. On the technical side, these consist of the validity and reliability of data, especially in the field of consumer wearables. In addition, interoperability and standardization are crucial for the transferability and comparability of measurement results in the healthcare sector. Another core element of technical development concerns behavioral science principles that have an important impact on the long-term use of digital health technology. In this context, Chiauzzi et al. (2015) present three core components for a long-term commitment by users to wearable solutions: "(1) habit formation (setting cues, routines, and rewards), (2) social motivation (sharing or competing for goals with others), and (3) goal reinforcement feedback to monitor personal progress."

Moreover, it is necessary to establish mandatory standards for the regulation of data exchange, national and international medical care guidelines and standards regulating data security, and a binding legislative framework for providers and users of digital health solutions that regulates risks of liability, registration requirements, protection of personal data, and the assumption of costs (Kramer and Lucht 2015).

Finally, it also means creating the necessary structures in the training of medical personnel, such as including digital health technologies in the curricula (Gaglani and Topol 2014).

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Learning for a Healthier Lifestyle Through Gamification: A Case Study of Fitness Tracker Applications

Aylin Ilhan and Kaja Joanna Fietkiewicz

1 Introduction

Eight hours of sitting at the office and driving in the car to work and back home to at last lie on the sofa and enjoy the end of the day—this scenario is true for many people all over the world. Otherwise, how come "that more than 80% of the world's adolescent population is insufficiently physically active?" (World Health Organization 2018a). Tedros, World Health Organization Director-General, is right with his statement that "You don't need to be a professional athlete to choose to be active. Taking the stairs instead of the elevator makes a difference. [...] It's the choices we make each and every day that can keep us healthy. [. . .]" (World Health Organization 2018b). But in the end, people do not like drastic changes, and their lifestyle is usually shaped by habits. Nowadays, to actually change our lifestyle and be serious about it is perceived as a difficult challenge. Even though "insufficient physical activity is one of the leading risk factors for death worldwide" (World Health Organization 2018a), it does seem unattainable for many people to change their unhealthy habits.

Ultimately, such behavior changes like taking the stairs instead of the elevator or walking to the bakery instead of taking a car can be understood as a process of learning. "Learning is a change in human disposition or capability, which persists over a period of time, and which is not simply ascribable to processes of growth" (Gagné 1977, p. 3). It is difficult to precisely define the time a person needs until a newly introduced behavior becomes a habit, hence, has been learned. It could last from 18, through 21 up until 254 days of repetition until an activity is automatized and can be seen as a new habit (see, e.g., Rubin 2009; Lally et al. 2010). With the

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new wearable technologies, here activity or fitness trackers, we learn to be more physically active by setting, e.g., daily step goals and orienting our behavior toward attaining a particular goal.

Ilhan and Henkel (2018) confirmed with their investigation on perceived service quality and acceptance of activity trackers that those devices have an impact on users' behavior and that they are perceived as useful. Fritz et al. (2014) investigated the usage of wearable technology and found out that some of their study's participants were continuously motivated by the wearables even when they were using those devices over a longer period of time. Fritz et al. (2014) made recommendations for the developers of wearables by indicating that long-term users may have other goals and motivations than new users in their first weeks of application. Therefore, it is crucial to design the activity and fitness tracker applications in an elaborate way if one wants to induce the engagement in physical activity and a healthier lifestyle in the long term.

According to IDC (2018), the demand for activity trackers is increasing. As for 2017, there were 115.4 million wearables sold all over the world. They convinced buyers with their main features such as counting steps, sleep tracking, and monitoring of heart rate. These are only few examples of their functionalities, as depending on model and price, they might offer even more features. These new information and communication technologies make the so-called self-quantification possible. They enable people to measure, e.g., sensor-based data which is subsequently transferred into readable information. All these data can be used to manage and improve personal health. The self-quantification tools enable monitoring, collecting, and analyzing of different data, e.g., steps, burned calories, sleep duration, and more (Almalki et al. 2016).

Activity tracker manufacturers such as Fitbit, Garmin, Samsung, or Xiaomi offer their users not only basic functionalities for self-quantification but also different game elements (mechanics) integrated in their fitness applications. These include, for example, challenges, achievements, overviews, points, and levels. To the best of our knowledge, the gamification elements implemented in activity trackers were not intensively researched until now; however, there are several studies on gamification and its motivational force to engage users in changing their behavior, for example, in educational, business, or health environment. This leads us to analyze fitness tracker applications developed by ten biggest brands, namely, Apple, Fitbit, Garmin, Huami, Moov Now, Withings, Polar, Samsung, TomTom, and Xiaomi, with focus on gamification elements (mechanics), to compare them with each other. Furthermore, we create a theoretical background for further user-oriented research in this area by linking different theories, from conceptualization and integration of gamification elements to influencing motivation and behavior change regarding physical activity with the help of fitness tracker applications.

This investigation is supposed to determine how varying user's characteristics (task- or ego-driven, intrinsically or extrinsically motivated) and their experience during exercise (flow) can affect the process of improving user's engagement and learning process to live healthier and be more physically active in the long term. First, the concept of gamification is introduced. Afterward, several theories considered relevant for research on fitness tracking apps will be presented: goal orientation theory, self-determination theory, and flow theory. Subsequently, the content of selected fitness tracking apps is analyzed, and the applied game elements are discussed in the context of aforementioned theories.

2 Gamification

This subchapter will introduce several definitions commonly used when describing the concept of gamification and its elements. This is necessary in order to get a general understanding of gamification components, its goals, and aspects making gamification either successful or not. There appears to be no exact definition of gamification, because the "discontent with current implementations, oversimplifications, and interpretations have led some to coin different term for their own arguable highly related practice" (Deterding et al. 2011, p. 9). Indeed, there are a lot of various descriptions (Dicheva et al. 2015; Deterding et al. 2011; Huotari and Hamari 2012; Seaborn and Fels 2015); therefore, in the current research, it will be refrained from creating a new definition or combining the existing ones. In the course of this subchapter, the most common notions about gamification are summarized, and it will be explained which of them are suitable for this investigation.

One of the established and commonly used definitions in the research is the one by Deterding et al. (2011, p. 10): "'Gamification' is the use of game design elements in non-game context." It consists of two aspects: (1) game design elements and (2) non-game context. To understand the meaning of game design elements, it is necessary to understand the meaning of "game" itself (Deterding et al. 2011). It is hardly surprising that, according to Kapp (2012), there are a lot of "game" definitions as well. One of them states: "A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (Salen and Zimmerman 2004, p. 80).

Gamification can be understood as the implementation of game elements in a non-game environment with the objective to increase user's motivation and to trigger a specific behavior (Sailer et al. 2017). Kapp (2012, p. 9) revealed that gamification elements and further aspects, for example, feedback, emotional reaction, or challenge, are used to support both learning and engagement. They have "the power to [. . .] inform, and educate" (Kapp 2012, p. 10). In contrast to other authors (e.g., Huotari and Hamari 2012; Robson et al. 2015; Porter 2009), Deterding et al. (2011, p. 12) define game design elements by classifying them into five different levels: (1) game interface design patterns (badges, leaderboards, levels); (2) game design patterns and mechanics (time constraint, limited resources, turns); (3) game design principles and heuristics; (4) game models, e.g., MDA (Hunicke et al. 2004); and (5) game design methods. Additionally, a definition of gamification from a service marketing perspective is laid by Huotari and Hamari (2012, p. 19): "Gamification refers to a process of enhancing a service with affordances for gameful experiences in order to support user's overall value creation." Huotari and Hamari (2012) point out that the focus of this definition is set on the goal of gamification—the gameful experiences that improve motivation and engage users in value creation. Furthermore, Huotari and Hamari (2012, p. 19) claim that "there [does not] seem to exist a clearly defined set of game elements which would be strictly unique to games, neither they automatically create gameful experiences." Seaborn and Fels (2015, p. 14) describe gamification as an "interactive system that aims to motivate and engage end-users through the use of game elements and mechanics. As yet, there is no agreed upon standard definition." Last but not least, Kapp (2012, p. 10) states that "Gamification is using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promoting learning and solve problem."

There are different opinions on how these game elements should be described. Cugelman (2013, p. 2) points out that the problem with naming the game design elements is that "gamification researchers do not always agree on what these ingredients are, and some researchers take the position that these ingredients cannot even be named." Dicheva et al. (2015) show that badges are sometimes considered as game interface design (Deterding et al. 2011), game mechanic (Zichermann and Cunningham 2011), game dynamic (Iosup and Epema 2014), motivational affordance (Hamari et al. 2014), or game component (a specific instantiation of mechanism or dynamics) (Werbach and Hunter 2012). Zichermann and Cunningham (2011, p. 36) explain that "mechanics make up the functioning components of the game." Game design expert Amy Jo Kim explains that game mechanics "are a collection of tools and systems that an interactive designer can use to make an experience more fun and compelling" (Porter 2009). Deterding et al. (2011, p. 12) use the term game mechanics to define such aspects as "time constraint, limited resources, turn," whereas leaderboards, badges, and levels are game interface design patterns. Kapp (2012, p. 11) points out as well that mechanics include "levels, earning badges, point system, scores, and time constraints."

As every gamification definition has its eligibility and depends on the perspective, in this investigation, all game design elements such as points, badges, time constraints, and every aspect that is developed and implemented by the game designers themselves are defined as game mechanics. In this context, "game elements" is understood as a generic term for mechanics, dynamics, and every other term related to games. However, the game mechanics (points, badges, time constraints, etc.) are not being defined as dynamics. For this study, the definition by Zichermann and Cunningham (2011, p. 36) was chosen and game dynamics are understood as "player's interactions with those mechanics." Kim (2015, p. 18) explains that mechanics "refer to the various actions, behaviors, and control mechanisms afforded to the player within a game context." Robson et al. (2015, p. 415) differentiate between mechanics and dynamics: "Contrary to mechanics that are set by the designer, the gamification dynamics are produced by how players follow the mechanics chosen by designer." Hence, mechanics are the gamified elements and the dynamics are the behaviors that are triggered while making use of those gamified elements (Robson et al. 2015). Furthermore, Blohm and Leimeister (2013) show which game mechanics trigger which game dynamics. For one example, rankings create a game dynamic of competition. What could be a motive to implement those game mechanics? According to Blohm and Leimeister (2013), the answer is social recognition.

One of the benefits of using game design elements is the possibility to positively motivate users (Deterding et al. 2011). Furthermore, game design elements are affecting the emotional experiences of users (Lee and Hammer 2011). Based on this notion, gamification seems very promising regarding motivating users, but one should keep in mind that "Gamification can only provide tools [...]" and "is not a universal panacea" (Lee and Hammer 2011, p. 148). A tool itself is not enough, so how are researchers and developers supposed to activate users' motivation and interest and be successful in a long term? Kapp (2014, p. 52) mentioned that points, badges, and leaderboards are not the success formula of a game, because "[p]eople don't play a game just for points, they play for mastery, to overcome challenges and to socialize with others." Hamari et al. (2014) clarify which motivational elements are being implemented, which psychological outcomes are caused by those elements, and which kind of behavior change is recognizable. Their analysis of 24 peer-reviewed papers revealed the positive effect of motivation affordances (e.g., badges, leaderboards, and points) (Hamari et al. 2014). One of the most popular contexts of those studies is the education/learning environment. Hamari et al. (2014) explain that in this environment, the motivation, engagement, and enjoyment related to learning new tasks have increased.

Aparicio et al. (2012) recognized that game mechanics have the potential to satisfy psychological and socially motivated needs, such as autonomy, competence, and relatedness (intrinsic motivation). Aparicio et al. (2012) recommend to select game mechanics which match with these three motivational needs. For autonomy they propose "profiles, avatars, [. . .], privacy control, notification control," for competence "positive feedback, optimal challenge, progressive information, [. . .], points, levels, leaderboards," and for relation "groups, messages, connection to social networks, chat" (Aparicio et al. 2012, p. 2). Hamari and Järvinen (2011) explain that game mechanics are crucial for having fun while playing the game or engaging in the activity. This task of choosing and developing game mechanics that engage user is the responsibility of game designers.

Mechanics are purpose-built, which means that the use of those mechanics supports the general objective of the service. "[T]hey are either used for pursuing the goals, or the game as a system is using them for giving feedback to the player in relation to the goals" (Hamari and Järvinen 2011, p. 353). Attali and Arieli-Attali (2015) explain that game mechanics can have different effects on users depending on whether they support the extrinsic or intrinsic motivation. They recommend to characterize game mechanics, such as points and badges, as extrinsic rewards for a successful completion of a task (Attali and Arieli-Attali 2015).

One main problem, which Robson et al. (2015) point out, is that gamification will fail if the concept is not elaborated. It is necessary that developers understand its benefits, challenges, and the varying interaction possibilities between game elements and users which, in the end, will lead to the desired behavior or outcome. Hamari (2017) points out that empirical evidence on the effectiveness of gamification is rather minor. Another problem related to the effectiveness of gamification appears to be the fact that a lot of studies on this topic are not homogenous or do not focus on an empirical research to confirm the effectiveness of gamification in general. Apart from mentioned problems, the different player types can affect the received emotions or triggered motivation as well. Hamari and Tuunanen (2014) show different definitions by authors related to player types, such as the one from Bartle (1996), namely, “Achiever,” “Socializer,” “Explorer,” and “Killer.” Considering the presented definitions and understanding of gamification and differentiation between game mechanics and dynamics, the next subchapter offers an overview of game mechanics and their characteristics.

2.1 Gamification Mechanics

For this investigation, the following game mechanics implemented in the fitness tracking applications were evaluated:

- *Goals*: clearly defined goals are necessary to know what a user is supposed to achieve (Kapp 2012).
- *Points*: show user’s progress during the game (Kim 2015), and depending on the point system, they can reflect the earned skills, or they show the difficulty of the tasks during the ongoing game (Zichermann and Cunningham 2011).
- *Levels*: show progress while doing and successfully finishing tasks (Kapp 2012). The use of levels might increase player’s ego-oriented attitude (Zichermann and Cunningham 2011). Levels are often linked to experience points and the higher the level, the more points can be received. This creates a feeling of mastery and accomplishment (Kapp 2012).
- *Progress Bars*: enable the monitoring of one’s progress. They can engage users and show how much effort is needed to reach the next level or to fulfill the task (Zichermann and Cunningham 2011).
- *Feedback*: offers clear information (how far away a user is from a goal) based on a current situation (Kapp 2012; Zichermann and Cunningham 2011). This enables to “evoke the correct behavior, thoughts, or actions” to fulfill the task (Kapp 2012, p. 36).
- *Documentation*: creating an overview of (historical) data of all activities, which may be motivated by intellectual curiosity (Blohm and Leimeister 2013).
- *Badges*: represent succeeded achievements. They make the achievements or skills more impressive (Sailer et al. 2013). Besides visible badges (achievements), there are invisible ones as well, which can trigger curiosity to explore and find more badges (Hanraths et al. 2016). Buchem et al. (2015b) define use of badges in two ways, as a trigger and as an award. Badges can also support social interaction, for example, when they are awarded for likes and post.

- *Leaderboards*: are visualizations of a ranking/scoring system among users (Kapp 2012). Usually, they include the user name and the reached score (Zichermann and Cunningham 2011).
- *Time*: can be defined as a motivator, for example, in the form of a countdown. It increases not only the stress level but the motivation and need to succeed in a task (Kapp 2012).
- *Quests*: are specific tasks for which the user can receive, e.g., experience points, and which are usually used in educational context as they "contain the learning content" (Hanraths et al. 2016, p. 850). For the purpose of this research, we use the term "Challenges" instead of "Quests" as the evaluated applications apply this terminology.
- *Avatars*: are a general visual representation of users within a game and are not necessarily used to characterize the attitudes of a user (Hanraths et al. 2016).
- *Storytelling*: is narrative content (e.g., prologue, epilogue) that is defined as an atmospheric element. Storytelling elements may be crucial to understand how to solve a task or why to do it at all (Hanraths et al. 2016; Kapp 2012).
- *Community Features*: include the possibility "to stay up to date through following [...] or befriending function" (Scheibe et al. 2018; Scheibe and Zimmer 2019).
- *Rules*: describe the conditions of a "quest"/challenge and how achievements can be achieved or, generally, how they are calculated (Kapp 2012).

2.2 *Gamification in the Domain of Health*

Nowadays, gamification is used in various domains, starting with education (Hanraths et al. 2016; Attali and Arieli-Attali 2015; Barata et al. 2013) and business environments (Huotari and Hamari 2012), through social live streaming services (Scheibe and Zimmer 2019; Scheibe 2018; Scheibe et al. 2018), right up to health management. There are many studies within the health domain, but to the best of our knowledge, none of them analyzes gamification elements within mobile applications of activity tracker providers. Mobile applications meant, for example, Fitbit and Garmin, and not fitness applications by third-party suppliers, like Runkeeper or Strava, for running or cycling. Koivisto and Hamari (2014, p. 179) explain that gamification can support the improvement of physical activity and name such services as "Mindbloom," "Fitocracy," "Zombies," "Run!," and "Nike+."

In their project "Fitness MOOC," Buchem et al. (2015b) concentrated on the gamification designs used in wearable enhanced learning. It "focuses on enhancing user engagement on five levels of design [...] with the aim of enhancing the daily fitness of senior users" (Buchem et al. 2015b, p. 9). Buchem et al. (2015b) pointed out, although the results are not generalizable due to the sample size and focus on senior users, that gamification is a crucial element of the user engagement design. They reported positive effects of the use of gamification design elements such as a better orientation in the training program, increased motivation, and an enjoyable experience. As this was a long-term project with different stages, Steinert et al.

(2018) tested their “fMOOC@Home” in a subsequent 4-week study. All in all, their results showed significant health improvements.

A lot of studies (e.g., Zhao et al. 2016a, b, 2017; Chung et al. 2017; Walsh and Golbeck 2014; Ribeiro et al. 2016; Chen and Pu 2014) investigated already developed gamified systems promoting use of activity trackers or physical tracking in general. These studies mostly revealed positive effects of gamification, for example, that the implementation of gamification in health domain can result not merely in short-term engagement but rather in long-term improvement as well. One study showed that “based on existing technologies and user needs, the idea of employing wearable activity tracker for gamification of exercise and fitness is feasible, motivating, and engaging” (Zhao et al. 2016a, p. 339). As the aim of the integration of gamification is to increase the motivation to be physically active, Zhao et al. (2016a) confirmed that users’ engagement is linked to the integrated game elements and can improve the physical activity.

Nelson et al. (2016) thematized and analyzed aspects which motivate or rather empower users to reach their personal health goals. According to Walsh and Golbeck (2014), who did a controlled study (30 days) with 74 Fitbit-wearing participants who interacted with a specially developed web application (“StepCity”), games and social experiences can motivate users to take more steps and to be more active. Besides applications, Chung et al. (2017) investigated gamification in the health domain by using twitter and observing Fitbit users. Chung et al. (2017) developed a mHealth intervention (2 months) with overweight/obese and healthy (normal weight) participants that had to use a Fitbit Flex and twitter during the study. They integrated challenges such as 1-day or multiple-day challenge. The study revealed positive impact on the amount of steps taken during the day. Dadaczynski et al. (2017) analyzed the impact of gamification during a 6-week browser-based online intervention (“Healingo Fit”) and using Fitbit Zips. They implemented a daily step goal, quizzes (knowledge about physical activity and general health), and the possibility to choose health goals (up to 3 out of 60 predefined goals). Dadaczynski et al. (2017) mentioned that tracking-based online intervention supports the increment of physical activity, e.g., walking. In their study “Gamification shows the greatest explanatory power in predicting health related experience of competency” (Dadaczynski et al. 2017, p. 7).

Barratt (2017) analyzed the application “Strava” and pointed out the positive effects the app had on cyclers. According to Barratt (2017, p. 335), “the research illustrates that a gamified fitness app and health tracker can be used successfully to enhance the activity of an engaged community of enthusiasts.” Lister et al. (2014, p. 10) confirmed that health applications “show an abundant use of gamification in health and fitness apps.” Edwards et al. (2016) analyzed 1680 mobile health and fitness applications, and 64 of them use gamification elements. In the end, they investigated the 64 applications in order to gain some insights in the techniques of changing the human health behavior.

In a literature review, Alahäivälä and Oinas-Kukkonen (2016) showed that out of 15 studies on health interventions that included gamification elements, nine publications concentrated on increasing the physical activity. Johnson et al. (2016) did a systematic review of gamified health and well-being applications to analyze the effectiveness and quality of such applications. They identified 19 papers which revealed the effect of gamification in the domain of physical activity. The applied gamification elements were, for example, points, leaderboards, challenges, achievements, and levels. Generally, the most game design elements mentioned in the reviewed 19 papers were rewards, followed by avatars and leaderboards. A systematic literature review by Johnson et al. (2016, p. 104) showed that "gamification could have a positive effect on health and well-being, especially when applied in a skilled way." Ahola et al. (2013) also detected positive effects of the use of gamification, like increasing activity. Orji and Moffatt (2018) did an empirical review of 85 papers about persuasive technology for health and wellness. Here, again, the majority (92%) of the reviewed papers showed positive effects. "[S]ome of the technologies are aimed at reinforcing and strengthening existing behavior (e.g., increase daily step count [. . .]" (Orji and Moffatt 2018, p. 78). Hamari and Koivisto (2013) investigated to what extent social factors (e.g., high-score lists, collection of points for social reasons like recognition) influence the acceptance of gamification or rather support the continued use of gamification elements. They investigated the application "Fitocracy," a gamified service for physical exercise. Hamari and Koivisto (2013) revealed that social aspects are an important and influential factor related to the acceptance and continued use of gamification elements. Additionally, Koivisto and Hamari (2014) empirically investigated the concept of gamification and its benefit related to demographic differences (age and gender) with "Fitocracy" as a case study. They showed that women perceived gamification elements and its influence related to social benefits stronger than men did.

3 Goal Orientation Theory, Flow Theory, and Self-Determination Theory

Gamification elements or the game mechanics can provoke certain game dynamics, hence, a desired behavior of users. Since each person is unique, the implemented game mechanics will not have exactly the same impact on all users. One theory about human motivation to engage in certain activities that was intensively researched in the context of sport and exercise psychology is the so-called goal orientation theory of achievement motivation (Jackson et al. 1998; Cumming and Hall 2004; Murcia et al. 2008) and can help us determine which game mechanics might be more successful in influencing behavior of certain types of people. This theory is adequate for our study since it also focuses on human motivation (in our case induced by game elements). "[. . .] [M]otivation is a key ingredient in understanding behavior patterns as well as in determining the intensity and direction of behavior (Iso-Ahola and St. Clair 2000)" (Murcia et al. 2008, p. 182).

"Individuals' goal orientation will influence their definition of success, which, in turn, will impact their motivation to perform physical activity" (Cumming and Hall 2004, p. 748).

In general, physically active people might have different perception of sport and its benefits. For some of us, these benefits are materialistic and individualistic (fame, fortune, recognition); for others, these benefits are "intrinsic to the activity itself (e.g., becoming physically fit)" (Duda 1989, p. 320). This differentiation is also the basis of the goal orientation theory. On one hand, we find task-oriented people who, e.g., focus on personal improvement and mastery (Duda 1989) and are more likely to "adopt a self-referencing criterion for evaluation" (Cumming and Hall 2004, p. 748). On the other hand, we have ego-oriented people who are more competitive and focus on beating others, they "define success [...] in normative terms, such as outperforming others or being the best on a task" (Cumming and Hall 2004, p. 748; Duda 1989). In terms of perceived ability, a task-oriented person tends "to believe that ability is reflected through effort and improvement," whereas ego-oriented person believes that "ability is expressed by outperforming others" (Murcia et al. 2008, p. 182).

In our study, we only focus on the mobile applications provided by fitness tracker manufacturers, and therefore, we do not have any insights into the goal orientation of the users (the dispositional component of the goal theory) and their actual change in motivation and behavior due to the usage of these apps. However, some researchers indicate that the so-called motivational climate (the contextual component) can influence the development of the goal orientation (Ames 1992; Nicholls 1989; Cervelló and Santos-Rosa 2001; Ebbeck and Becker 1994; Escartí et al. 1999; Pensgaard and Roberts 2002; Murcia et al. 2008). "Parents, coaches, teachers and peers can all influence the motivational climate which can also be of two types: a mastery or task-oriented motivational climate and a competitive, or ego-oriented, motivational climate (Ames 1992)" (Murcia et al. 2008, p. 182). Therefore, we suggest that the mobile fitness applications together with the fitness community that can be reached through these applications constitute such motivational climate. During evaluation of the apps, we will try to classify the implemented game mechanics as fueling either a competitive or a mastery/task-oriented motivational climate.

The different goal orientations of the users together with the different motivational climates can lead to diverse behavioral consequences and experiences, one of which is the so-called flow (Jackson and Marsh 1996; Murcia et al. 2008). Jackson and Roberts (1992) examined the role of goal orientations and perceived ability as psychological correlates of flow states "[. . .]. Relationships were found between endorsement of task involvement, high perceived ability, and frequency of flow experiences" (Jackson et al. 1998, p. 359). The concept of flow was coined by Csikszentmihalyi (1975), who explained why individuals engage in free time activities (e.g., sports). "[H]e defined the 'optimal performance state' as the extensive engagement in a specific task with a feeling of pleasure" (Türksoy et al. 2015, p. 302).

Why is the flow theory important for our research? "Experiencing frequent flow states within a specific activity leads to a desire to perform that activity for its own sake; that is, the activity becomes autotelic (Csikszentmihalyi 1975, 1990)" (Jackson et al. 1998, p. 359). Hence, a frequent flow state during an activity (e.g., exercise) can lead to the desire to perform it for its own sake (behavioral change would indicate that the person "learned" to be more active). In the game and gamification context, the state of flow is an important part of the user experience (Buchem et al. 2015a). But also in sports, this is a very relevant motivational factor: "[. . .] athletes in a flow state are known to demonstrate greater commitment to the activity, to be more intrinsically motivated, and to demonstrate greater persistence in their sport practice, each of which reduces the likelihood of sport dropout (Jackson 1996)" (Murcia et al. 2008, p. 182). The autotelic experience witnessed during the flow was "described by Csikszentmihalyi (e.g., 1990) as an intrinsically rewarding experience. Deci and Ryan (1985) describe flow as a purer instance of intrinsic motivation" (Jackson et al. 1998, p. 360). Hence, an autotelic state strongly connected to flow experience leads us to the next theory, which also becomes an integral part of this study, the self-determination theory.

Deci and Ryan (1985) distinguish between three types of motivation: the inner motivation (intrinsic), external motivation (extrinsic), and lack of motivation (amotivation). The intrinsic motivation is given "when the individuals involve in an activity they are interested in or feel pleasure doing it. On the other hand, individual with external motivation involves in an activity to achieve distinguishable results (Lonsdale et al. 2008) [. . .]. Those with lack of motivation can feel incompetency or lack of control (Pelletier et al. 1995)" (Türksoy et al. 2015, p. 302). This could mean that people who are intrinsically motivated should be more likely to experience flow since they are interested in the task at hand (Deci and Ryan 1985; Jackson et al. 1998). "The intrinsic needs for competence and self-determination motivate an ongoing process of seeking and attempting to conquer optimal challenges (Deci and Ryan 1985, p. 32)" (Jackson et al. 1998, p. 361), which in turn reminds us of the task-orientation of the users as well as the mastery or task-oriented motivational climate. According to Csikszentmihalyi (1988), individuals with an autotelic personality might indeed have a greater tendency to experience flow, since they are able to "enjoy the process of engagement without concern for extrinsic rewards (Mandigo and Thompson 1998)" (Murcia et al. 2008, p. 182), they focus on the task rather than on the anticipated outcomes (Jackson et al. 1998). The importance of task-orientation for the flow experience was already mentioned by other researchers: "Kimiecik and Jackson (2002) discovered that the task goal orientation was the best predictor of flow in sport. Recent research has also revealed that the dispositional flow state correlates positively and significantly with self-efficacy, the tendency toward a task orientation, and the perceived value of physical activity (Tipler et al. 2004)" (Murcia et al. 2008, p. 182).

Still, autotelic personality (or task-orientation) of the users together with task-oriented motivational climate do not necessarily lead to a flow experience and subsequent behavioral change. Another important aspect mentioned by many researchers is the (perceived) abilities or skills of the users:

> “[. . .] both challenges and skills must be relatively high before anything resembling a flow experience comes about. Importantly, we focus on ‘perceived’ sport ability, because within the flow model ‘it is not the skills we actually have that determine how we feel, but the ones we think we have’ (Csikszentmihalyi 1990, p. 75). This provides the basis for the notion that high perceived ability may be a necessary precondition for flow states” (Jackson et al. 1998, p. 361).

In order to reach the flow experience, one’s perceived skills and the challenge need to be in balance. The orthogonal model of flow theory by Csikszentmihalyi (1982) indicates what can be the result of an imbalance. When the perceived skills of an athlete exceed the perceived challenge of the activity, then he or she will experience relaxation. In turn, when the challenge outweighs the perceived skills, the athlete will experience anxiety. Finally, when challenge and skills are perceived as low, the athlete will experience apathy (Stavrou et al. 2015). Only “[w]hen the challenges and skills are perceived as being in balance, the person enjoys the moment and stretches his or her capabilities to learn new skills and increase self-esteem and personal complexity” (Stavrou et al. 2007 p. 439). What does this mean for fitness app developers? How can they prevent user’s amotivation toward their product? In order to develop an application that motivates users to exercise and actually change their behavior in the long term, the implemented game elements, especially challenges, would need to be adjusted to user’s perceived abilities. Too easy tasks will not challenge the users and may lead to relaxation and boredom, whereas too challenging ones can cause anxiety. Both a bored user and a stressed and anxious one are less likely to continue using the applications or be somehow influenced by it. In turn, a user who is being challenged, but also gets sense of achievement, is more likely to experience flow and carry on using the application.

4 Methods

The aim of this study is to detect and compare gamification elements in the analyzed fitness tracking applications and implicate which behavioral dynamics they can evoke, to finally conclude whether the implemented user engagement design (game mechanics) supports long-term engagement and learning to be physically active. First, the most popular fitness trackers were detected. The focus of this investigation was set on the top ten activity trackers and their applications. This amount of applications is assessable to report in detail and still constitutes a representative overview as it includes manufacturers that were omitted in scientific studies until now. For the content analysis, conducted during September–October 2018, we used the versions of the applications that were current at that time. We referred to the four-eye principle to analyze the game mechanics of the applications thoroughly and to warrant objectivity. Before coding the game mechanics included in the applications, we referred to literature on gamification to acquire a better understanding of the concept and its elements. The insights that we gained are summarized in the literature review. The coding process was iterative. In the first round, both authors coded independently of each other based on the acquired knowledge. For each application, coders created a user account. The comparison and discussion of the results enabled the researchers to prevent any ambiguities and to adjust the definitions of game mechanics to the objects of the study. In the second round of the analysis, the criteria were more accurate for the fitness tracker applications and led to removal or addition of further relevant game mechanics.

Table 1 shows the results of this process and serves as a codebook. It includes the relevant game mechanics and their respective definitions. One of the elements could not be accurately evaluated ("Feedback") as this would require connecting the respective device. For current analysis, the notification settings within each application were used as an indicator for giving such feedback. Furthermore, the game element "Rules," as defined in Sect. 2.1, was not included in the analysis as in the context of fitness tracker applications. This element is not very elaborated

Table 1 Definitions of game mechanics related to applications of fitness tracker

Game mechanics	Description
Points	Points that are not related to a specific challenge, they reflect the overall performance of the user and are necessary to level up.
Leaderboard	Lists of users (friends, strangers) ranking them according to a specific criterion (total steps, distance, etc.).
Badges	Visualization of achievements; can be received for successfully accomplished challenges or for reaching a milestone; may contain title, description, date of receiving, etc.
Levels	Show the overall advancement of the user since using the app (not related to a specific challenge or short-term goals); are estimated based on points that the user receives for different activities; usually displayed in user profile.
Story/theme	Narrative elements, e.g., theme, motto, prologue, epilogue, additional information during a challenge.
Clear goals	For example, number of steps, distance/meters to achieve, number of activities, daily step goal, or other daily goals.
Feedback*	Notifications during a physical activity, reminder of the (clearly defined) goal; also notification when the goal was reached; notifications on smartphone, not only the tracking device.
Progress	Visualizations which show, for example, how many steps, points, etc. are missing to reach the goal/next level.
Challenges	Tasks setting clear goals for a user; can contain time constraints; can include group challenges leading to an inter-user competition.
Documentation	Documentation of physical activities, statistics, general overviews.
Time Pressure	Time constraint for challenges or goals (e.g., daily step goal).
Avatars	Possibility to choose a profile picture and a nickname; a personalized icon, for example, during challenges or on leaderboards.
Community Features	Possibility to connect with friends within the application.

*Note: "Feedback" in form of notifications on the phone and not on the wearable tracking device.

and the outcomes would be redundant with the outcomes for “Clear goals” or “Challenges.” All investigated challenges are necessarily defined by rules (e.g., number of competitors, time constraints); the same holds for clear goals (e.g., how many steps need to be reached within 24 hours).

5 Results

The results of the analysis are listed in Table 2. The most gamification elements were implemented in Samsung Health, Garmin, Fitbit, as well as Withings Health Mate, Apple Activity, and Moov Now. The identification of game elements appeared difficult regarding few cases. The deeper analysis of Moov Now shows that the wearable device might offer a possibility to endorse people who are already sporty or even more active than an average person. Therefore, Moov Now’s levels are different than the ones applied by Garmin or Samsung Health. Moov Now’s levels are not completed through collection of points or challenges but rather through finishing a workout and improving the own performance. Furthermore, in this investigation, “Clear goals” mean, e.g., daily step goals or the count of exercises one would like to accomplish weekly. Moov Now provides various workouts including certain requirements and defining clear tasks and subsequent goals (which is a short-term goal); however, these are not directly comparable with, e.g., a clear goal of doing at least 10,000 steps per day (which through a long-term repetition can lead to a learning effect). Furthermore, unlike virtual worlds in the gaming context, stories/themes found within the fitness tracker applications were very simple. The only two examples are Fitbit and Samsung Health, which included a kind of background stories in some of their challenges. Finally, it was not possible to define clear goals (e.g., 10,000 steps per day) in the Polar Flow application but only general activity goals that are not apparent for the user. Furthermore, it was possible to connect with friends, but only through third-party applications.

The mostly applied gamification elements in the investigated applications were documentation (usually historical overview of physical activities and sleep), avatars (profiles with profile pictures), clear goals, progress (toward these goals), and time pressure (usually linked to clear goals that need to be achieved within 1 day or 1 week). The top three gamified fitness tracker applications, based on this categorization, are Samsung Health, Garmin Connect, and Fitbit (Table 2).

5.1 Samsung Health

The Samsung Health application includes the most gamification elements. The content analysis showed that Samsung focuses more on creating a competitive and ego-oriented climate. In particular, there are four different elements that seem to mostly address the competitive type of users and support increase of their physical

Table 2 Overview of implemented game mechanics related to the fitness tracker applications: (1.1) Health, (1.2) Activity, (2) Fitbit, (3) Garmin Connect, (4) Amazfit, (5) Moov Coach, (6) Health Mate, (7.1) Polar Beat, (7.2) Polar Flow, (8) Samsung Health, (9) TomTom Sport, and (10) MiFit

	Apple Watch		Fitbit	Garmin	Huami	Moov Now	Withings	Polar		Samsung	TomTom	Xiaomi	Total
Game mechanics	1.1	1.2	2	3	4	5	6	7.1	7.2	8	9	10	
Points				•						•			2
Leaderboard			•	•		•	•			•			5
Badges		•	•	•		•	•			•			6
Levels				•		(•)				•			3
Story/theme			(•)							(•)			2
Clear goals		•	•	•	•	(•)	•		(•)	•	•	•	10
Feedback			•	•			(•)			•			4
Progress		•	•	•	•	•	•		•	•	•	•	10
Challenge		•	•	•			•			•			5
Documentation	•	•	•	•	•	•	•	•	•	•	•	•	12
Time pressure		•	•	•	•	•	•		•	•	•	•	10
Avatars		•	•	•	•	•	•	•	•	•	•	•	11
Community features		•	•	•		•	•		(•)	•		•	8
Total	1	8	11	12	5	9	10	2	6	13	5	6	

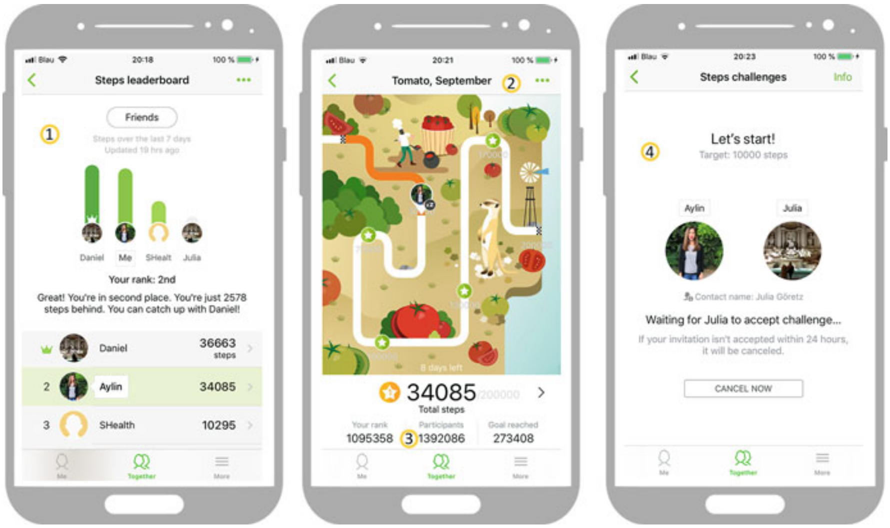

Fig. 1 Screenshots of the Samsung Health App (I)

activity. The first feature is the "steps leaderboard," a global ranking where one's performance is set into relation to the performance of all users as well as one's respective age group. Furthermore, the leaderboard includes ranking of the user and his or her friends (Fig. 1; 1). The second element is the global challenges (Fig. 1; 2), which are topical monthly challenges (story/theme element), e.g., "Tomato, September" or "Avocado, October." Here, one has the possibility to compare oneself with all participating Samsung Health users (Fig. 1; 3) (e.g., the Tomato Challenge had 1,392,086 participants) by making over 200,000 steps within 1 month. The challenge contains a walking path divided into several stages that need to be completed within a limited period of time (time pressure). Upon completion of each stage, the participant receives an orange star. Furthermore, there are health missions for which one can get bonus challenge points. There are also bonus points for being in the top 30%, top 10%, as well as top 3 participants. Each challenge has a dedicated animal that shares different information with the participant during the challenge.

The third feature is the possibility to create a 1:1 challenge with a friend (Fig. 1; 4). The challenger defines a step goal (10,000, 30,000, 50,000, 70,000, and 100,000 steps) to reach within a specific period of time. The user who reached this goal first wins.

Finally, Samsung Health is working with experience points (XP), which are called "challenge points" and are necessary to level up (Fig. 2; 5). The "Challenge levels" reflect the challenge experience of the user. On each level, a respective description is assigned to the user: "Newbie," "Achiever," "Expert," "Master," and "Champion" (Fig. 2; 7). A progress bar for each challenge level shows

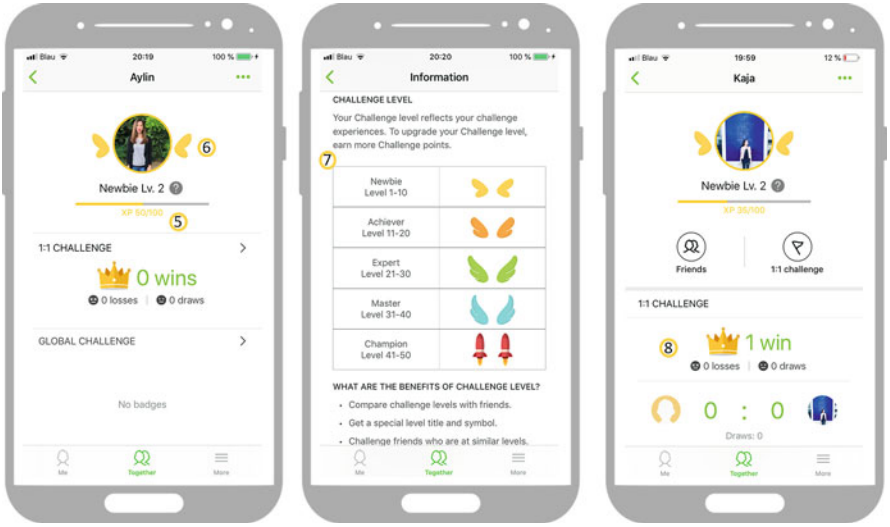

Fig. 2 Screenshots of the Samsung Health App (II)

how many experience points the user needs to reach the next stage (Fig. 2; 5). Additionally, the profile picture is distinguished with wings graphically reflecting user's progress (Fig. 2; 6). For users who would like to present themselves within the community, this could satisfy their need for self-presentation. According to Samsung Health, the benefits of the challenge level are to "[c]ompare challenge level with friends," "[g]et a special level title and symbol," "[c]hallenge friends who are at similar levels," and "[j]oin an event or promotion" (Samsung Electronics Co., Ltd. 2015–2016). Samsung Health also suggests that in order to level up fast, one should "[c]hallenge a friend who has a higher Challenge level" (Samsung Electronics Co., Ltd. 2015–2016). Here, the user is being provoked to compete with users/friends who might be more physically active. Depending on the particular case, the user can be either sufficiently challenged (when the gap in physical ability is not too big) or demotivated (when the divide is too significant). Another aspect that can either motivate or repeal users is the display of number how many times a user had won, lost, or withdrawn from a challenge (Fig. 2; 8). With those game mechanics, it seems that the Samsung Health application creates are more competitive and ego-oriented climate.

Apart from the leaderboards and challenges, it is possible to receive badges (rewards) as well. However, the badges remain hidden until their receipt. This means that users cannot see or work toward earning a specific achievement (badge). It is possible to receive badges for different breakthroughs, e.g., sleeping well, for reaching a daily step goal, or achievements in global challenges (e.g., the best explorer or reaching the step goal).

Finally, activity trackers should encourage users to be more physically active as well as raise awareness for one's health and well-being. Samsung Health enables it by providing overview of the progress toward a clear goal (categorized here in activity, nutrition, and sleep). The user can record diverse activities, heart rate, meals, weight, as well as water or caffeine intake. The app shows a clear overview and summary of the data over weeks for user to reflect on.

5.2 Garmin Connect

Garmin Connect offers many game mechanics. For example, it awards achievements (badges) categorized into seven different groups: steps, running, cycling, activities, health, challenges, and "Garmin Connect Features." These categories may appeal to different user types. Users who would like to be more physically active can focus on step badges. Those badges are connected to clear goals, for example, exceeding yesterday's step goals. We assume that the badges have a progressing pattern. The amount of points that one can earn with a badge is increasing, while the objective itself is also becoming more challenging. For example, after the badge for "3-Day Goal Getter" (achieving the daily step goal 3 days in a row) for 1 point comes the badge "7-Day Goal Getter" (hitting the daily step goal 7 days in a row) for 2 points. There is no predefined order showing which badge has to be received first, but if a user starts to be physically active and would like to increase the activity levels gradually, earning badges by participating in challenges with increasing difficulty could be helpful. The badges are visible and include clear goals, which might not only be challenging but could also increase the level of activity in the long term by inducing the feeling of flow.

With task badges, Garmin might motivate users enjoying social aspects or interacting with the application itself. Task badges also enable users to earn points (Fig. 3; 1) and level up (Fig. 3; 2); therefore, the feeling of flow may be maintained. For example, it can happen that users are not motivated enough or are not in a good mood or too tired to do few more steps and reach their daily goal. Before they get frustrated by not achieving the daily objective and not getting any points, they can share or like content, change the profile picture (once), and this way receive, e.g., 1 point. This way the frustration on less active days leading to possible amotivation in using the application can be prevented.

Another way of avoiding user's frustration is the filtering function in the overview of all badges. Thereby, a user can decide if he or she only sees less difficult badges/challenges for 1 or 2 points (which seem more reachable), or also badges for 4 or 8 points (which, for some people, can be also motivating when, e.g., they are spurred by ambition).

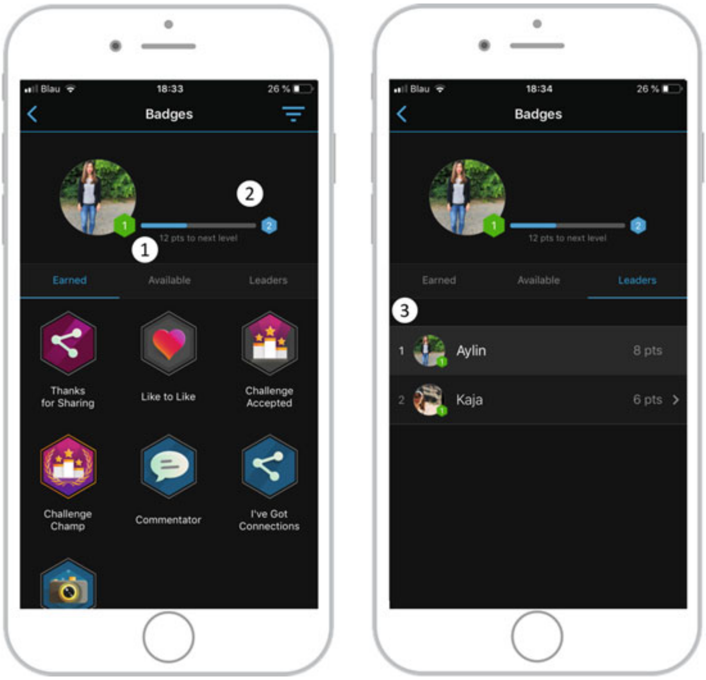

Fig. 3 Screenshots of the Garmin Connect App (I)

Some badges can be received only once. This is an interesting method to encourage the progress of the user as well as flow that he or she experiences. Hereby, one is forced to try to reach another, possibly more challenging goal or otherwise one will stop earning points and cannot reach the next level. From the flow theory perspective, this way the user remains challenged and does not get bored. If we consider the intrinsic motivation to accomplish or to learn something new, badges with clear goals and increasing difficulty may create a task-oriented climate. Nevertheless, they can also offer an ego-oriented and competitive component, since the points that can be received increase user's level, which together with acquired badges can be seen by user's friends on his or her profile. Furthermore, Garmin offers a leaderboard (Fig. 3; 3). Additionally, the ego-oriented competitive climate is fueled by the fact that the own achievements can be directly compared with achievements of a friend (Fig. 4; 4) in a juxtaposition. There is a difference between seeing only friends' achievements within their collection/profile (Fig. 4; 5) or seeing a direct comparison of the performance (Fig. 4; 4). Finally, Garmin Connect offers the possibility to create own challenges, which can be predefined by the activity (e.g., steps, cycling, swimming, etc.), duration (a day challenge, weekend challenge), and number of competitors (Fig. 4; 6).

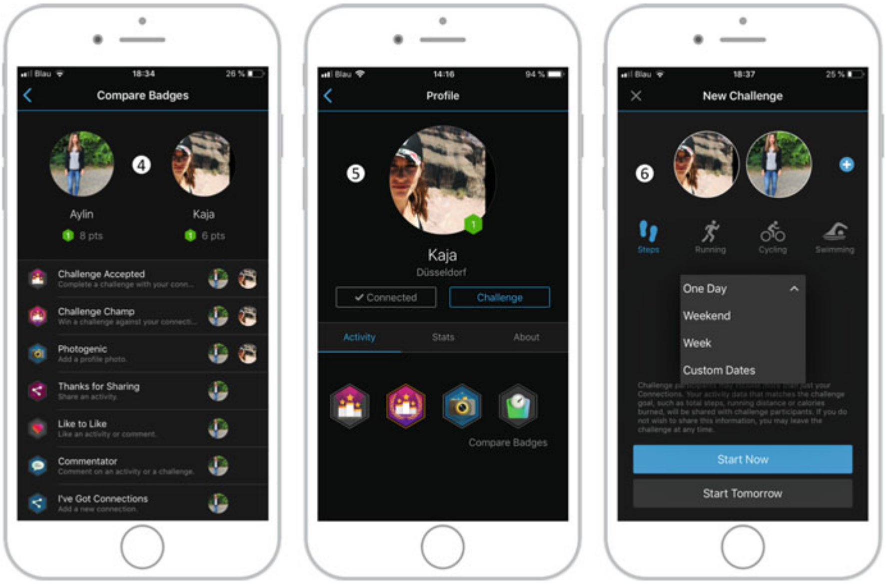

Fig. 4 Screenshots of the Garmin Connect App (II)

5.3 *Fitbit*

Fitbit is the third application with most game elements. It appears that Fitbit is creating both an ego-oriented (competitive) and a task-oriented (mastery) climate. For ego-oriented people, it can be motivating to use the challenges (Fig. 5; 1) and the "friends" leaderboard. Game mechanics such as challenges trigger competitive dynamics, e.g., wanting to be the best. Apart from such inter-user competitions, there are three types of "Solo-Adventure" (Fig. 5; 2) challenges which may be more appealing for task-oriented people.

The multiplayer challenges (2–10 people) have different time restraints. The "Daily Showdown" lasts for 24 hours, while "Workweek Hustle" lasts for 5 days. Here, the focus is set on the step count and ranking of the participants. Additionally, the users can communicate within a challenge messenger screen window. Another type of multiplayer challenge is the adventure challenges (Fig. 5; 3) that relocate competitors into a virtual geographical world (virtual world, story/theme aspect), for example, to the "Pohono Trail" (62,500 steps) or "Valley Loop" (35,800 steps).

During the challenge, it is possible to receive narrative information about the location and to unlock, for example, panoramic photos. As for the rules of multiplayer adventure challenges, winner is the one who reaches the predefined count of steps first. All challenges include feedback, e.g., that a user tiptoed or overtook another user or that the step goal is completed. During a challenge, Fitbit sends many notifications of this kind within the challenge chat window. It also

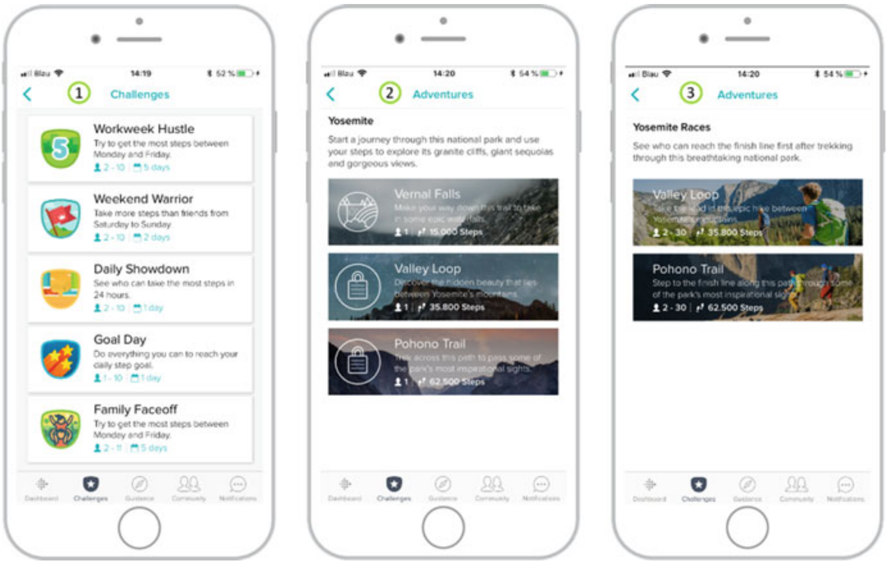

Fig. 5 Screenshots of the Fitbit App (I)

informs other participants when, for example, one of the users reached a daily step goal or got an achievement. Extrinsically motivated people can be motivated by these game mechanics (challenges, feedback, and competition). Furthermore, challenge participants have the possibility to write messages and cheer others on. It is possible, that when all participants in those challenges are similarly skilled (in this case, equally physically active), they will experience flow and enjoy the challenge. The feeling of flow can be maintained as long as the challenge is dynamic through frequent ranking/position change of the participants and when there are only minor gaps between their performances.

All introduced challenges set clear goals for the users, e.g., to be the first to reach a predefined amount of steps. During the challenges, users get different kinds of feedback on their progress, e.g., competitive notifications within the challenges or virtual places, or simply the number of steps left to reach the daily goal. Apart from the challenges, the user can accept the predefined daily step goal of 10,000 steps or define an own objective. Also here Fitbit sends notifications to user's smartphone or the wristband informing him or her how many steps are missing to reach the daily step goal. The user can also check the overall progress overview (Fig. 6; 4) of his or her activity and access statistics from previous weeks (Fig. 6; 5). This constitutes a more task-oriented environment.

Apart from an ego-oriented or competitive climate, Fitbit's application also offers a task or mastery environment, where the main aim is not being better than others but to master an exercise and work on self-improvement. When people want to focus more on the task or activity itself instead of external factors, they can use Fitbit's "Cardio Fitness Score." This is a score bar (Fig. 6; 6) reflecting the fitness level of a

Fig. 6 Screenshots of the Fitbit App (II)

user. If a user is getting fitter, the value on score bar will be higher; when his or her physical activity stagnates, it will decrease.

Another element that might appeal to both task-oriented and ego-oriented users is the achievements/badges (Fig. 7; 8), which, in Fitbit, remain hidden. A user gets one when he or she reaches a certain milestone, however, without knowing them in advance. Those achievements are categorized as badges, for example, “Daily Steps,” “Daily Climb,” “Lifetime Distance,” “Lifetime Climb,” “Weight Goal,” or “Challenge.” It is possible that users who are interested in exploring new elements will be engaged in more physical activity (usually walking) in order to receive new, unknown badges, e.g., for every additional 5000 steps per day. This could enhance the feeling of flow as well. Another category of achievements is “Trophies” that, unlike badges, are visible from the beginning to the user. Both badges and trophies that a user received are displayed on his or her profile.

By offering and rewarding badges (Fig. 7; 8) and trophies (Fig. 7; 7), Fitbit creates both task-oriented and an ego-oriented/competitive climate. The users have the possibility not only to collect achievements (as a way of self-fulfillment or just for fun), but also to share the earned badges and trophies with others. Additionally, during challenges, Fitbit informs all participants of badges or trophies that the user earned. Fitbit users have a profile with a picture that lists all their rewards and friends. They can hide their badges and trophies or leave it public for others to see. When seeing friend’s achievements, one can feel motivated to earn such badge or trophy as well.

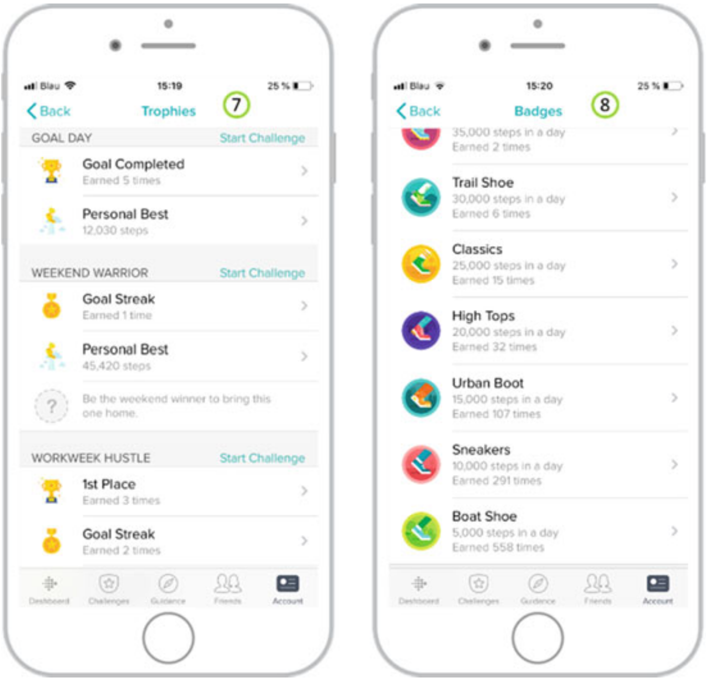

Fig. 7 Screenshots of the Fitbit App (III)

6 Discussion

In this investigation, we analyzed applications provided for ten fitness trackers and the game mechanics that they contained. Previous literature revealed that gamification can help to increase user's motivation and encourage higher engagement with a service. Following this reasoning, we hypothesize that gamification elements within activity trackers and their applications can improve the physical activity of people in the long term.

To the best of our knowledge, no previous studies analyzed or compared the gamification mechanics of activity trackers' applications. We are aware that empirical research is necessary to better understand effects of gamifications and its impact on user behavior in context of activity trackers. This study, however, was an important first step laying out theoretical background and summarizing the results of our content analysis of the applications. With this study, we would like to show that besides an increased implementation of gamification elements, the developers need to consider the dispositional components like users' goal orientation (ego-oriented or task-oriented), motivation (intrinsic or extrinsic) or amotivation, as well as adequate contextual components like the motivational climate (competitive/ego-oriented, mastery/task-oriented).

The analysis of the fitness tracker applications showed that the gamification elements are implemented in various ways. Interestingly, while some studies pointed out that leaderboards, challenges, and points are one of the core mechanics of gamification, it is obvious that this was not the case for our investigation. Some applications (Samsung Health, Garmin Connect, Fitbit, Moov Coach, Health Mate) offer leaderboards, so that the users can compare their performance among each other. Similar effect can be achieved through challenges (e.g., Fitbit, Garmin Connect, Health Mate, Samsung Health). Based on that comparison, a real competition can start when users try to beat each other. This may lead to change of the user's behavior so that he or she is able to be better than others. These behavioral changes are usually accompanied by emotions such as ambition or willpower.

This competitive climate, introduced and triggered by game mechanics being leaderboards or challenges, may especially influence the ego-oriented people. For them, this type of game mechanics can lead to the state of flow. Ego-oriented users are engaged in the activity just as a means to an end, which is enjoying the moment of outperforming others. However, these circumstances might not be the ideal requirement for learning progress, since the dispositional and contextual components at hand are ego-oriented and extrinsic. Duda (1989) and Cumming and Hall (2004) showed that ego-oriented people do not focus on the activity itself; instead, they concentrate on rewards or confirmation that they can gain. Those circumstances as well as the rewarding feeling are rather short-lived. This happens especially when the user has no real competitors and remains on the first place for a long time (his or her abilities exceed the task; hence, he or she is unchallenged), or the distance to other and better competitors is way too big (the challenge exceeds one's abilities; hence, the user is overchallenged). Furthermore, such under- or overchallenge can often lead to boredom or anxiety, which in turn can end in amotivation of the user to engage with the service. In consideration of the above, leaderboards and (group) challenges might not be the best motivation for task-oriented and intrinsically motivated people and lead to long-term engagement or behavior change. It is debatable whether users who are always on one of the top ranks continue to engage in the activity because they learned to be more physically active. Based on the literature overview, the answer would be that they do it because of the competitive climate. The physical activity (here, taking steps) is only a means to an end, namely, to be the best. Based on the self-determination theory, the extrinsic motivation thrives on pressure and fear of failure but also social recognition and appreciation of one's performance. Some of investigated applications offer the possibility to share, like, and comment on activities or achievements. Those functionalities may boost extrinsic motivational needs as well.

It is more difficult to assign levels and experience points to a respectively triggered behavior. Experience points or skill points as well as levels reflect users' ability and progress. For example, the badges of the category steps from Garmin Connect can ensure that a user is getting more physically active and keeps up the own progress. Gagné (1977) pointed out that we can speak of learning when a change in behavior occurs over a period of time. For example, if a user usually does 15,000 steps a day and would like to try to reach 20,000 steps, it is possible that this progression will occur over a longer period of time and will require the user to adjust his or her behavior. These changes in everyday behavior could include dismounting the bus one stop earlier than usually or taking a slight detour on our way to school or work. If the user repeats these changes frequently enough (at first with the intention to reach the 20,000), they might become a habit and the behavioral change will remain permanent (and not only until reaching the step goal). This long-term change is, however, more feasible in a mastery climate, where the activity itself and the user are in focus. In a competitive climate the focus switches to competition and short-term (peak) performances (one-time effort to beat other participants), which does not support formation of habit and learning. Therefore, this type of game mechanics and motivational climate is favored by task-oriented and intrinsically motivated users.

These intrinsically triggered behaviors are more likely to lead to the state of flow. Furthermore, related to the intrinsic motivation, the autonomy to choose, for example, which task should be tried out (Garmin Connect) supports the intrinsic motivation, however, not if the goals are too demanding or, in contrary, too easy for one's abilities. The balance between skills and the tasks is therefore essential. This is why it is important to give users the autonomy to decide which goals with which difficulty they want to strive for. This can foster their motivation and reduce the risk of being overwhelmed or afraid of failure. A counterexample is levels and points that can be earned through challenges (e.g., Samsung Health). These points are more likely to foster a competitive climate. Here, the focus lies on beating others, being the best, and possibly earning some kind of social endorsement. Here, it is doubtful whether the activity leads to creation of new habits and, in general, learning.

It is necessary for the user to have a clear goal in order to achieve a long-term behavior change. Without goals (possibly not only short-term but also long-term goals), the user can lose focus and motivation. Progress bars support clear goals, since this way users get feedback on how far they are away from, e.g., their daily step goal. Some goals have time constraints, which, on the one hand, can increase the motivation and incite ambition but, on the other hand, may decrease motivation when users realize that it is not possible to reach the goal or are stressed by the time pressure (leading to amotivation).

Historical overviews of all activities and reached goals show the users their progress over time and might be especially appealing for task-oriented people. The possibility to evaluate one's progress and to explore how one's performance is getting better (or worse) can trigger curiosity and develop awareness for the evaluation and interpretation of collected data. Especially, these progress overviews are improving mastery climate as they only focus on the user and his or her performance, excluding any external aspects (performance of others, outcomes of competitions, etc.). Especially, the feeling of competence, to evaluate and recognize own progress and success, increases intrinsic motivation. Unless, it is possible to see the performance overview (or parts of it) of other users or to even share and post own performance within the community—this can create a more competitive climate, since this enables comparison with others and/or social recognition.

Finally, achievements (badges or trophies) provide a wide range for discussion. For users who enjoy collecting badges, such achievements can be motivating. They can maintain the state of flow as users are focused on performing the activities and change their behavior so that they can accumulate achievements (self-fulfillment). Even if the state of flow is maintained (which may be motivating and enjoyable), the progress of learning does not need to be given. In order to let the behavior patterns become a habit and learn in the long term, the achievements (badges) need to be associated with clear goals which support a thoughtful change of behavior over long period of time. In the end, users still have the possibility to share their achievements (social recognition), or see the badges and trophies of friends and compare them with own achievements (competition). Therefore, achievements in the form of badges or trophies can generate both mastery and competitive climate.

Game mechanics of the investigated fitness tracker applications show that there are many possibilities to motivate people to be more physically active, but the induced behavior change can usually be short-dated, instead of becoming a habit. The process of actual learning might depend on different factors, which are not limited to the gamification elements but include the dispositional motivation of users (extrinsic, intrinsic, task- or ego-oriented), their goals, skills, acceptance of an application, and, abstracting from our theoretical implications, the knowledge and general understanding of the principles as well as importance of physical activity and a healthy lifestyle.

7 Conclusion and Outlook

The investigation showed that most of the game mechanics were integrated in Samsung Health, Garmin Connect, and Fitbit. Except for Apple Health and Polar Beat app, all remaining applications included at least five of the investigated elements. The theoretical investigation implied that it is reasonable to create a mastery climate in order to improve the process of learning, hence, a long-term change of behavior concerning physical activity. Competitive atmosphere and extrinsic influence refer more to such needs as external approval, social recognitions, competition and the presentation of one’s skills. These conditions, however, do not support long-term changes, because the incentives are only temporary, and sooner or later, the allure gets lost. Nevertheless, this does not mean that game mechanics creating a competitive climate are not beneficial; after all, they are motivating and make the activity enjoyable. The only question here is for how long and with what impact.

Referring to the gaming domain in general, one should take into consideration the different types of gamers. This means that some game mechanics might be more appealing for specific gamer types, such as the “Achiever” or “Explorer.” This also shows that implementation of gamification elements is a very elaborate undertaking that requires more than incorporation of points, badges, or levels. This should be considered in the future research.

Our investigation has few limitations. In the future, it is necessary to conduct empirical research in order to derive and connect certain game mechanics to behavioral dynamics and intrinsic as well as extrinsic motivation. As a next step, we would like to quantitatively and qualitatively investigate how game mechanics cohere with behavioral dynamics. With the theoretical background laid out in this study, we would like to empirically confirm our implications. Furthermore, this study focused only on the fitness tracking applications. Consideration of the respective wearables and their interaction with the users (e.g., in the form of sound or vibration notifications) is a further necessary step to better understand how gamification and fitness trackers can teach the users to lead healthier lifestyles.

To conclude, the introduced and applied theories reveal that developers of wearable-enhanced learning environment need to consider the different needs and attitudes of users. Its effectivity is defined through the satisfaction of users and their continued usage of the service or product. However, the study also showed that there is no one right formula to develop such successful wearable-enhanced learning environment. Here, it might be advisable (1) to analyze the target group (e.g., task-orientated users, ego-orientated users, or both), (2) to set individually manageable aims adjusted to user's health and fitness level (e.g., with the help of fitness pretests), and (3) to integrate challenges and tasks with incrementally growing intensity, which in turn supports the shift from a task one needs to complete from time to time to a long-term healthy habit. Furthermore, considering the intrinsic motivation being a good foundation for long-term learning, a wearable-enhanced learning environment needs to satisfy such users' needs as autonomy (e.g., to choose own challenges or tasks, time goals), competence (e.g., for mastery-oriented people, the aims should be manageable and challenging, but not frustrating), and relatedness. While addressing several interconnected theories, this study showed how complex is the concept and implementation of a successful wearable-enhanced learning environment. This also explains why not every health or fitness tracker application might be suitable to induce long-term changes, hence, teach the users to lead a healthy and fit life.

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Part VI
Research and Data

Virtual Reality as an Environment for Learning: Facilitating a Controlled Environment for Pupils with Diagnosed Concentration Disorders

Eva Mårell-Olsson, Thomas Mejtoft, and Jenny Kinert

1 Introduction

In the media consumption pattern, it is possible to notice that different types of entertainment are becoming increasingly important, especially among children. When reflecting on youngsters' spare time, games and gaming have an enormous impact on the youth of today. In 2015, the teenagers (13–18 years) in the USA spent, on average, 9 hours on entertainment media, out of which 81 minutes were spent on playing different types of computer games (Common Sense Media 2015). In Sweden, 46% of 14-year-old boys and 13% of 14-year-old girls spend 3 hours or more a day playing computer games (Statens medieråd 2015).

However, according to an annual survey of children 12–18 years of age, by the Swedish Central Bureau of Statistics, concentration is raised as an issue. In the 2016 survey, approximately 30% of those 16–18 years of age agree with the statement: "I often find it hard to sit still and concentrate" (Statistiska centralbyrån 2017).

Virtual Reality (VR) is a technology with a lot of different application areas. Even though the technology behind VR has been around for a long time (Robertson and Zelenko 2014), it is just recently that the technology was started to be used in common application and is becoming widespread. Part of the interest in VR technology has to do with the availability when an ordinary smartphone can be converted to a VR headset for just a few Euros. Early successful adoptions of the ideas behind VR date back to the early 1900s, with, e.g., the View-Master, which created a static VR environment. Even though visually similar, this is, however,

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far from the immersive interactive environments that can be created with today's VR technology. Even though one of the first areas of use that come into mind today is games, professional applications, such as military, health care, education, experiences, etc., have been around for decades.

Kadesjö (2010) describes that many children with diagnosis of concentration disorders such as ADHD (e.g., attention deficit hyperactivity disorder) have problems of social nature as lack of school success. One of the problems they have is that they are easily distracted by their environment (Kadesjö 2001). Literature on how teachers can design their teaching for pupils with concentration disorders suggests adopting the less distractive school environment (Juul 2003). What if it is possible to use VR technology to increase motivation and concentration of pupils who have trouble maintaining their concentration level? According to Psotka (1995, p. 405) VR is distinguished from other visual technologies by the "sense of immediacy and control created by immersion: the feeling of "being there" or presence that comes from a changing visual display dependent on head and eye movements." Hence, the immersive nature of VR could be an alternative to the "reality" in schools to facilitate a more controlled setting. This study aims to investigate if the use of VR technology could be a way to control the school environment to a higher extent and thereby decrease the perceived distractions and, hence, be a suitable support for pupils with diagnosed concentration disorders.

2 Background

2.1 Inclusive Teaching Practices and the Use of Technology

Sweden has been, over the last few decades, actively building a democratic, comprehensive schooling system, with the aim of providing inclusiveness to create a "school for all" (Persson 2010). An inclusive practice is characterized by active participation and engagement of all pupils, and researches show increasing knowledge on the values of teaching in relation to inclusive practices (Raffo and Gunter 2008; Lindqvist and Nilholm 2013; Nilholm and Alm 2010). Surprisingly, there is little research that is investigating how an inclusive pedagogy can be created and enacted within the classroom (Florian and Spratt 2013) and, in addition, how technology can support pupils with difficulties (Brodin 2010; Bolic et al. 2013). A recent study (Mårell-Olsson et al. 2019), examining 27 teachers' digital didactical design in teaching within tablet-based one-to-one computing initiatives in Sweden, shows that teachers are trying to adapt assignment to every pupil's specific needs to customize the education for all pupils in the classroom. However, even if the participating schools were among the earliest (Rogers 2003) in Sweden to use one-to-one computing, the teachers in the study did not use emerging technologies such as wearables (i.e., VR glasses, augmented reality (AR) glasses, or other type of technology) for adapting assignments and the learning environment to the pupils' specific difficulties (e.g., pupils with concentration disorders). Internationally, there are few studies examining the use of technologies in teaching and how these can be used for supporting pupils with, for example, concentration disorders (Abbott 2007). According to Abbott, research on pupils with learning difficulties tends to focus particularly on topics such as dyslexia.

2.2 How Pupils with Concentration Disorders Can Be Affected by Their Education

Children and young adolescents with concentration disorders are often very extroverted and sometimes seen as noisy and inconvenient and according to Kadesjö (2001), there are a few typical problems for these pupils. Further, he argues that pupils with concentration disorders do not have to suffer from all the problems. It depends on situation and the individual how much and what kind of problems there are. Kadesjö's (2001) definitions of concentration disorder problems are:

- Attention deficit
- Impulsiveness
- Difficulty with finding the appropriate concentration level
- Difficulty in perceiving and following instructions or rules

Attention deficit is concerning that the individual has a hard time focusing on its attention. Individuals with this problem easily lose their focus by distractions in their environment. Because of this they have a hard time completing tasks and taking instructions.

Impulsiveness refers to that the individual does not take responsibility for their actions. They react on the first thing that comes into their minds. This causes the individual to not entirely know why they performed a specific action, because they only acted on an impulse.

Difficulty with finding the appropriate concentration level is connected to the above description of problems. This difficulty is mainly concerning if the individual is either hyperactive or not active at all. Here the first one is the most common.

Difficulty in perceiving and following instructions or rules are also difficulties related to the first two. This specific issue is the most common and is concerning if and to what extent the individual does understand the purpose of instructions or rules. This is regarding different steps from hearing instruction or the rule to obeying it. Firstly, there might be difficulties concerning listening and understanding what they are being told to do. Secondly, the difficulty can be in performing the action and maintaining it for a longer period. In addition, the difficulties can also be affected if the individuals are *impulsive* or *attention deficit*.

Teaching and learning in school are not adapted for pupils with concentration disorders and do not specifically use emerging technologies for this purpose (e.g., Bergström et al. 2017; Mårell-Olsson et al. 2019). Since pupils with concentration disorders are not able to maintain focus for a longer period, their performance is thereby affected; this might contribute to the lack of motivation in doing schoolwork, which in turn affects the possibility of being successful in school (Kadesjö 2010).

In a research study by Meaux, Green, and Broussard (2009), it has been described that students with a diagnosis of ADHD often struggle through the education system. Lack of parental supervision and structure, variable course schedules, and increased freedom the older they are might cause distractions and can lead to health-risk behaviors. Further, the results showed that challenges to school success were concerning poor time management and organization skills, difficulty staying focused, failure to complete work on time, poor motivation, poor reading and study skills, and difficulty sleeping and getting up in the morning.

Consequently, this in combination with a lot of failed assignments can lower their self-esteem, which in turn decreases their motivation of doing schoolwork (Kadesjö 2001). According to statistics approximately 3–6% of children in Sweden have ADHD or a similar diagnosis (Polanczyk et al. 2014). As mentioned earlier, approximately 30% of the youngsters participating in the Barn-ULF study between 16–18 years feel that they have a hard time concentrating or sitting still during class in school. The margin of error in the evaluation is ±5%; this indicates that there are lot more pupils than just the ones with ADHD who have problem concentrating in school (Statistiska centralbyrån 2017).

Kadesjö (2001) argues that the motivation for school performance and for completing assignments is of great importance for the individual's ability to concentrate. Many pupils with concentration disorders have a history of making mistakes and failures, which in turn affect their self-confidence and the vision of themselves (Kadesjö 2001; Kadesjö 2010). Previous failures and low self-confidence are usually sources of the pupils' lack of motivation. Hence, this is something that is not special for pupils with concentration difficulties. This is something that can be applied to all pupils in school (Wery and Thomson 2013).

Lessons in schools are usually designed so that the teacher can deliver lectures using the board or digital slides, followed by practical exercises with the teacher's guidance (see, e.g., Bergström et al. 2017, Mårell-Olsson et al. 2019). The length of a lesson varies between 45 minutes to several hours. Children and young adolescents with concentration disorders usually have problems with focusing on a target, they are impulsive, and they are not able to find an appropriate activity level. In turn, they have trouble following instructions or rules (Kadesjö 2001). When designing teaching strategies for pupils with concentration disorders, it is important to come up with a teaching design that helps them to succeed with the assignments they are given. Kadesjö also describes that these pupils need a lot of encouragement and clear tasks. Further, the environment plays an important role since these pupils are easily distracted by classmates or other events that might appear in the classroom (Kadesjö 2001).

2.3 Technology for Virtual Reality

Virtual Reality (VR) is a computer-simulated environment and the technology allows the user to interact with a virtual environment (Fordell et al. 2011). In short, this means that the user enters a new environment that feels so real that they forget it is artificial and behave as they do in the real world. However, the definition of Virtual Reality differs a lot and the one used in this study comes from the Virtual Reality Society (Virtual Reality Society 2017):

> Virtual reality is the term used to describe a three-dimensional, computer generated environment which can be explored and interacted with by a person. That person becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions.

Elements of Virtual Reality (VR) can be tracked back to the 1860s. For example, in the avant-garde work of French playwright Antonin Artaud, he argued that a theater audience should suspend their disbelief and consider the performance to be reality (Virtual Reality Society 2017). A vision more suitable for today's use of the technology came in 1930 from Stanley G. Weinbaum in his short story *Pygmalions Spectacles*. Here he describes a goggle-based game where individuals can experience virtual stories including both touch and smell (Grauman Weinbaum 1949). The public awareness of the technology came in the 1980s when Jaron Lanier began to develop a gear including goggles and gloves to experience what he called Virtual Reality (Virtual Reality Society 2017). With the increasing use and performance of digital technologies, Virtual Reality has gone from being just a concept, in the beginning of the 1900s, to becoming an affordable reality, and as it continues to develop, the more popular it becomes.

To achieve this kind of immersive "reality" today, ranges of systems are used, such as headsets, omnidirectional treadmills, and hand controls. All these artifacts are used to stimulate the users' senses to create the illusion of a reality. Usually the artifacts are connected to a computer or phone, which visualizes the environment and performs the user's action (Virtual Reality Society 2017).

The purpose of using VR technology is to create an immersive experience (Davies 2002) for the user that both can be explored and interacted with. In addition, this allows the user to experience places they will never be able to visit or learn new things by a virtual experience. Depending on how the VR application is created, the user sometimes can build and create a whole new world, new items, or new experiences for themselves. With this so-called diversity, a VR application can stimulate the user's own creativity, zoom in on special details of a subject or similar, zoom out on the world for a bigger perspective, and offer guidance in a special subject.

2.4 Why Use VR as a Support in Teaching and Learning for Pupils with Concentration Disorders?

When educating pupils with concentration disorders, a valuable technique used is to visualize tasks with pictures and sketches. It then becomes easier for the individual to understand the purpose of the task (Olsson and Olsson 2013). The biggest benefit, or more specific the added value, with using VR technology in teaching and learning situations could be that the pupils are more interested in using the new technology, and this in turn could motivate them to learn to a higher extent (Allison and Hodges 2000). Compared to real-life situations, this could also provide the teacher with an increased ability to control the learning environment to a higher extent for pupils with concentration disorder and actually allow to show them their own vision (i.e., first person view). Hägerström (2017) gives some examples of how to apply Virtual Reality in education, for example, in history lessons, where ancient Rome can be explored and where the pupils can walk the streets, talk to the natives, and explore the environment. Another example can be to explore the universe and both experience and being immersed of how the Big Bang happened or how stars die (Hägerström 2017). Previous research (Allison and Hodges 2000) indicates that pupils find VR technology interesting and fun to use even if the task itself is not particularly relevant, boring, or unnecessary for their education. One study conducted in the field of VR and education indicates that pupils who are using VR for educational purposes can focus on a task for longer period, and they enjoy themselves while studying (Allison and Hodges 2000). Another study by Donaldson (2006) indicates that the use of digital technology can be successful when it comes to educating children due to an increased motivation of doing schoolwork.

A hypothesis for this presented study is that using VR as a teaching and learning technology might involve a more visual setting for the pupils similar to the visualization done by pictures (Olsson and Olsson 2013). Another valuable technique could be to design and create assignments for meaningful learning (Jonassen et al. 2003), especially for pupils with concentration disorders. VR technology might provide this to a higher extent than before, since pupils now could explore the learning environment in another way. In this type of learning setting, the pupils could both get a context and visualization of the task and in turn understand the purpose of it. It could also be possible to repeat certain parts if there is something they do not understand and, in turn, they can have fun while learning with no other distractions. These factors could be valuable when teaching pupils with, for example, concentration disorders.

Overall, research on the use of VR technology in teaching and learning are presenting positive results, specifically regarding increasing pupils' motivation to do schoolwork. Research presenting challenges or the backside with the use of this type technology is scarce. This raises some new questions. How can the use of VR technology be applicable to pupils with diagnosed concentration disorders as a support for learning with an aim of enhancing their learning processes?

2.5 The Study's Aim and Research Questions

This research study investigates how Virtual Reality (VR) technology can be used as a complementary tool for learning purposes for pupils with diagnosed concentration disorders by facilitating a controlled learning environment.

Research questions:

1. How can VR technology support learning for pupils with diagnosed concentration disorders by offering a controlled environment?
2. What possibilities and challenges are there?

3 Theoretical Framework

To be able to understand and describe how VR technology can be used to support pupils with diagnosed concentration disorder, activity theory (Leontiev 1986) has been used as a theoretical framework. Activity theory embraces an understanding and an exploration of a context in relation to how tools and intentions, social relations, and materials affect, for example, actions in different situations. It is of great importance to study the role an artefact or a tool plays in everyday life (Nardi 1996). As a starting point, Leontiev's (1986) concepts of *motives*, *goals*, *actions*, and *operations* have been used for understanding how different actions are linked to each other (Fig. 1). These concepts create possibilities to investigate actions taken within an activity system and the interplay among these actions.

The object within an activity system, *the goal*, is based on *the motive* of a business (i.e., activity system), whereas it is the subject that gives the business a determined direction. Within an activity system or work process, the processes of *actions* are carried out by, for example, individuals. The actions are subordinated to the conscious goal. *Operations* are the approaches or routines that the actions of a work process are realized with (Fig. 1).

Leontiev (1986) also describes that an activity system is considered as always having a *motive* when implementing tools in working processes, even if it is not always visible to the individual. There cannot be any business (e.g., activity system) without any motives; unjustified activity is not an activity that lacks motives, but one whose motives are hidden or not explicitly expressed. The most important parts within an activity system are the actions taken. *Action* is a process which is

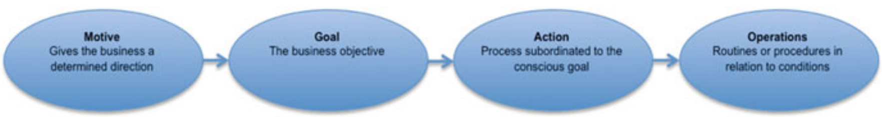

Fig. 1 Activity theory and Leontiev's (1986) concepts and relations within an activity system

subordinate to the conscious goal or the idea of the result to be achieved. Hence, the concept of *the goal to achieve* is thus related to the concept of actions. Actions are not individual units in an activity system. Human activities (e.g., actions) consist of an act as part of a chain of different actions at different levels (Fig. 1). *Operations* are the routines or procedures that the actions in a work process are realized with (e.g., in this study the use of VR technology for controlling the learning environment for pupils with concentration disorders).

4 Methods and Study Context

To investigate if VR technology can be useful as a supporting tool, a case study was performed during fall 2017. The study was conducted as an embedded multiple-case design study (Yin 2003). To get reliable results, the study was carried out in three steps: (1) observations during a key task test; (2) qualitative interview sessions; and (3) a survey of the general view among young adolescents' view of the use of VR for learning purposes. In the first part of the study, a purposeful sampling technique (Patton 1990) was used. Two participants, one girl and one boy, between 17 and 19 years, both diagnosed with different degrees of concentration disorders, were selected. The different parts of the case study (e.g., the observations during the key task test and the interviews) were not performed at the same time. There was 1 day in between the conducting the test and the interview.

4.1 Material Used in the Study

Before deciding on a specific VR headset for the key task test, a couple of different common VR headsets were evaluated—Samsung Gear, Google Cardboard, and Spectra Optics. The Google Cardboard is very cheap and suits all android phones and some iPhones (Google VR 2017), however, a decision was made to exclude them due to the inadequate performance and uncomfortable fit. The spectra optics was also evaluated due to its adjustable lenses. Nevertheless, the performance of this model was also decided to be too inadequate and could therefore not be used for the study. Out of the evaluated headsets, Samsung Gear was the one that fulfilled the demands on performance and comfort during use. Hence, the VR technology used in this study is the Samsung Gear VR SM-R321 Innovator Edition headset, Samsung S6, and the VR applications *Mondly* and *Our solar system*. The Samsung Gear (Fig. 2) is equipped with a touchpad on the user's right hand side to perform actions in the interface. The headsets dimensions are 82.8 × 196.1 × 98.5 mm and weigh 420.4 g. The headset is designed to be comfortable for longer periods of time. It has therefore a rear strap that distributes the weight of the device evenly across the user's head. It is also possible to charge the headset when in use. The headset has adjustable glasses to enable custom adjustments for sharpness (Samsung 2017).

Fig. 2 Samsung Gear headset used in the study

The educational materials chosen for the test were two different Virtual Reality applications. The first one, *Mondly: Learn Language in VR*, is developed by ATi Studios. Using this application, the user can learn new words and practice real conversations with virtual characters (Mondley 2017). The second application, *Our solar system*, is developed by Crenovator Lab Corporation. This application contains five lessons with various topics regarding the solar system (WEARVR 2017). A difference between the two applications is that in *Our solar system,* a voice holds a lecture and the user listens to the lecture, while in the other application, *Mondly,* the user interacts with a virtual character. Both applications were available in the Oculus store during fall 2017.

4.2 Test Procedure

Before the study started, the test participants filled out a consent form to make sure they understood the purpose of the study and that the data collected would be treated confidentially. In the key task test (Krug 2000), the participants tried out and explored the different applications, starting with Mondly. They were assigned to perform the first two lectures in each of the two applications. After each test case, the participants graded their experience from 1 to 4, where 1 was perceived as bad and 4 was perceived as great. The choice of an even scale is due to the test participants being unable to be just generally neutral in their opinion. They had to make a choice whether the experience was leaning to either positive or negative in some way. Explanations for the answers were also requested to get a better understanding of their grading. During the key task test, the participants were observed (Nielsen 1993) by an observer taking notes during the test for documenting their experience, thoughts, and flow within the applications used.

After the key task test, interviews with the two participants were conducted. The interviews were a mix between a focused and an unstructured interview, and the interview guide consisted of open-ended questions so the participants could have an opportunity to elaborate their answers more widely (Fontana and Frey 2005). The interview questions were designed and categorized to investigate the headsets performance, the participants' experience, if they learned something from the experience, and to what extent this technology could be used in education for supporting learning purposes. The choice to conduct the interview 1 day later than the key task test was due to minimizing the impact of affecting the answers regarding that Virtual Reality could be perceived as a new interesting technology and in turn perceived as just fun to try out.

Lastly, the survey that was carried out contained 13 general questions about Virtual Reality, the participants' own experience of school, and the benefit and constraints about the use of VR technology in learning. The survey had 16 respondents that had, either, just left high school or was university students. The idea was that these respondents could look upon their motivation in school in retrospect. The choice of also conducting a survey was to get a broader understanding of what general perceptions people have about Virtual Reality itself and how it can be used for learning purposes in the school system.

4.3 Analysis

The "activity system" that is investigated and analyzed in this presented study is, as mentioned earlier, the learning environment for pupils with diagnosed concentration disorders and how it might be controlled to a higher extent with the use of VR technology. Thematic analysis (Ely 1991) has been used in the analysis process to construct understanding and meaning of the collected empirical material and for identifying key themes and emerging patterns. The process of analysis is understood as *seeing* and *seeing as* (Boyatzis 1998) and included several readings in iterative processes of the empirical material for identifying emerging patterns. The different steps of the analysis process included (1) reduction of data (coding), (2) presentation of data (thematization), and (3) summary in the form of conclusions and verification.

By carrying out observations during the key task test, interviews and a survey as data collection, three sources of data are used for deepening the understanding and, in addition, increasing the study's reliability. The analysis processes for this study were conducted in three phases. First, the results from the test were analyzed and second the interview study. Third, the survey was analyzed and, lastly, the three sets of data collections were then analyzed in comparison (i.e., triangulation). To be able to identify and establish the emerging themes, data was first reduced to categories, codes, and emerging patterns and then sorted into themes. When themes were established, conclusions and verifications were drawn.

Quotes chosen and presented in the next section of findings should not to be seen as evidence, but more as illustrations of the presented themes that emerge in the analysis of the empirical material.

5 Findings

The purpose of the study was to investigate how Virtual Reality can be used as a complementary and supportive learning tool for pupils with diagnosed concentration disorders by offering a controlled learning environment. The findings are presented in three themes: (1) increasing the ability for concentration, (2) the suitability of using VR technology in learning, and (3) developing knowledge acquisition with the support of VR technology.

5.1 Increasing the Ability to Concentrate

During the interviews, both participants argued that it was easier to maintain their focus in the application *Mondly* compared to the application *Our solar system*. The participants also evaluated their concentration experience in comparison with normal lectures. Test participant 2 clarified:

> Mondly was much better than a normal lecture! It was much more fun than just listen to the teacher and write. ... It also went fine to focus while wearing the headset. I rather have a VR assessment than an ordinary assessment since it is much more fun and therefore easier to concentrate.

Test participant 1 also experienced an improved concentration level. According to this participant, it was beneficial that the view of sight was limited to the application and no distractions, e.g., friends around, were present.

According to the survey of the overall impression of what Virtual Reality could improve, the concentration level got a high score. Seventy five percent of the respondents agreed to this statement "Do you believe the use of Virtual Reality in education can increase the students' ability to concentrate." The motives given for these answers align with the test participant opinions about the concentration level using VR. Motives like "it is fun," "interactive," "less distractions in the environment," "more efficient," and "easier to focus on the right things," were the explanations given about how to increase the concentration level. The findings indicate that the use of VR technology can strengthen a user's ability to concentrate due to the ability of a controlled environment.

5.2 The Suitability of Using VR Technology in Learning

To use VR in educational settings, the pupils need to have an interest in using this type of technology in school. Both participants in the key task test and interviews agreed that they would like to use VR as a teaching component in school. They would like to exchange all lectures to VR. Participant 2 described that she wanted to exchange some parts of the activities in school by using VR technology instead.

Both participants shared a specific increased interest in applying VR technology in the subject English and other languages, especially while practicing speaking languages. This was also something they were expressing while exploring the Mondly application. When the participants graded the experience of the application *Mondly*, it got a positive result (both participants graded the experience as 3 out of 4). Here a proper question to ask could be, if a positive VR experience can increase the motivation for a specific subject and therefore increase the learning interest.

The participants were also asked about their own experience about the subject English (a second language in Sweden, not mother tongue) in school. Both participants answered that they did not like English at all and participant 2 described it like this:

> Damn it all, it is boring, awful and hard. It is very difficult before you have learned something, and then it gets very boring. When I do not understand anything at all, I can focus for like 2 minutes and then I cannot learn any more.

Despite the dislike of English as a subject, both participants described the use of the Mondly application as fun. When they were asked about what subjects VR could be suitable for the first alternative that came to their mind was the subject English: "The reason is because it would be more fun" (Participant 1). The correlation between being perceived as fun and motivational can also be found in the survey. The survey question "Do you believe the use of Virtual Reality in the education can increase the motivation for learning?" shows a positive result, and a total of 94% out of the respondents answered yes to this question. Five of the respondents in the survey argue that they would be more motivated if using VR technology and in turn that education overall would be perceived as more fun.

The findings indicate that the use of VR technology could increase the motivation of performing an assignment by adding a factor of perceived "fun" to it, even if the participants dislike the subject itself. This is also in line with the results from the survey where the survey respondents mentioned that VR could increase their motivation for learning and knowledge acquisition due to VR being perceived as fun to use.

5.3 Developing Knowledge Acquisition with the Support of VR Technology

If pupils are not able to increase their learning using VR technology, the whole purpose of using it in school could be seen as wasted. In order to be able to measure if the participants did learn something from the applications, some control questions about the solar system were asked during the interview. No control questions about the Mondly application were asked since this application is perceived as being on a too basic level for the participants.

Before receiving the control questions about the application *Our solar system*, the participants were asked if they experienced that they had in fact learned something when exploring the applications. Both participants answered negative, without hesitation, to this question, but explained that they could have learned something if the Mondly application was more advanced and if it would be easier to concentrate when using the application *Our solar system*. According to their own experience, none of the participants expressed that they learned something while testing the applications. However, when the control questions were asked the participants proved the opposite. They actually did learn something. Control questions asked during the tests were, for example: "Which is the solar system's largest planet?" and "Our moon does not emit any light, so why does it look so bright?" Participant 2 answered the first question like this:

Test leader: Which is the solar system's largest planet?
Participant 2: Oh, no how the hell should I remember that? Could it bee... Oh, I know he said it yesterday! (thinking for some time)
Test leader: You are allowed to guess.
Participant 2: Is it the sun?
Test leader: No, it is supposed to be one of the planets. Participant: Jupiter!
Test leader: Is that your answer?
Participant 2: NO! Which planets are there... it could not be earth, maybe the moon. No it has to be Jupiter. I answer that.

The test leader noted the participant 2's answer and asked the participant if she wanted to know the right answer. Participant 2 said yes and was eager to know if the answer was right or wrong. When the test leader answered *Jupiter* the participant outburst: "Oh, oh oh, (triumphing). How the hell could I say earth or the moon? When I knew, it was Jupiter!"

After answering this question, the test leader and participant 2 discussed why she hesitated on the answer. Participant 2 concluded that she did not know this answer earlier and had to think back and remember what had been explained from the test the previous day. To the next question test participant 2 answered like this:

Test leader: Our moon does not emit any light, so why does it look so bright in the night?
Participant 2: Ah! I believe that's because the sun is shining on it or something like that.
Test leader: That is correct. Did you learn this yesterday?
Participant 2: Yes, I actually did not know that before.

The first thoughts from both participants were that they did not learn anything but, when answering the control questions correctly, they actually had learned something. This indicates that pupils can learn and develop their knowledge with the support of VR technology even if they do not think that themselves.

6 Discussion

This paper presents a study about how VR technology can be used as a learning support for pupils with diagnosed concentration disorders. Further, the aim was to examine if this type of technology could support learning for pupils with special needs such as concentration disorders by offering a controlled environment. The study was performed as a multiple-case design study (Yin 2003) with three sources of data set: observations from a key task test, interviews with two participants, and a survey. Overall, the findings show positive attitudes toward using VR technology in learning by all participants. Pupils with diagnosed concentration disorders have trouble maintaining their focus (Kadesjö 2001, 2010; Raffo and Gunter 2008; Meaux et al. 2009; Nilholm and Alm 2010; Persson 2010; Florian and Spratt 2013; Lindqvist and Nilholm 2013; Olsson and Olsson 2013; Wery and Thomson 2013; Polanczyk et al. 2014). This is also the case for the test participants in this presented study concerning their narratives about their own schooling. Therefore, it is important that schools can provide an environment for learning where it is easy to concentrate for all pupils. The participants experienced a higher level of concentration compared to participating in a normal lesson. Research shows that it is easier to learn with an increased motivation (Juul 2003; Olsson and Olsson 2013).

It could also be beneficial for the teacher that will gain a positive attitude in the classroom with more engaged pupils. Therefore, the so-called fun factor is an important feature that the VR technology can provide for both pupils and teachers. This could however change if the content of an application would be perceived as too boring or too complex to understand. It is of great importance to adapt the content of normal lectures to an individual pupil's ability to learn (Kadesjö 2001). One can assume it could be the same even if VR technology is being used. If applications being used do not fulfill this criterion, the concentration level might be lowered. On the other hand, pupils enjoy VR as a medium and find it fun to work with (Allison and Hodges 2000). One of the primary conditions for learning processes is having a positive attitude regarding the school environment, which to some extent can be provided by using VR technology (Olsson and Olsson 2013). Therefore, it is possible that the content does not have to be fully adapted to the individual pupils' specific needs due to an increased level of motivation. However, it is of great importance that teachers select applications that match the pupils' specific needs as far as possible.

In providing VR as a tool in education for pupils with concentration disorders, it is of great importance that the technology must be available when needed. This raises questions about who will be responsible for this. According to test participant 1, the physical technology around VR must stay at school, because of the challenge to remember bringing the technology to school in the morning. This is perceived as a too big challenge to conquer. Therefore, a responsibility to bring these tools back and forth to home every day could decrease participants' willingness to use VR technology in school. The problem could potentially be solved if the technology needed is present in a special room or locker close to the classrooms, where it is easy for the pupils to get. On the other hand, this can cause problem in a bigger school, for example, where the classrooms are spread over a bigger area.

The main obstacles to use VR in school could be that it might cause more "fuzz" due to excitements from other pupils. This problem could decrease the ability of the pupils with concentration disorders to learn and gain knowledge. Teachers could prevent this issue when presenting the technology and by limiting the possibilities for the pupils to deviate from the tasks set up; the problem could then be eliminated. In the interviews, the participants described that they learned nothing from their experience while testing, even though they did. Therefore, either the applications or a teacher needs to provide them with exercises that can help and support them to succeed with the assignments. Features like this support the normal learning techniques and teachers can use them for pupils with concentration disorders, as a lot of focus is needed to make the pupils succeed and finish the assignments. In turn, being able to feel pride over an accomplished task increases the motivation toward the subject and schoolwork over all (Kadesjö 2001).

7 Limitations and Recommendations for Future Research

The findings indicate a positive willingness from the participants to use Virtual Reality as a complementary tool in teaching and learning. However, there are some other aspects to consider as well. For example, the VR applications were tested in the participated pupils' home environment with no distractions of the outside world. This might not be the case when using the technology in school where the possibility to provide the pupil a room for themselves is limited. The technology might have the same effect with different conditions of the outside world, but that is no guarantee. Changed conditions might also affect the concentration level in a negative way.

The first recommendation for future research is to expand the number of test participants. This would give a broader understanding and perspective on how VR technology might be used for learning purposes and in school. An advantage could be the possibility to more easily discover trends and apply these more generally to the target group. The second recommendation is to perform a study in a real school environment. This is to be able to further investigate usability, concentration level, and the use of VR technology in school. This will gain more knowledge about if pupils with diagnosed concentration disorders can concentrate in the school environment to a higher extent or not. Another interesting aspect to investigate could be the difference between the learning performance while using an interactive application like *Mondly* language and a less interactive application like *Our solar system*.

8 Conclusions

The contribution VR technology can provide to the pupils using it (e.g., added value) is an increased motivation for doing schoolwork or a specific subject by making the knowledge acquisition more fun. Another added value is the possibility to control the learning environment, especially, regarding pupils with concentration disorders. It is also shown in the study that the use of VR technology is perceived as increasing the ability to concentrate compared with an ordinary lesson in school. The test participants assumed that they did not learn anything new when exploring the applications. However, the opposite was seen during the interview when the participants answered the control questions correctly. Hence, the outcome of using VR technology in schools is dependent on the conditions provided by the school itself. Therefore, using VR in school is not without challenges, and more research is needed before introducing the technology more widely. It is of great importance to conduct research where more participants are included to ensure if it is truly possible to use VR technology as a supportive tool in school and to know what possibilities and challenges the use of this technology will bring.

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Real-Time Auditory Biofeedback System for Learning a Novel Arm Trajectory: A Usability Study

Sophie Hall, Fridolin Wild, and Tjeerd olde Scheper

1 Introduction

Stroke is one of the leading causes of disability (Stroke Association 2017). Stroke rehabilitation can be limited to physical manipulation of the affected limb(s) or simple mundane tasks that offer little stimulation, reward or insight into motor progress (Scholz et al. 2015; Carr and Shepard 2010). This problem is more significant for upper arm rehabilitation due to the primary focus on regaining lower limb mobility post-stroke (Cirstea and Levin 2007; Merians et al. 2002). Biofeedback is a tool used to inform patients of how to efficiently reduce motor error and compensatory movements whilst motivating and encouraging them to persevere through the intensive and repetitive actions required to produce fluid and smooth movements (Scholz et al. 2015; Krakauer and Mazzoni 2011; Carr and Shepard 2010). Through wearable or optical tracking technology the movement is captured and explicit feedback of the quality of the motor performance and its overall success is provided in a bid to supplement and enhance motor synchronisation cues, proprioception and other natural sensory feedback (Carr and Shepard 2010). With the rapid technological developments in augmented reality (AR), virtual reality (VR) and motion tracking, there is a wealth of research into how computer-generated

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visual graphics can be used to provide dynamic and challenging gamelike scenarios that facilitate motor learning by providing personalised visual performance feedback (Laver et al. 2015).

Whilst there are several examples of rehabilitative auditory biofeedback systems, the numbers are comparatively smaller than those employing visual AR and VR. Using explicit auditory feedback can provide accurate spatio-temporal information of the motor performance as an indication of error whilst allowing the end-user to problem-solve and develop new natural feedback pathways by engaging with the real world. This may also provide significant economic and functional benefits in reducing the overall obtrusiveness of rehabilitative technology by removing the requirement of immersive headsets. Research indicates that sound interacts with our reward systems, and its interaction with our mirror neurones and motor cortex may be used to improve motor synchronisation, to motivate, to improve engagement and to reduce feelings of exertion in end-users. However, the field lacks an understanding of the long-term functional motor benefits possible from using auditory feedback systems, especially in direct comparison to visual feedback. Furthermore, the technological acceptance and usability of such a device has not been quantified from the clinician's perspective or from a representative sample relevant to the demographic of stroke patients.

This research presents a proof-of-concept auditory biofeedback system that provides error-corrective sonification, through a custom audio engine, of the arms spatial orientation and acceleration throughout a reaching task in order for users to learn and follow a novel trajectory. Furthermore, it presents the results from a System Usability Scale (SUS) study undertaken on those studying in the field in rehabilitation, providing evidence towards whether this concept should be further investigated in a more clinical environment as a tool for upper arm rehabilitation in stroke victims. The chapter is organised as follows: Section 2 presents related literature in the field and a discussion on their findings. Section 3 describes the system in terms of hardware and the core approach to motion tracking and sonification. Section 4 describes the implementation of the system. The experimental set-up and trial procedure are described in Sect. 5. In Sect. 6, the results and an evaluation discussion are presented. Section 7 provides a comparison to the state of the art. Section 8 presents an overview into the system's limitations and the suggested areas for future work. Section 9 concludes the chapter.

2 Related Work

2.1 Biofeedback

Biofeedback can be classified as receiving information regarding the success of a movement, either throughout or after the movement has been completed (Salmoni et al. 1984). Intrinsic feedback, as described by Krakauer and Mazzoni (2011), is information inherently present within our physiology, such as proprioception, vision or hearing. Krakauer and Mazzoni (2011) also provide the distinction between intrinsic feedback and explicit feedback, augmented information which is artificially and externally created to provide additional guidance towards achieving the intended behaviour, i.e. deliberate instructional information which is not found naturally. Implicit sensory feedback in contrast is not directly instructional and is naturally used by the body to adapt to and learn new environments and skills. Performance feedback is documented as an explicit extension of this implicit process (Cirstea and Levin 2007). The results of providing performance feedback have been well documented in current rehabilitative literature, although its long-term effect is unknown. Within the acute learning phase, motor accuracy is seen to consistently increase amongst participant groups receiving performance feedback (Fujii et al. 2016; Laver et al. 2015; Scholz et al. 2015; Sigrist et al. 2014; Cirstea and Levin 2007; Huang et al. 2005; Huang et al. 2006; Carr and Shepard 2010). Furthermore, there have been encouraging results that indicate that this skill acquisition continues into the retention stage. Studies which have completed some form of longitudinal analysis have signified that those who receive performance feedback show a transfer of knowledge; the ability to apply the motor skills learnt in one task environment to a new, similar, yet unknown environment and a retention of skill; and the ability to maintain the same level of motor performance when the feedback is removed (Fujii et al. 2016; Danna et al. 2015; Cirstea and Levin 2007; Huang et al. 2006).

2.2 *Auditory Feedback in Rehabilitation*

There are several notable auditory biofeedback systems for arm rehabilitation. Fujii et al. (2016) studied the effect performance feedback during a reaching task has on learning a new joint coordination pattern. They used three goniometer sensors attached to the elbow, shoulder and trunk to track the joint angles of the participants during the movement, which was then represented as a trajectory in three-dimensional space. During a trial, the error between the target trajectory and actual trajectory was calculated as the root-mean-squared error and mapped to the intensity of a 440 Hz pure sine tone, increasing in loudness as the error increased. Participants were asked to minimise this sound level during the reaching movement. They found that those who received auditory feedback had much lower root-mean-squared-error levels during trials and an increased level of skill retention when completing the task without feedback both immediately and after a period of time.

This skill retention and transfer of knowledge was also discussed by Sigrist et al. (2014), who analysed the effect auditory feedback has on spatial and velocity error during a motor task, compared to haptic feedback. The experiment used a rowing simulator coupled with a visual ocean scenario and augmented visual feedback. Auditory feedback was provided in the form of oar-water interaction (sounds whilst the oar is in the water and when transitioning to and from the water) and movement sonification, where the oar angle was mapped to the frequency of a violin sound. Users were presented with the reference oar movement sound in one headphone and asked to make their dynamic feedback match this reference, heard through the other headphone. Haptic feedback was also provided in the form of water resistance simulation, and as the user deviated from the ideal trajectory, this resistance increased. Subjects were provided with either visual, audio-visual or visuohaptic feedback. They found that those with multimodal auditory feedback decreased velocity and spatial error to levels never acquired within the visuohaptic or visual group. Significantly, they found that when removing the auditory feedback, these participants were able to maintain the same levels of error found when provided with feedback, indicating a transfer of skill.

In a study on moving with music for stroke rehabilitation, Scholz et al. (2015) compared auditory feedback therapy to conventional stroke therapy across four post-stroke patients. Using inertial measurement sensors placed on the wrist and upper arm, the system tracks patient movement and position through the acceleration, rotations and gravitational forces of the arm. The movement data was mapped into a three-dimensional sonic space so that the deviation across the *x*-axis affected the sounds brightness by changing the instrument, the *y*-axis affected the pitch of the note and the *z*-axis affected the sounds loudness. The participants with auditory feedback were initially asked to play a simple scale across the three dimensions using their arm. Patients then progressed onto more complex patterns that focused on the speed of movement between notes (spaces) and the precision in which the arm landed on these spaces. Finally, once trained on the system, participants were required to play simple melodies using just the arm. The control group performed the same movements but without auditory feedback. The auditory feedback group showed significant improvements across the Fugl-Meyer Upper Extremity Scale after practice compared to those who completed the task with no auditory feedback.

In a cross-modal study, Huang et al. (2005) introduced musical feedback within a virtual reality rehabilitative tool to provide temporal and spatial information about a reaching task. They introduce a database of biofeedback rules which govern the levels of augmented feedback and the difficulty of the task provided based on the patient's baseline capability. Should the patient be unable to complete a part of the movement, the task rules are adjusted based on the current and previous performance levels. They used virtual reality to provide 3D graphics of different scenarios which focus on reaching for different objects. The target object moved location and shape each time the game was played. The joint angles, end-point trajectory and shoulder positions were tracked using multi-sensors through each movement. The auditory feedback mapped the temporal progression of the movement in relation to the starting point and the end goal to the harmonic progression of an instrument, informing the user about how far along in the movement they were. Additionally, they used the concept of steadiness, tension and stability in the harmonic progression to indicate whether the user should continue to complete the task or return to the origin point. They also provided feedback of compensatory movements by sonifying the shoulder position movement to increasing collections of dissonant tones as the unwanted, compensatory movements increased. In summary, they concluded that those who were provided with the auditory feedback reduced their spatial error and produced smoother movements with less compensatory movements compared to those without auditory feedback.

Without this level of complex musical processing, Dailly et al. (2012) assessed whether simplistic sonification alone could provide enough information to correct the deviation from a known trajectory. Subjects were trained to trace a figure-of-eight pathway using their hand. An ideal trajectory was initially visually provided to users during training before this was removed, and the participants were asked to retrace the trajectory from memory. Using optical tracking of the arm by locating individual LEDS placed upon the subject, the deviation between the ideal and the actual trajectory was calculated. Some users were provided with auditory feedback in the form of a mix of white noise and music whilst completing the movement. The balance between the two sounds indicated the level of error against the ideal trajectory; the greater the level of white noise presented in comparison to music, the greater the error was. They found that all subjects who received the feedback improved their accuracy and were able to learn the movement more effectively than those without feedback. Their study is important as it assesses how even simple auditory feedback can be beneficial compared to complex musical systems.

3 System Overview

The core system requirements can be summarised as the ability to:

- Record a reference trajectory
- Perform a trial movement
- Explore the sonification mapping for increased system learnability
- Generate and adjust custom audio in response to arm movements

To realise the above system requirements, the following tools were used:

Hardware The Myo armband is an embedded wearable device that provides both gestural and spatial tracking of the wearer’s lower arm and hand. The device uses an Invensense MPU-9150 9 degrees of freedom inertial measurement unit (IMU) consisting of a three-axis accelerometer, three-axis gyroscope and three-axis magnetometer to provide local spatial information (Stern 2017). These data sets are communicated over a wireless Bluetooth connection, with the spatial (IMU) data being provided at a sampling rate of 50 Hz (Thalmic Labs 2014) (Fig. 1).

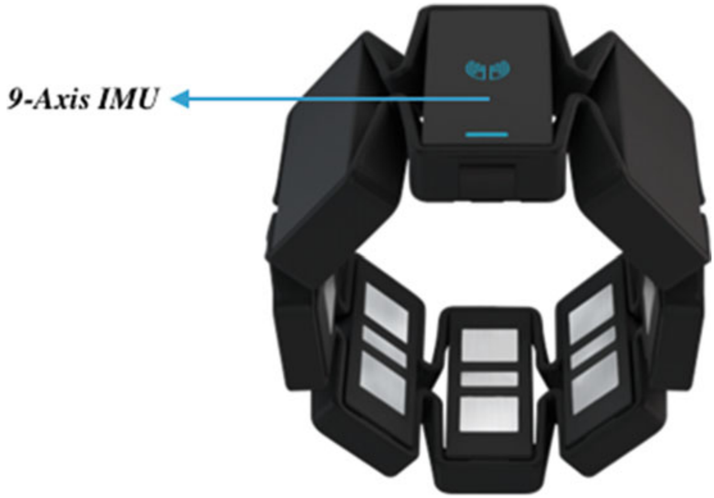


Fig. 1 The Myo armband

Development Environment The software is designed in Unity, a platform regularly used for real-time systems, games and VR projects. The Myo is interfaced using the Myo Software Developers Kit provided by Thalmic Labs. The custom audio is developed using the Synthesis Toolkit, a C++ framework for digital signal processing (DSP) programs. The DSP code is compiled into a bundle and used as a native audio plugin in the Unity game engine.

3.1 Arm Movement Model

This research defines the movement of the arm using a single sensor, calculating the angular displacement, in terms of pitch, roll and yaw, relative to a point of origin. Pitch, roll and yaw correlate to the following rotations about the X, Y and Z axes (see Fig. 2).

The temporal aspects of the movement are defined through calculating the magnitude of linear acceleration.

Myo Rotations The system defines the following core rotations required to represent the arm movement in 3D space (see Figs. 3, 4, and 5). The diagrams depict these rotations and how they correlate to the Myo's output. The red arrow indicates the *Z* axis and the upwards direction of the Myo armband.

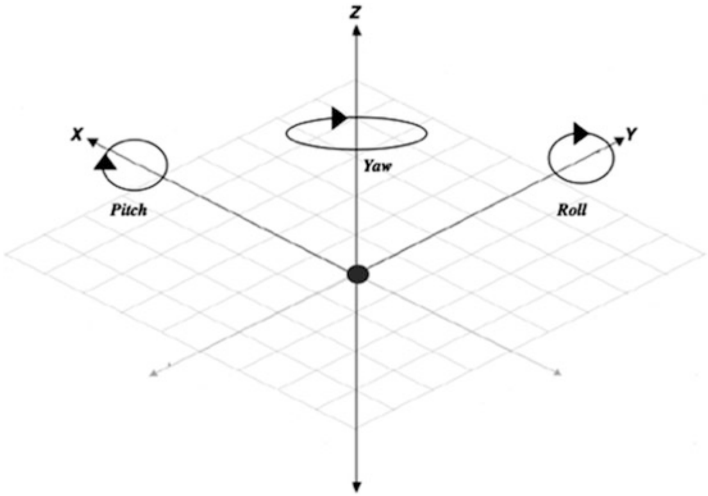
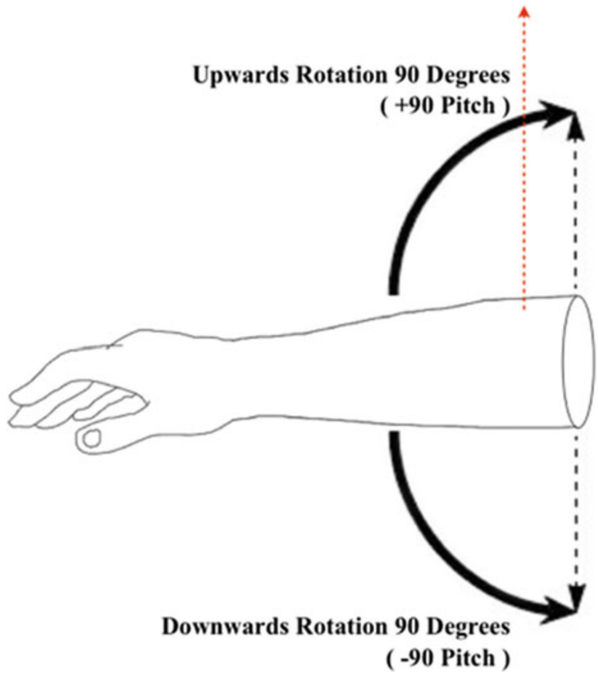


Fig. 2 Pitch, roll and yaw against the *XYZ* axis; own figure

Fig. 3 Ninety-degree pitch rotations; own figure



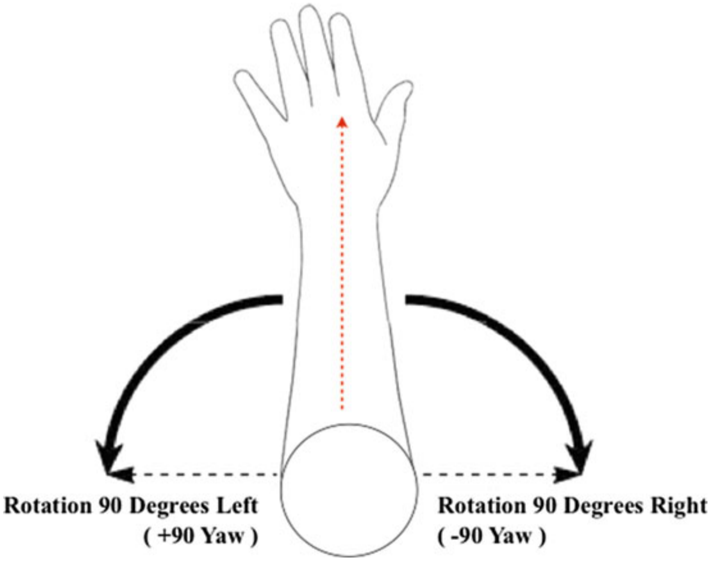


Fig. 4 Ninety-degree yaw rotations; own figure

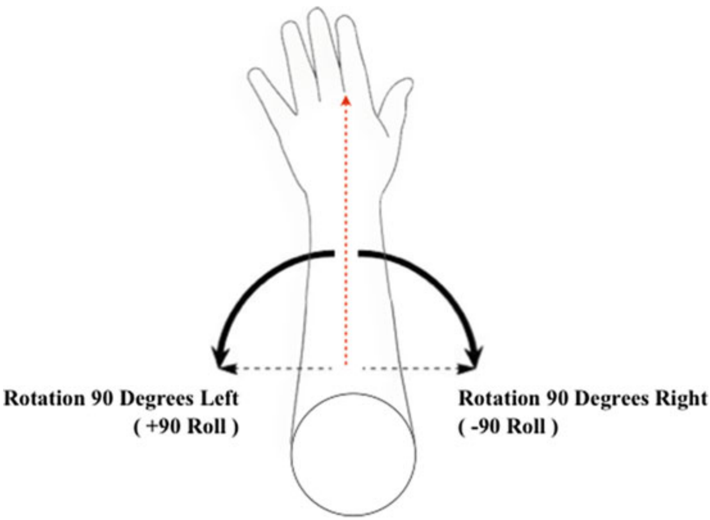


Fig. 5 Ninety-degree roll rotations; own figure

3.2 Sonification Model

Parameter mapping sonification (PMSon) is the direct mapping of physical quantities or data values to auditory parameters within an audio engine in such a way that the user is able to analyse the change in data through the change in sound. As sound is highly parametric, this is suitable for a situation where representing multivariate data is required (Herman et al. 2011). This research defines a sonification mapping that generates continuous sound by directly manipulating acoustical parameters through human movement. This mapping is defined in Table 1.

The mapping works in the following polarities:

- An increase in pitch angle (upwards rotation) results in a decrease in frequency.
- An increase in roll angle (anti-clockwise rotation) results in an increase in volume.
- An increase in yaw angle (rotation to the left) results in a pan position to the right.
- An increase in the magnitude of acceleration results in an increase in BPM and a shorter note length.
- An increase in the absolute error in pitch angle results in an increase in the white noise volume.

The model is configured with the aim to inform the user of how to move synonymously to the reference trajectory. The reference trajectory is defined, sonically, as a point of equilibrium in the audio engine, where the stereo position is centred, the fundamental frequency is 261 Hz, the volume of the instrument is −10 dB, the BPM is 60 and the volume of the white noise is 0. The deviation across each parameter from the reference movement at any given time is sonified in a way that it encourages the minimisation of error and provides information on how to correct the trajectory. The concept of the sonification is to encourage users to maintain the sound parameters as found along the reference trajectory.

Alternative Auditory Design Solutions The focus of determining the auditory mapping was to ensure the user was provided with enough spatio-temporal resolution that the feedback can act as a sensory replacement throughout a reaching task whilst also ensuring that there is not such a complexity and lack of intuitiveness in the sonification system that a long period of system training and learning is required, which may decrease system usability. A simpler approach with less parameters

Table 1 Movement sonification parameter mapping

Kinematic parameter	Auditory parameter
Pitch angle	Fundamental frequency of instrument
Roll angle	Volume of instrument
Yaw angle	Stereo pan position of instrument
Magnitude of linear acceleration	Beats per minute (BPM/tempo) of instrument, length of note
Absolute error on pitch angle	Volume of white noise

could be considered when using a configuration where less DSP power can be provided. By sonifying the root-mean-squared spatial error from the reference trajectory by reducing the volume of a static sound or musical track as the error increases, an analogy could be simulated which mimics the acoustic result of being far away from a source. This scenario could provide a faster learning experience by reducing the number of variables to initially master. However, for a reaching task, where an end goal needs to be searched for, not providing individual auditory cues per axis of rotation may reduce the ability to effectively search for the ideal positioning, as well as limit the motor training of the individual degrees of freedom throughout the movement.

Where additional DSP can be provided and a more advanced motion capture device used, i.e. a camera tracking system, it could be possible to improve the resolution of three-dimensional spatial positioning by tracking absolute position and therefore increase the complexity of the sonification itself. With the absolute 3D positional information, additional parameters could be integrated, such as the distance from the target and therefore the temporal progression throughout the movement. Using this, a target melodic phrasing throughout the movement could be defined by marked points along the reference trajectory. At these marked points, the sonification would respond by changing the frequency of the note and the timbre of the sound itself. Integrating this may produce a more natural feel to the movement model and increase engagement by behaving more like a musical instrument playing a tune along the trajectory. Increasing the complexity of the sonification model in this way may generate more abstract sounds with a dual mapping behind a change in perceived frequency. In the system presented, frequency changes represent a change in pitch angle alone, and with frequency being adjusted throughout the temporal progression of the movement as well, it may increase the training time required before the user feels confident with the dual meaning of this mapping. With the target audience in mind, overwhelming the user with sensory input within a small temporal task may also be counterproductive. A comparative study between the different levels of sonification complexity and the perceived feeling of usability would need to be undertaken to determine the benefit of using increasing DSP power over a simpler approach.

3.3 Feedback Loop Interaction

The overall flow of interactions is described further on (see Fig. 6). After calibrating the Myo device, the user, wearing headphones, performs motor movements whilst wearing the Myo on the right arm. The spatial data and accelerometer data are communicated to Unity via Bluetooth. Data processing occurs in Unity, calibrating the orientation and compensating for drift. The deviation between the reference and actual trajectory is then calculated. These deviation values are fed into the DSP audio engine which provides error-corrective auditory feedback through Unity to the end-user where the feedback loop restarts. Throughout the movement processing, no permanent data storage is performed; refer to Sect. 8 for a further discussion.

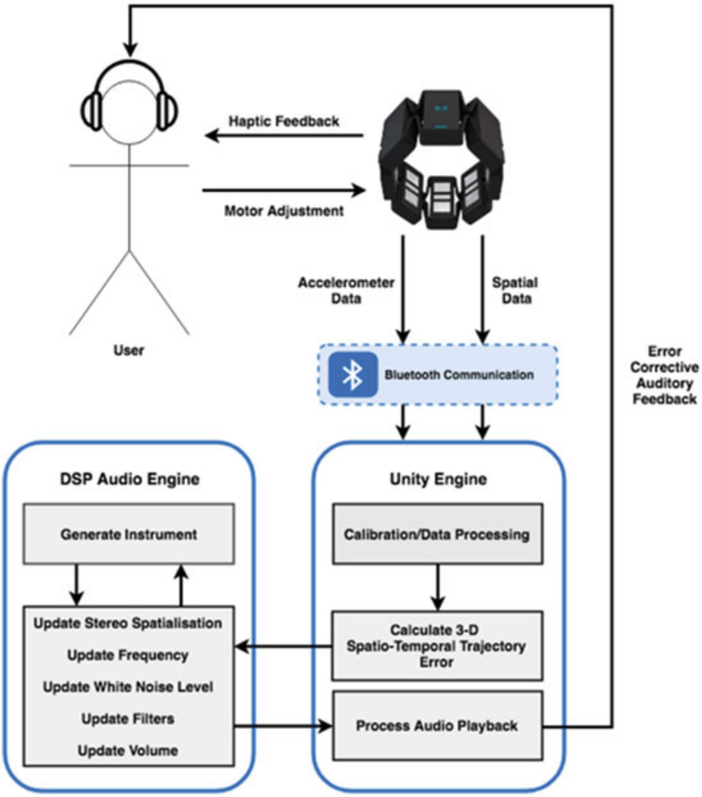


Fig. 6 Feedback loop interaction

4 Implementation

The audio engine produces a complex timbre designed to model the strum of a synthesised guitar using the Synthesis Toolkit and custom C++ classes. Using additive synthesis, a Fourier series of sine waves is produced for each string in the strum. Each group of sinus tones is combined with square waves, string impact sounds and pluck tones generated using synthesis techniques, tuned to a particular note in the strum. The instrument tone is distorted with a custom non-linear distortion algorithm and processed with reverberation and filtering. An equal power stereo spatialiser was developed that integrates high-pass filtering for the alternate channel to extenuate the stereo placement. The fundamental frequency, pan position, white noise level and decay time of the notes are exposed to Unity and are updated in response to changes in spatial orientation and/or tempo.

The Myo armband presents the devices orientation as an orientation quaternion which is in relation to its local coordinate system, defined during the synchronising gesture (wave out), rather than the world axis (where Z is upwards). To align the

Myo's orientation with the world frame of reference, the band is aligned using a centring gesture. At the point of the centring gesture, the orientation quaternion is captured and conjugated (cQ):

$$cQ = -Q_x, -Q_y, -Q_z, Q_w \tag{1}$$

All raw orientation quaternions (Q) from this frame onwards are multiplied by this conjugated quaternion (cQ) to give the relative orientation (rQ):

$$rQ = cQ \cdot Q \tag{2}$$

Pitch, roll and yaw are used to calculate relative position across each axis, creating three individual values for manipulation with the sonification system. To calculate the pitch, roll and yaw angles, in radians, from the relative orientation quaternion, the following formulae are used:

$$\text{Pitch} = \arcsin\left(2\left(wy - zx\right)\right) \tag{3}$$

$$\text{Roll} = \arctan\left(2\left(wx + yz\right), 1 - 2\left(x^2 + y^2\right)\right) \tag{4}$$

$$\text{Yaw} = \arctan\left(2\left(wz + xy\right), 1 - 2\left(y^2 + z^2\right)\right) \tag{5}$$

The radian value is then converted into a degree reading by multiplying by $\frac{180}{\pi}$.

As the Myo's acceleration vector is in reference to the Myo's local coordinate system, to determine the acceleration in relation to the world frame of reference (rA), where Z is upwards irrespective of the devices orientation, the acceleration vector (A) is rotated about the Myo's orientation quaternion (Q), as noted below:

$$\underset{rA}{\rightarrow} = Q \cdot \underset{A}{\rightarrow} \tag{6}$$

From this oriented vector, the 1 g of gravitational forces is removed to attain linear acceleration.

As the pitch, roll and yaw values provide the spatial orientation, the magnitude of acceleration is used to determine the overall force the armband is undergoing at a given point, used to indicate the rate of change in speed, independent of direction. The magnitude of the oriented acceleration vector (A) is calculated as follows:

$$\text{Magnitude} = \sqrt{A_x^2 + A_y^2 + A_z^2} \tag{7}$$

The novel trajectory is defined by a single movement throughout the motor task (see Sect. 5), where the pitch, roll, yaw and magnitude of linear acceleration are captured and persistently stored. During an attempted movement, the difference between the reference trajectory values and the actual trajectory values is calculated.

Each difference parameter is given a threshold of reasonable error, $\pm$ 5 degrees; once this threshold has been exceeded, the value is used to drive the sonification providing error-corrective feedback of how to return to the reference trajectory and point of sonic equilibrium, e.g. a + 10-degree difference in pitch angle from the reference trajectory results in shifting the frequency of the instrument down a semitone. This feedback indicates to the user that they should go downwards 10 degrees.

4.1 Movement Data Analysis

The spatial and acceleration data is not subject to constant jitter or noise, a simple static five-frame averaging filter was applied and once these data sets have been rounded to the nearest integer value, they are not subject to variability during periods of inactivity. This provides smooth, reliable results capable of driving digital signal processing applications and for slight movement analysis. No noise or offset level was detected for the angular displacement units (pitch, roll, yaw), and each returns to stable 0-degree values when realigned at the centring position. A low offset noise level was detected and compensated for in the magnitude of acceleration, calculated at 0.02 per fifth frame (each average reading).

As with many inertial measurement units (IMU), the Myo armband is subject to rotational drift over a period of time. These findings have been identified and verified across most of the academic literature which cite using the Myo and from the developing organisation, Thalmic Labs. To identify the rate of drift across the three units of measure (pitch, roll and yaw), a series of stationary readings were taken from the Myo, whilst the armband was being worn on the right arm lying flat on a surface. It is necessary for the device to be worn to prevent the automatic sleep mode from setting in after 20 s of inactivity. Readings were taken from each unit, and the average rate of drift was calculated per average frame (1/6 of a second using a 30 frame-per-second rate and a five-frame static average) over a period of 2 min. The most stable data value was pitch, with the drift rate being negligible at less than 2×10^{-7} degrees per frame. The average drift for yaw was equal to 2.34×10^{-4} degrees per frame, and the roll drift equated to 4.4×10^{-5} degrees per frame. As the system does not need to operate for long periods of time without realignment, these values are considered acceptable and were compensated for at each average reading; however, for longer movement patterns, it may be necessary to integrate intermediate alignment phases.

The Myo's angular units of measure represent relative rotations with accuracy and produce appropriate ranges of data. The reliability and accuracy of these units of angular displacement provide enough detail to represent the arm's spatial orientation in relation to a point of origin, however cannot be used to determine the absolute position of the arm in three-dimensional space. The range of pitch in use was observed to be within $\pm$5 degrees of 180 degrees, spanning from -85 to $+85$ degrees from the centre position. The yaw values have a range of $\pm$175–180 degrees from the centre point, and rotations beyond the core $\pm$90 degree can be used reliably to indicate a change in the heading of the arm during use. Representing full rotations in roll whilst wearing the band is limited by the sensors' placement on the upper forearm. The forearm rotates to a notably lesser degree than the wrist or hand, in particular with anticlockwise rotations. This results in a range of ~ -80 degrees to $+70$ degrees for the roll angle whilst in use.

The secondary data set produced by the Myo is acceleration across the x, y and z axes. Once the gravitational forces have been removed from the data sets, these values provide reliable linear acceleration patterns across all orientations of the band with minimal noise. However, the signal-to-noise ratio is much poorer than that of the spatial orientation data with offsets observed and a smaller range of data in each axis. For the purpose of determining position in relation to some trajectory or end goal, these acceleration patterns are a less viable data set, as they will always return to a stable state of equilibrium when the acceleration forces are removed, rather than representing the current position. To search for an end point in space, there can be periods of inactivity or slow movement where it is important to be able to use the feedback to compare your current position to the goal. To compensate for this whilst still providing an indication of the overall speed of the arm, this research used a smoothing filter, interpolating between the real-time magnitude of acceleration values throughout a movement to provide a continuous profile of speed.

Whilst the Myo armband cannot provide accurate details of absolute position in three-dimensional space, the movement data provides a comprehensive picture of relative orientation and the overall forces the arm is undergoing at any given point. Additionally, in comparison to common optical motion tracking solutions such as cameras and object markers, this data is not limited by environmental changes such as field of view occlusions or lighting differences.

5 Experiment

The focus of the experiment was to determine the usability of the system to indicate whether further investigation into the subject field, with a focus on potential motor gain, is recommended. Usability is one component of a system being able to enhance a learning process, such as learning a new motor pattern. To undergo rehabilitation and relearn motor skills requires extreme concentration, motivation and engagement with the programme. Where external systems are used to enhance the rehabilitation process, it is important that these systems themselves do not hinder the patient's progress, leading to technological and potential programme rejection. Understanding how functionally usable a system is, that is, whether it provides users with the expected experience, is simple to operate and is perceived as useful to the user, enables developers to understand the potential for a possible deeper technological connection to develop between the user and the system. Systems which can create a platform where the user feels confident, is engaged and has autonomy are known to provide a platform for enhanced learning in rehabilitation and, therefore, an increased perceived feeling of usefulness of the device (Danzl et al. 2012; Lewthwaite and Wulf 2012). With this, the user can develop a feeling of being in sync with the wearable device and focus on the learning task. Systems with low usability typically have characteristics that inhibit the user's ability to perform the core tasks freely and naturally. For example, they may require too much prior training for the target audience to be able to use it independently, the intended information may not be clearly portrayed and therefore the results are confusing or the system outputs are not consistent enough to develop an understanding of and learn how to use the device efficiently to perform the required operations. Systems with these characteristics could decrease the possibility of learning a complex task as engagement with the device, motivation to continue and confidence in use may stop before this is possible.

A SUS study was used to quantify the feedback system's usability. SUS studies are an evaluation method which can provide quick, reliable and valid quantifiable data from a small sample size, to indicate potential ease of use and proof of concept for a prototype system before continued investigation and development take place. The SUS has been documented in over 1300 publications and has become a de facto standard for assessing the appropriateness for use of a wide range of technologies, applications and systems (Brooke 2013). Its generalists and technology independent style makes it applicable to novel or prototype systems whilst still providing a score that is comparable to previous projects or systems.

The study is a Likert-scale-based questionnaire that aims to give an overview of the system's usability factor by analysing the user's perspective on factors such as how complex or easy the system was to operate and understand, how confident they felt using it, the consistency provided from the system's output and whether they felt that they would like to use it often. The individual scores for the SUS study range from 0 to 100. Extensive research on SUS score analysis and interpretation is available given its mass application (Sauro 2011). Bangor et al. (2009) have produced several notable contributions to this analysis including research on mean SUS scores and their equivalent qualitative meaning in terms of acceptability and quality. Table 2 illustrates an accumulation of their research data.

The methodology's major constraint is that it is not a diagnostic tool and provides no insight into why the product scored low or high, merely serves as an indication as to whether there needs to be adjustments (Brooke 2013). To compensate for this,

Table 2 System Usability Scale score interpretation

SUS score range	Acceptability rating	Grade	Mean SUS score	Equivalent adjective
0–9	Not acceptable	F	12.5	Worst imaginable
10–19	Not acceptable	F	20.3	Awful
20–29	Not acceptable	F	35.7	Poor
30–39	Not acceptable	F	50.9	OK
40–49	Not acceptable	F	71.4	Good
50–59	Marginal	F	85.5	Excellent
60–69	Marginal	D	90.9	Best imaginable
70–79	Acceptable	C		
80–89	Acceptable	B		
90–100	Acceptable	A		

Table data generated from Bangor et al. (2009)

participants were also given an additional and optional feedback form where they could provide further comments regarding their experience using the system. These comments were not led by questions or topics of conversation. Participants provided informed consent indicating their willingness to participate with the understanding that they may withdraw at any time without giving reason. All collected subject data was anonymised.

A total of eight participants were recruited for the study due to their academic subject field. All participants were from a healthcare, physiotherapy or rehabilitation background. One participant's involvement was discounted due to not following instructions for performing the movement as required. The seven remaining participants were made up of three males and four females. All subjects were self-declared to be free from any hearing impairment and/or motor impairment which may affect their ability to complete the task or assess the system.

The participants were asked to perform a single motor task whilst using the system. Each participant was asked to reach across the body to grab a ball which is balanced from a small height (41 cm). This movement and the physical environment are depicted below (see Figs. 7, 8 and 9).

Position A

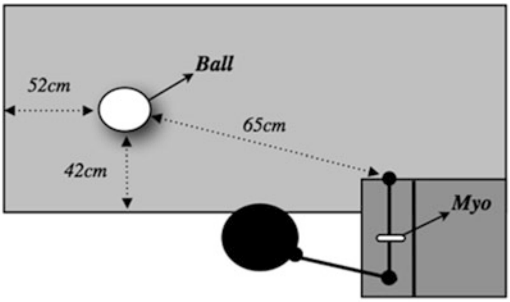


Fig. 7 Position A, the starting position of the trial movement

Position B

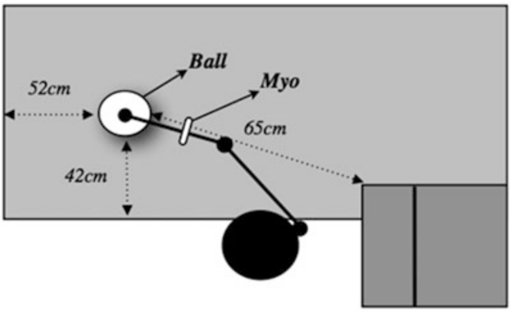


Fig. 8 Position B, the finishing position of the trial movement

Demonstration of Experiment in Use

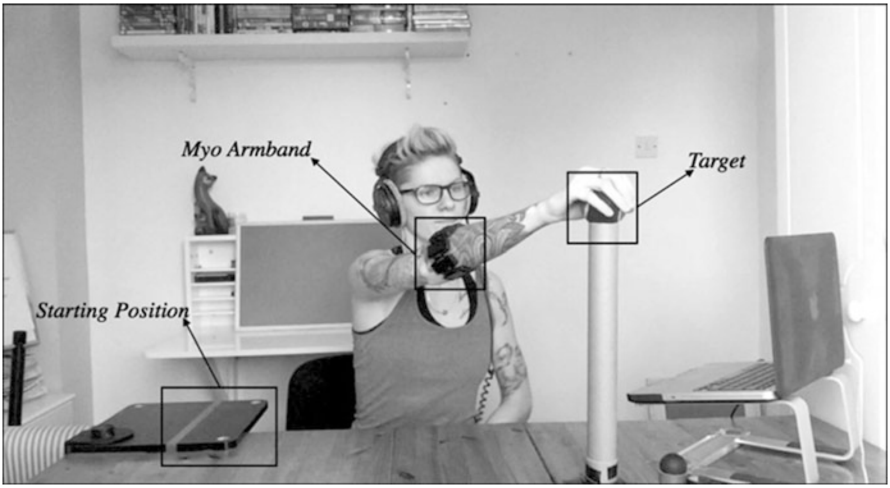


Fig. 9 Demonstration of experiment in use

Participants were seated in front of a table (see the depiction above) and were provided with instructions on how to perform basic synchronisation with the Myo armband (wave out). Note that this synchronisation is avoidable with additional programming to make the system more suitable for those unable to perform this gesture. Participants each wore a pair of open backed Beyerdynamic DT 990 Pro headphones with a frequency response of 5 Hz–35 Khz. During all trials, the computer screen which displayed spatial information for the operator to monitor was out of sight to ensure participants were not provided with external guidance towards the target.

First, participants were given an exploration period with the sonification. They were instructed to move their arm around to experience what movements produced which changes to the sound. During this period, the sonification uses the deviation from the centring gesture point to drive the parameter mapping rather than the deviation from the reference trajectory. This period of time was roughly 3–5 min and was guided by the participant; once they felt comfortable with the mapping, they indicated to the researcher that they were ready to move on with the experiment.

The participant was asked to place their right arm on the right-hand board, position A (see above). The Myo armband was realigned at this point. The participant then listened to the reference tone and was instructed that this was the tone to maintain throughout the movement. Participants could listen to this until they felt comfortable with it. The participant was provided with an auditory countdown to indicate the start of the trial movement. The participant is asked to then move from position A to position B, using the sound to guide them. The researcher ended each trial movement once they had reached position B. The participant repeated this process fully sighted, with auditory feedback, ten times.

Once this process had completed, the participant was asked to repeat the same task a further ten times without their vision to guide them, enabling them to rely on using the auditory feedback alone as a guide. This is due to the unimpaired nature of the participants recruited.

6 Results

Each individual SUS score is calculated as follows:

- Minus one from each odd numbered question.
- Minus the score of each even numbered question from five.
- Sum these new scores and multiply by 2.5.

The mean score is then calculated by summing the individual SUS scores and dividing by the number of participants, seven. The mean score across the seven participants was 74.64. The standard deviation across the scores was 12.28. The maximum SUS score achieved was 90, and the minimum SUS score provided was 52.5.

The mean score of 74.64 indicates that the prototype system provides an above average score of usability (68) when comparing it to other evaluated systems. Considering the novelty of the prototype and the concept, this is a promising result which is further validated by using those who have an understanding into the needs of those with impairments. From this result, this research suggests that continued investigation is highly recommended. However, it suggests that more work is needed on the design aspects before testing the system on impaired users. This continuation should include integrating multidisciplinary research and be predominantly driven by clinical guidance. The standard deviation found, 12.28, indicates that there is some instability between the participants' experiences. This finding highlights the limitations of the SUS evaluation method as these individual scores do not provide an insight into the reasons why people did or did not engage with the system. For this, the qualitative feedback coupled to each SUS score requires analysis.

There were several pieces of anonymous qualitative feedback provided by the participants. The SUS scores and anonymous feedback forms were coupled together to enable cross-analysis. All participants gave their explicit consent for the following comments to be quoted in the projects' publications. Whilst the SUS scores are not meant for individual interpretation, the lowest score of 52.5 deserves some deliberation. Analysis of the qualitative feedback provided from this participant highlights some important areas. The participant noted that:

> "[D]id not find [the] correlation between movement and sound easy to understand. Found the noise not one I liked . . . ".

This highlights the problems faced in designing auditory feedback systems, as aesthetically pleasing audio and a comprehensive movement to sound mapping is subject to personal preference. However, this participant was the only one to not actively search for the reference pathway or to adapt the position of their arm to remove unpleasant auditory feedback unlike the other six participants. It is unclear as to whether this dislike to the sound was because of tonal preference or a product of the non-corrective actions they took during the movements. There were several comments which directly contrast the above feedback regarding the sound:

> "Hearing the sound made it easier to find the tennis ball especially with closed eyes!"

> "The unique sound is strange at first, but conveys the 3-D angular information in a good way"

> "..[A]fter the first times I felt like the sound was smoothly guiding me through."

Some notable comments from participants provide an insight into the suitability of the system for a rehabilitation environment:

> "I think this system has potential to help people with a stroke to perform a movement. Only the calibration movement could be hard for people with a stroke."

> "I think that this will definitely help people who suffer from a stroke or motor impairment."

> "[S]ystem could have huge benefits in terms of upper [and] lower limb rehabilitation. The great advantage would be within the application in more complex, yet controllable movements, essential for independent living [and] quality of life!"

The feedback provides a clear insight into the future clinical acceptance of such a device whilst highlighting the importance of personalisation in the sonic tone and mapping.

7 Critical Appraisal

The given research defines the arm movement using three-dimensional points compromising each of a pitch, roll and yaw angle and the magnitude of acceleration as an indicator for speed or force of movement, together defining a trajectory from a point of origin to an end target. This concept of defining a movement trajectory and providing auditory feedback of the deviation from this throughout the task is used with successful results in Fujii et al. (2016), Scholz et al. (2015), Dailly et al. (2012) and Huang et al. (2005). This research uses a predefined trajectory which is unknown to the participants; this is a similar concept to that found in Fujii et al. (2016) who studied whether auditory feedback could be used to learn a novel joint co-ordination pattern which was customised for each participant. They also successfully used the difference between the actual and novel trajectory as an indication of spatial error. However, their contribution to the state of the art is one based on a multi-sensor approach. This research in comparison suggests that a single sensor alone is sufficient enough to guide users towards an unknown trajectory. Both contributions identify that to provide evidence that auditory feedback can be used as a performance feedback modality for spatial error, there is no need to provide a visual reference to a novel trajectory.

There are several examples of the difference in complexity found in the sonification models across the state of the art. One example of a promising simplistic sonification technique can be seen in Dailly et al. (2012) who indicated the error between an ideal trajectory and an actual trajectory through the mix of music and white noise. As previously discussed in Sect. 2, they provided evidence that this feedback can be very effective at improving tracing error. More complex reaching sonification models can be seen in Huang et al. (2005) and Scholz et al. (2015), who both used and adapted complex instrument models and harmonic progressions to indicate a correct movement. Scholz et al. (2015) provided this in a physical environment, assigning the axes of a three-dimensional cube to different sonification values, whereas Huang et al. (2005) integrated their sonification into a virtual environment driven by computer graphics. For more on their models, refer back to Sect. 2.

The current research gave a parameter map of five individual values, providing three-dimensional spatial information through the frequency of the note (pitch angle), the stereo position (yaw angle) and volume of the sound (roll angle). Furthermore, it provides additional supporting feedback for the pitch angles (vertical position) by mapping the overall error in pitch angle to the level of a white noise sound. Temporally, it represented the overall force the arm is undergoing, indicating speed, through the tempo of the notes. Generally, the current model presents a sonification system with a mapping complexity that is in line with other publications, indicating its potential applicability for further research. Models such as those found in the works of Huang et al. (2005) and Scholz et al. (2015) should be considered a benchmark sonification models to follow for future development and would be a natural extension of the work already presented, given the melodic and error-corrective, trajectory-based concept we both employ.

It also provides this comparatively complex feedback in a non-virtual environment, requiring the user to attend to a physical object and maintain natural proprioception and visual feedback throughout their rehabilitation. This provides a sense of transferability to the system, as a reference movement could be trained to the individual's real-world motor problems such as reaching to a shelf in their kitchen. Removing the requirement for an immersive headset provides the end-user with the potential benefits of feedback during their home therapy whilst reducing the overall cost of the technology and obtrusiveness of the device. Whilst for some, the advent of more exciting and interactive rehabilitation tools, i.e. VR, has been shown to improve feelings of motivation and confidence towards completing treatment (Heunis 2016), a lack of technological exposure and/or understanding has been shown to produce higher rates of patient disengagement and rejection for technological devices (Rama Murthy and Mani 2013). For the core demographic of stroke patients (UK average age of stroke, 2017; male = 74, female = 80) (Stroke Association 2017) who may have little exposure to VR, the presented equipment would be less invasive and would remove the issues surrounding motion sickness and disorientation found in fully immersive VR headsets.

One of the areas for comparison between the presented research and the state of the art is in the methods and aims of the evaluation. A key area of difference is seen in the aims of the evaluation procedures. To the best of the author's knowledge, there is little literature on using a SUS study to evaluate auditory biofeedback systems. The focus of the state-of-the-art work is more clinical, assessing the systems functional motor benefits on healthy or impaired users over a period of extended use. Typically, assessments are made based on the Fugl-Meyer Upper Extremity Scale and other clinical mobility scores, or statistical data analysis is made on the change in error found by participants prior and after system use. Few feasibility or early stage exploratory papers on auditory feedback were found which focused on the user's or clinician's response to the system and ease of use.

The academic field is currently lacking quantifiable results on the general acceptability and usability of auditory guidance systems from clinical professionals. The work in this research provides an overview into how healthcare professionals may react to integrating these types of systems in their work place. An analysis of the results provided indicates that whilst more work is needed on the given design, there is generally a high level of acceptance for systems similar to this as a tool for assisted living and rehabilitation. This research would suggest, however, that more quantitative data is needed from a broader demographic profile to assess this concept further before trials on impaired users and extended development take place in the field.

The differences found in the evaluation methods make the quantifiable results of these studies difficult to compare to those presented in the given research. The state of the art has shown preliminary evidence that auditory feedback systems can improve motor performance and that further work is advisable, but it is yet to provide statistically relevant, longitudinal outcome measures on motor rehabilitation. The evaluation results from this work corroborates this by indicating that these systems can provide a very usable environment for learning a novel trajectory, but there is more work to be done on designing auditory feedback systems in such a way to maximise the clinical usefulness and end-user usability.

8 Limitations and Future Work

8.1 Study Limitations

The study itself recruited participants from a healthcare background who helps verify the results. However, the sample size is limited. Whilst the SUS study is designed to gather qualitative data from small sample sizes, the nature of the system means there is inevitably a high level of variance between individuals' experiences. For this reason, a larger and more representative sample size is required to get a better understanding into how the general public would respond and interact with the device, in particular, participants who are representative of the demographics of stroke victims, namely, older users. Although the SUS study indicated the potential usability of the system and the appropriateness of continued subject investigation, the research presents no evidence of functional benefits for user's mobility and rehabilitation. To identify whether the auditory feedback presented in this research could improve motor error during a simple reaching task, a longitudinal study would need to be undertaken which analysed the motor performance of a more quantitative participant group with upper limb impairments prior to and after an extended period of use with the system. Using a standardised test for functional motor capability post-stroke, such as the Fugl-Meyer Upper Extremity Scale, would provide the study with comparable motor results to other rehabilitation trials (Singer and Garcia-Vega 2017). It would be important to also measure patient engagement and enjoyment during this period of use and to determine whether the feedback provided a transfer of knowledge improving motor performance without the feedback present and across tasks which deviate from those on which the user was trained.

8.2 Gamification

Whilst the system provides evidence that auditory information can be used to follow a spatial pattern, the current design is limited in its engagement factors. Future work would need to see the system expand on the game play aspects of the task. By integrating several segments of movement, each which had a melodic phrasing to be played, the difficulty of the task could be progressive depending on the changing baseline capability of the end-user. This would enable a more gamelike scenario where the aim of the rehabilitation exercise, following a successful skill level in each segment, is to play the entire song. As mentioned in Sect. 3, this increase in complexity of the sonification would require that a more advanced motion tracking system be used so that absolute position throughout the movement is known as the Myo cannot reliably provide this.

Another element required for a more gamelike scenario is the concept of providing a score and terminal feedback to the end-user. By replaying the sound which the users produced during their movement against the ideal sound, users may be able to address repetitive errors and problem-solve in-between attempts. A score indicating overall accuracy level across spatial and temporal parameters may increase feelings of determination and motivation in users by providing the sense of self-competition (Carr and Shepard 2010). Finally, the system should be further developed to offer a choice in the instrument so as to improve baseline engagement through personalisation.

8.3 Reference Trajectory

The system defined the reference trajectory using a single movement through the motor task. This provides a platform for understanding healthy user's ability to follow a novel trajectory using the auditory guidance system, but for future work there would need to be a clinically guided *ideal* movement which was personalised to match the patient's physical make up. Parameters such as the user's height, weight, dominant handedness (left or right) and arm size need to be taken into consideration as these all influence the baseline positioning and orientation of the arm and the amount of trunk movements required to complete the movement (Faraway 2001).

8.4 Clinical Reporting

The overall usefulness, level of integration and acceptance of the technology rely on both the end-user's and clinician's satisfaction (Sathiyanarayanan and Rajan 2016). One of the key benefits of employing technology in rehabilitation is the access it provides to quantifiable kinematic data otherwise not available from face-to-face contact. For example, Phelan et al. (2015) used wearable electromyography sensors to track and monitor the progression of Parkinson's disease as a tool for providing more effective associating levels of care. Additionally, it is important to ensure that the clinicians are able to analyse patient progress and identify problems as they arise. The presented prototype system currently does not store the movement data of each user, and therefore, it cannot use this to provide either personalised feedback to indicate improvement or provide personalised learning based on past performances, neither can it provide a platform for remote clinical analysis of the patient's progress. This would limit the system in its functional benefit to the potential clinicians involved.

Storage and remote analysis of end-user movement data would be essential to integrate within the system in the future. Key areas to monitor would be spatial error or overall accuracy, the overall fluidity of movements and the speed at which they are being performed. These have all been identified as the key aspects towards completing a motor task successfully (Carr and Shepard 2010). A simple web application which allows remote monitoring of attempted movements against the ideal trajectory would allow the clinician to assess the rate, smoothness and error in real time and aid in the identification of any repetitive errors which could be addressed during patient reviews (Sigrist et al. 2014). Monitoring the habitual data, i.e. time in use and frequency of use, would also serve as an indication into the patient's overall engagement and enjoyment with the rehabilitation programme.

Lastly, by providing features for a retention test, a movement session with no feedback, the clinician would also be able to gauge the transfer and retention of skill the system is providing and assess at what level of functional independence the patient may be at and when to move onto a new task environment.

9 Conclusion

This research presented the design and evaluation of a proof-of-concept auditory biofeedback system. The objective of which was to guide healthy participants towards following a novel trajectory, providing error-corrective spatio-temporal feedback in response to deviations from this trajectory. It defined an arm movement model using angular displacements and linear acceleration. The research provides an insight into the general usability of such a guidance system from people with a healthcare background. The system provided an above average usability score and qualitative feedback indicating the devices applicability for arm rehabilitation and guided assisted living tasks. Participants were able to adjust their trajectory to the novel one provided and felt the *sound was smoothly guiding them through* the movement when their primary sense, vision, was impaired. This research concludes that although this study provides evidence in favour of these systems, more literature is needed from the domain on the clinical acceptance of guidance systems, and further work is required to improve the design of the sonification concept itself, helping to improve engagement and the gamification aspects of the task.

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Exploiting Wearable Technologies to Measure and Predict Students' Effort

Barbara Moissa, Geoffray Bonnin, and Anne Boyer

1 Introduction

Students' effort has often been cited as a key factor of learners' success. For instance, Carbonaro (2005) collected teacher-reported data about students' effort and found a stronger relation between acquisition of knowledge and effort, than with curricular tracking. Another example is the study of Gipps and Tunstall (1998), where learners were asked to report the main reasons for success and failure. Effort came first, followed by competence and the role of the teacher. Similar studies with similar outcomes include the works from Swinton (2010) and Meltzer et al. (2001).

The aforementioned studies measure effort by asking participants (teachers or learners) to assign grades. Another possibility is to rely on effort-related objective measurements. One advantage of such measurements is that they can be automated and can be much easier to acquire. Perhaps the most frequent method is to measure the time spent on tasks. This method is particularly simple but lacks reliability. For instance, it is possible that a learner spent a long time on a given activity because she/he was not putting much effort on it. Moreover, it does not allow to analyze the internal and external conditions of the learner (a given activity may require more effort for the same learner depending on whether she/he is tired or not, if she/he is in a noisy or in a quiet environment). This is one possible explanation for the fact that some researchers were able to correlate time spent on a task to learning outcomes while others were not (Schuman et al. 1985; Hill 1990).

The unreliability of indicators, like the time spent on a task, can be refined by comparing the time spent on the same task by other learners in the same and in different contexts. In general, the more additional information is available, the more

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the resulting measurement is reliable. One of the most promising ways of acquiring such additional information is to exploit wearable technologies. For instance, eye tracking glasses can be used to measure the attention of the learner. This information can be, for instance, combined with the time spent on a task to better estimate the effort. This type of devices have been around for approximately 20 years but have only recently become popular as the underlying technology has improved, as their prices have reduced, and as they have become easier to use (Alvarez et al. 2016).

Still, in the literature, only a few works have studied the exploitation of these technologies for education, and to this day, it is not clear how we should use them in this context (Alvarez et al. 2016). Studies that focus on exploiting wearable technologies to measure or predict learners' effort are even rarer. Thus, our main intent with this chapter is to provide a landscape of research on the use of wearable technologies for effort measurement and prediction. We will review and discuss how the data gathered by these technologies can be combined with already available data and propose perspectives for future research.

The reminder of this chapter is organized as follows: Sect. 2 provides the required background by showing the different ways students' effort is defined and operationalized, by describing it in detail and showing its implications on learning based on the cognitive load theory and by describing wearable technologies showing what they are and what data they can capture; Sect. 3 shows current students' effort measures and how wearable technologies can be used for that end; Sect. 4 describes current works on effort prediction and how wearable devices can help to build better prediction models; Sect. 5 describes the major changes wearable devices offer in the measurement of students' effort, their limitations, and current challenges. Finally, Sect. 6 presents the conclusions.

2 Background

This section provides some definitions of effort, introduces the concept of cognitive load (Sect. 2.1) and explains how it influences learning and its outcomes (Sect. 2.2). We then review wearable technologies, as it is important to know what they are in order to understand how they can help us to measure and predict cognitive load (Sect. 2.3).

2.1 Students' Effort: Definitions and Interpretations

A number of different definitions for the concept of effort have been proposed in the literature. For instance, Dev (1997) defines students' effort as the ability to persist with the task, the amount of time spent on it, the curiosity to learn, the feelings of efficacy related to it, or a combination of these factors. Schuman (2001) proposed a shorter definition: the amount of studying. Carbonaro (2005) defines effort as the amount of time and energy expended to meet formal requirements established by the teacher and/or by the school. Interestingly, Carbonaro (2005) further classifies effort into three categories: rule-oriented effort, procedural effort, and intellectual effort. *Rule-oriented effort* relates to students' compliance with school's rules and norms (e.g., showing up for class regularly). *Procedural effort* relates to students trying to meet the demands of the teacher (e.g., completing assignments, turning in assignments on time, participating in class discussions). *Intellectual effort* relates to the wish of doing the tasks correctly. As can be seen from these examples, although related, the definitions of effort can take different forms. As stated by Meltzer et al. (2001), there are no widely adopted definitions for this concept.

Differences can also be observed in practice. For instance, parents and teachers evaluate students' effort differently. According to a study carried in English schools by Stables et al. (2014), teachers evaluate students' effort by checking if they meet deadlines, complete their work, produce work of good quality, follow standards of presentation, and have good grades. Parents also evaluate students' effort based on their grades (work of good quality), but they also take into account the time they spent studying.

As consequence, a number of different measurements have been used by researchers in related scientific studies. For example, Swinton (2010) used grades given by teachers to positively relate students' effort with students' outcome. Nagy (2016) used a similar approach (i.e., teachers grading students' effort) in a Learning Analytics tool, allowing teachers to know if their students are exerting more or less effort over time and to provide feedback to the students. In a different approach, Schuman et al. (1985) used time spent on a task as a measure for students' effort and were not able to correlate their measurements to learning outcomes. Hill (1990) also used time spent as a measure, but was able to positively relate time spent studying during weekends with learning outcomes, while time spent studying during weekdays did not have any correlation with the learning outcomes. Another different approach to measure students' effort is presented by Scariot et al. (2016), who proposed a more complex measurement that combines information about the amount of resources and assignments available with the students' interaction with a virtual learning environment (number of viewed resources and assignments submitted).

In this chapter, we propose to rely on the concept of cognitive load, often assumed as being the total amount of mental effort exerted by a person (Leppink 2017; Paas et al. 2003; Paas and van Merriënboer 1994). As will be discussed in the next section, this concept has several advantages as it allows a better understanding of how learning occurs and provides us with insights about the relationship between students' effort and learning outcomes.

2.2 Cognitive Load as Students' Effort and Its Implications for Learning

Cognitive load (CL) is a multidimensional construct that represents the load that performing a given task imposes on the cognitive system (Paas and van Merriënboer 1994). In other words, it is the load a student's mind experiences during a learning task. Based on that concept, the effort a student puts in a learning task can then be defined as the quantity of cognitive resources consumed.

The cognitive load theory (CLT), proposed by Sweller (1988), describes the relationship between students' effort and learning. This theory is based on a cognitive architecture that consists of a limited working memory (which experiences the CL) that interacts with an unlimited long-term memory (Paas et al. 2003). It defines learning as the development and automation of schemas in the working memory, which are then stored in the long-term memory to be easily accessed and used (Paas et al. 2003; Leppink 2017). Based on this definition, the theory states that the learning design must take into account the limitations of the working memory (Leppink 2017): in case of an overload, all the information will not be stored in the long-term memory, i.e., the learning will be decreased and the errors increased (i.e., lower performance).

This theory gained lots of attention, and later three types of cognitive load were identified: intrinsic cognitive load (ICL), germane cognitive load (GCL), and extraneous cognitive load (ECL) (Leppink 2017; Paas et al. 2003). While some researchers adopt this classification in three categories, others adopt a classification with only the ICL (or ICL/GCL) and the ECL, where the GCL is a part of ICL. However, these differences do not affect the proposed learning design guidelines and the comprehension of how CL works (Leppink 2017).

- *Intrinsic cognitive load* is determined by the interaction between the nature of the material being learned and the expertise of the learners (Paas et al. 2003). In other words, it corresponds to the difficulty of a task for a given student (e.g., calculating $1 + 1$ vs. solving an equation) (Chandler and Sweller 1991). Note that determining this difficulty requires to possess precise knowledge about the background of the students to whom the task is being proposed. Therefore, the instructional designer is usually not able to directly change the ICL of a learning task (Paas et al. 2003).
- *Germane cognitive load* is related to processes that contribute to the construction and automation of learning schemas (i.e., learning) (Paas et al. 2003), but it has also been understood as a load due to deliberate engagement in cognitive processes beneficial to learning, including asking the right questions, appropriate self-explanation of content, accurate metacognitive monitoring of learning and performance, and following up on that monitoring with adequate learning activity (Leppink 2017).
- *Extraneous cognitive load* are cognitive processes that do not contribute to learning (e.g., dividing attention between information sources, in different spaces

or times, that could be integrated into a single source) (Leppink 2017). As it uses the cognitive resources available, it is desirable to reduce it in order to free working memory resources to ICL and GCL (Leppink 2017; Ginns 2006).

These three subtypes of CL help the CLT to explain why students' effort is an important factor to achieve better learning outcomes (i.e., without exerting the proper amount of effort the student cannot store new information in the long-term memory) and why sometimes it does not happen despite the effort exerted on learning tasks (i.e., too much ECL was exerted that did not allow new information to be stored in the long-term memory). Having a good attendance, delivering learning tasks on time (or not), and other actions considered as procedural and behavioral effort by Carbonaro (2005) are good attitudes expected from students, but they do not necessarily make students learn (e.g., a student can never miss a course, but his mind can). Still, as those actions reflect the students' behavior, they should not be discarded as a source of information (see Sect. 3.4).

In practice, it is not clear how to distinguish ECL from ICL and GCL (Leppink 2017) and CL is often measured as a whole. Researchers often assume that the total amount of CL (i.e., ECL + ICL + GCL) reflects the total amount of mental effort exerted by a person (Leppink 2017; Paas et al. 2003; Paas and van Merriënboer 1994). For that reason, in the reminder of this chapter, we will consider that mental effort and CL reflect each other (i.e., the more effort exerted, the more load experienced and vice versa) and use the terms students' effort, mental effort, and CL interchangeably.

2.3 Wearable Technologies

Wearable technologies and wearable devices are terms that describe electronics and computers integrated into clothing and accessories that can be worn comfortably on the body (Wright and Keith 2014). Examples of such devices are watches, glasses, contact lenses, e-textiles, smart fabrics, headbands, beanies, caps, jewelry (e.g., rings, bracelets), hearing aid-like devices designed to look like earrings, and devices implanted in the body (e.g., micro-chips or smart tattoos) (Wright and Keith 2014; Tehrani and Michael 2014). The ultimate goal is to incorporate functional portable computers and electronics seamlessly into people's daily lives (Wright and Keith 2014).

As mentioned in the Introduction, these devices have been around for approximately 20 years, but have become more popular with the advances of technology (Alvarez et al. 2016). As a matter of fact, the Vandrico Wearable Technologies Database, a public database that lists the existing wearable technologies (Vandrico Solutions Inc. 2018), holds 431 devices from 266 companies across a range of sectors including fitness, medical, entertainment, industrial, gaming, and lifestyle. Some examples of already popular wearable devices are Fitbit, Nike+, Apple, and Garmin watches, Google Glasses, Google Cardboard headsets, and Microsoft HoloLens (Alvarez et al. 2016).

These devices have some shared tasks with handheld technologies (e.g., mobile phones, laptop computers), but the data they can collect can be much richer due to their sensory and scanning features (e.g., biofeedback and tracking of physiological functions) (Tehrani and Michael 2014). Wearable devices can also be used for other purposes than collecting information about the person who is wearing them. For instance, virtual headgears (e.g., Oculus Rift) can take users on 3D experiences (e.g., field trip, immersive foreign language instruction) (EdTech Review 2014); smartwatches can be used by students to send questions to the teacher, who can then answer them in the order they are submitted (Ødegård 2013); and exoskeletons allow people with disabilities to walk (ReWalk Robotics 2014).

One wearable device, like the ones cited above, can hold several wearable technologies. There are several wearable technologies currently available (Lu et al. 2017), such as:

- *Accelerometer:* Measures the linear acceleration along each of its three axes (i.e., x, y, and z). Its normal sampling rate ranges from 20 to 100 Hz and the maximum acceleration range is between 2 and 16 g.
- *Gyroscope:* Measures the rotational accelerations around each axis. Its normal sampling rate ranges from 20 to 100 Hz, and the maximum acceleration ranges from 250 to 2000 °/s.
- *Magnetic sensor:* Measures the direction and strength of the magnetic field of the Earth. Its normal sampling rate ranges from 20 to 100 Hz.
- *Heart rate sensor:* Measures the heart beat rate using infrared light. Its sampling rate ranges from 0.025 to 1 Hz. The sensor in wrist-worn devices detects the amount of light absorbed by the hemoglobin present in the blood to detect the volume changes in the blood vessels, and then calculates the heart rate.
- *Global Positioning System (GPS):* Identifies the devices geographic location and time information.
- *Temperature sensor:* Measures the body temperature.
- *Eye tracking:* Measures eye positions and eye movements.
- *Electroencephalography (EEG):* Records electrical activity of the brain.

The use of wearable devices is currently quite popular in health care, medicine, and fitness (Wright and Keith 2014). However, these devices are starting to be used for educational purposes. In classrooms, wearable technologies can be used for several purposes. For instance, the Portable Teaching Laboratory project (Alvarez et al. 2016) aims to deliver highly interactive lab-based learning experiences for students in a Cognitive and Brain Sciences course by implementing an affordable, wireless gaming system that monitors electrical brain activity. Lu et al. (2017) have a different approach for wearable devices. They propose a Learning Analytics framework that uses the data gathered from commodity wearable devices[1], merge it with data from virtual learning environments and infer learner context (e.g., student activities and engagement status in class). This work can be considered as a first step toward the use of data from wearable devices to measure students' effort, as they provide a framework to analyze the data gathered through wearable devices and hypothesize that physical actions reflect the cognitive state of a student. Although this approach would not work if the student is concentrated but motionless, the authors claim that this issue can be addressed by using other devices in combination.

3 Measuring Cognitive Load

Cognitive load is highly dynamic and can change from second to second, even within the execution of a given task (Chen et al. 2016). Xie and Salvendy (2000) proposed a framework that describes this behavior, distinguishing between instantaneous load, peak load, accumulated load, average load, and overall load. Instantaneous load represents the variation of CL over time. Peak load is the maximum value of instantaneous load reached. Accumulated load is the total amount of load experienced. Average load is the mean intensity of load experience during a task (e.g., time spent in task 1/time available for task 1). Overall load is the average load experienced during all the tasks done (e.g., time spent on all tasks/time available for all tasks).

It is important to note that CL cannot be measured directly; however, it can be inferred through measures which are believed to have a high correlation with it (Xie and Salvendy 2000). There are four types of measures that can be used to infer CL: subjective, performance, physiological, and behavioral measures (Chen et al. 2016). In practice, a combination of those measurements is more accurate than just one (Chen et al. 2016; Mulder 1992). This section describes those measurements and what they measure (i.e., instantaneous load, peak load, accumulated load, average load, and overall load).

3.1 Subjective Measures

Subjective measures, subjective ratings, rating scales, or also self-reports are a popular way of measuring CL (Paas et al. 2003; Shi et al. 2007). They are based on the assumption that people are able to introspect on their cognitive processes and report the mental effort exerted (Leppink et al. 2013), which has been demonstrated

[1]Smart equipment that can be worn by users and easily purchased on the market (Lu et al. 2017), such as smartwatches and glasses.

to be sensitive to relatively small differences, valid, reliable, and unobtrusive (Paas et al. 2003, 1994).

This approach consists in asking users to self-assess their CL by answering a set of questions in the middle of the task (Shi et al. 2007) or immediately after the task (Chen et al. 2016), being unsuitable for application that require real-time data. Those questions usually rely on Likert scales with five (Camp et al. 2001; Salden et al. 2004), six (Cierniak et al. 2009), seven (Ayres 2006; Hart and Staveland 1988), nine (Eysink et al. 2009; Paas 1992), or ten (Leppink et al. 2013) items.

With this approach, the variations of CL over time cannot be captured, i.e., it does not allow to measure the instantaneous load nor the peak load. Hence, only the average load or the overall load can be captured (Chen et al. 2016). An issue associated with this method is that if applied too often, it can annoy the students or even condition them to always give the same answers, losing reliability (Korbach et al. 2017).

3.2 Performance Measures

Performance measures are based on the assumption that the experienced CL will reflect on task outcomes, specifically, as CL increases, the performance is more likely to decrease, especially when the student is experiencing overload (Paas and van Merriënboer 1994). Those measurements can be the learning outcomes achieved by the students such as grades, number of correct exercises, and time spent on a task (Paas et al. 2003). However, two students can achieve the same outcomes, but exert different levels of effort. Based on this, Paas and van Merriënboer (1993) argue that performance measures combined with mental effort measures allow a meaningful interpretation of the instructional conditions' efficiency. In this approach, a high performance with low effort means high-instructional efficiency, whereas a low performance with high effort means low-instructional efficiency.

Performance measures are often used with a popular technique called the dual task technique (Chen et al. 2016). It consists in asking the subject to execute two tasks at the same time and to compare the corresponding results with those obtained in single-task conditions. If the performance decreases (e.g., the number of errors is bigger, the time to execute the task increases, etc.), it means the tasks interfere with each other, competing for the same type of mental resources. This approach cannot be easily used outside of controlled environments and provides only post hoc measures (Chen et al. 2016).

3.3 Physiological Measures

Physiological approaches (or psychophysiological approaches) are based on the assumption that changes on the psychological state lead to a physiological change

Table 1 List of physiological measures and their relationships with CL

Type	Measure	Wearable device
Brain	Alpha frequency (–) Theta frequency (+)	EEG Headband
Cardiovascular system	Heart rate (+) Heart rate variability (–) Blood pressure (?)	Smartwatch Fitness tracker
Skin	Temperature (–) Conductance (+)	Fitness tracker T-shirt
Pupil	Pupil diameter (∗) Percentage change in pupil size (∗) Mean pupil dilation (∗) Peak dilation (∗) Latency to the peak (∗)	Eye tracker

When CL is higher, the measure: (+) increases, (–) decreases, (∗) presents variations, (?) is unknown

(Paas et al. 2003). In other words, the increase of the experienced CL affects body properties (e.g., temperature, heart beats, etc.) (Kramer 1990). This type of data can be captured at a high rate and with a high degree of sensitivity (Paas and van Merriënboer 1994) and can therefore capture variations of CL over time (Paas et al. 2003; Chen et al. 2016). The explored physiological measures are related to brain activity, cardiovascular responses, skin responses, and pupil dilation. They can be seen in Table 1, together with some indicators, examples of wearable devices that can capture it, and their relationship with CL (i.e., if they increase or decrease when CL is higher).

Brain activity is analyzed through the power spectrum, which comprises the delta, gamma, alpha, and theta frequencies. It can be measured through electroencephalography (EEG), using either a proper machine or using wearable EEG devices. Another way of measuring it is through magnetoencephalography (MEG). According to the review of Klimesch (Klimesch 1999), alpha and theta frequencies, which behave in different and opposite ways (i.e., if alpha is high, theta is low and vice versa), are related to CL: if there is a higher task demand, the alpha frequency is reduced, and the theta frequency is increased. In theory, by gaining a better understanding of brain functions and activities, we could be able to directly measure the CL instead of just relying on indicators. However, this is still not the reality. It is therefore meaningful to also rely on other types of measures.

Cardiovascular measures refer to the heart rate (HR), to the heart rate variability (HRV), and the time between each heart beat (also called R-R interval or inter-beat interval). According to Mulder (1992), the HR increases and the HRV decreases when the CL increases. However, those measures are affected by blood pressure variations, which are affected by factors, such as sleep deprivation and ambient noise (Mulder 1992). For this reason, Mulder suggested that the blood pressure measure should also be measured to analyze HRV. However, its relationship with the CL is unknown. Respiration is another factor that can affect HRV, and can itself be influenced by other factors (e.g., the speech) (Mulder 1992). This measure is considered invalid by some researchers, as they are intrusive and insensitive to subtle fluctuations of CL (Paas and van Merriënboer 1994; Nickel and Nachreiner 2000; Naismith and Cavalcanti 2015). According to Naismith and Cavalcanti (2015), brain activity and eye activity (see Sect. 3.4) measures are more reliable than cardiovascular measures.

Skin response measures refer to skin temperature and electrical conductance. Or and Duffy (2007) conducted experiments to assess the correlation of nose and forehead skin temperatures with CL. The results showed that the drop of the nose temperature was related to a higher CL. On the other hand, the total amount of skin electrical conductivity (Shi et al. 2007) proportionally changes due to sweat secretion (i.e., more sweat, more electricity) (Darrow 1964), increasing when their CL level increases (Shi et al. 2007). It can also be called skin conductance, galvanic skin responses (GSR), and electrodermal activity (ECA).

Pupil dilation measures are also used to measure CL. As can be seen in Table 1, pupil diameter, percentage change in pupil size, mean pupil dilation, peak dilation, and latency to the peak increase when CL increases (de Greef et al. 2009; Beatty and Lucero-Wagoner 2000; van Orden et al. 2001). However, Schultheis and Jameson (2004) found out that, while reading some texts in a hypertext environment, the pupil size did not change when the text was easier or harder. An explanation to these conflicting results is that those measures are sensitive to luminance (the pupil dilates when there is light in the environment) (Kramer 1990), which may have interfered with the results due to the exposition of subjects to a computer screen.

3.4 Behavioral Measures

Behavioral measures capture objectively and implicitly (i.e., without interrupting the task) the subjects' behavior (Chen et al. 2016). These measures can be captured through eye tracking, mouse usage, digital pen input, speech features, linguistic features, gait patterns, head movements, and mouth openness. Table 2 shows these measures, some examples of wearable technologies that can measure them, and their relations with CL (as in Table 1, it shows if they increase or decrease when the CL is higher).

Eye activity measures are blink frequency, blink interval/latency, blink duration, fixation frequency, fixation duration, saccade distance/extent, and saccade speed. As can be seen in Table 2, blink frequency and blink duration decrease as the CL increases; blink interval, fixation frequency, fixation duration, and saccade distance increase when the CL increases; finally, no correlation has been found between saccade speed and CL levels (de Greef et al. 2009; Beatty and Lucero-Wagoner 2000; van Orden et al. 2001). These measures can be obtained through electrooculography (EOG) devices, eye trackers, and video records.

Speech features can also be used to measure CL. Khawaja et al. (2007) carried an experiment in which the subjects had to read a story out loud and then answer

Table 2 List of behavioral measures and their relationships with CL

Type	Measure	Wearable device
Eye	Fixation frequency (+) Fixation duration (+) Saccade distance (+) Blink interval (+) Blink frequency (–) Blink duration (–) Saccade speed (?)	Eye tracker
Speech features	Pause length (+) Response latency (+) Pitch range patterns (+) Speech rate (+) Speech energy (+) Amplitude (+) Variability (+) Specific peak intonation (+)	Devices with a microphone
Linguistic features	Word count (+) Word per sentence (+) Negative emotions (+) Swear words (+) Cognitive words (+) Perceptual words (+) Inclusive words (+) Disagreement words (+) Agreement words (–) Singular pronouns (–) Plural pronouns (+)	Devices with a microphone
Gait patterns	Residual variance (∗)	Devices with accelerometer and/or gyroscope

When CL is higher, the measure: (+) increases, (–) decreases, (∗) presents variations, (?) is unknown

a few questions about it, in order to investigate the suitability of speech features (length of silent and filled pauses, frequency of silent and filled pauses, and response latency) to measure CL. They found out that silent and filled pause lengths and response latency are significantly higher when the CL is higher. The frequency of silent and filled pauses is higher, but not significantly, which may occur in situations where a higher CL is experienced. Yin et al. (2007) collected data in an experiment very similar to the one carried by Khawaja et al. (2007) (i.e., asking the subjects to read out loud a story and then answering questions about it), and they used spectrum features (measured by the Mel-Frequency Cepstral Coefficients) and prosodic features (measured by fundamental frequency, or pitch, and speech intensity) as inputs to a Gaussian mixture model, achieving an accuracy rate of 71.1% when classifying CL.

Linguistic features have also been used to measure CL and can be collected when subjects are speaking or writing (Khawaja et al. 2014). Khawaja et al. (2014) analyzed subjects' linguistic features on speech during a firefighting task in a multitouch tabletop screen. They used a software tool called Linguistic Inquiry and Word Count to extract linguistic features from the audio transcription files: word count, words per sentence, negative emotions, positive emotions, swear words, cognitive words, perceptual words, agreement words, disagreement words, inclusive words, first-person singular pronouns, third-person singular pronouns, first-person plural pronouns, and third-person plural pronouns. As can be seen in Table 2, positive emotions, agreement words, first-person singular pronouns, and third-person singular pronouns were the only features that decreased, while CL increased. However, the decrease of positive words may have happened because it was a task that reflected a negative situation as it got more difficult (i.e., increased CL). Maybe if the task was different, the positive words and agreement word features would be higher (and the negative words would be lower). Khawaja et al. (2014) also analyzed other six linguistic indicators.

Verrel et al. (2009) studied the effects of CL on *gait patterns* on a treadmill. They used the residual variance (i.e., the relative amount of variance in the residual pattern) from the principal component analysis (PCA) method to measure how regular the subjects' body movements were. They found different relations between gait and CL on different age groups. Gait was more regular (i.e., reduced residual variance) on those whose age was 20–30 years, more irregular (i.e., increased residual variance) on those whose age was 70–80 years, and no correlation in those whose age was 60–70 years.

Other behavioral measures that have been explored are head movements and mouth openness[2]. According to Guhe et al. (2005), when CL increases, the subjects tend to move their heads and also to open their mouth more often. There are also tangible objects that can be used to gather behavioral data related to CL, for instance, a digital pen input (Ruiz et al. 2007; Yu et al. 2011) and a mouse (Arshad et al. 2013).

4 Predicting Cognitive Load

So far, we have discussed the importance of effort and the different ways of measuring it, with a special attention to wearable technologies. Although being able to measure the effort a posteriori can be useful, e.g., to help the teacher track the evolution of engagement of his students, much more can be achieved by predicting the required effort of the different tasks she/he can give to them. For instance, if a task requires too much effort for a given student, then she/he will not complete it. On the contrary, if a task requires too few effort, the student may be bored and easily distracted. Thus, being able to estimate in advance the required effort of learning activities is a promising way to optimize learning.

[2] According to Chen et al. (2016), it is a physiological measurement. But we chose to classify it as behavioral because the subject can control his head movements and mouth openness.

In general, predictions are made based on previous experiences (i.e., the data we already have about our subjects' behavior and characteristics) to identify future behavior (e.g., who is more likely to buy something, who is more likely to lie) and make better decisions (Siegel 2013). According to Siegel (2013), it is currently possible to predict with a relatively good accuracy if a person is going to use a discount coupon, what advertisements a visitor will access, what movies a person will like, etc. The same principles apply to learning, and in particular to the prediction of the CL. By using the data gathered from students to measure their CL, it is possible to predict the CL level a given student is going to experience in a task that has not been executed yet.

A few CL prediction studies related to learning tasks have been conducted. For instance, Spüler et al. (2016) trained a classification model (linear ridge regression model) with brain measurements (collected through EEG sensors), in order to identify the CL level of performing additions. Two approaches were considered: cross-participant (trained the model with data from a group and used a single model for everyone) and within-participant (each subject has his own model). Both were successful, but the within-participant approach had a higher accuracy. Borys et al. (2017) also trained a model to identify CL levels (low, high, and without task) on arithmetic tasks from brain and eye activity measurements (collected through EEG sensors and an eye tracker device). They used several classification models – bagged trees, discriminant analysis, logistic regression, support vector machines, k-nearest neighbor (KNN) classifiers, and ensemble classifiers – and two datasets to train the models. With the first dataset (a binary classification discriminating between the presence of CL and the no-task condition), they achieved an accuracy of 90.4% by using the support vector machines classifier. With the second dataset (discriminating the three mental CL levels), they reached a maximum accuracy of 73% with the KNN classifier. Walter et al. (2017) created a prediction model (linear ridge regression model) based on brain-related data (collected through EEG sensors) to predict cognitive states and used it to adapt an EEG-based learning environment. It was evaluated with arithmetic addition in the octal number system tasks, and the results suggest a significant learning effect.

In a different approach, Mock et al. (2016) used behavioral data instead of physiological data. They investigated the use of machine learning techniques (support vector machines and radial basis function kernel) of touchscreen interaction data of children solving math problems to predict CL. Their results show that the touch patterns can predict high CL with an average classification accuracy of 90.67%.

The prediction of user's cognitive state is also being done through the use of wearable devices. Webster et al. (2017) used data from a device embedded in a shirt that continuously collects 34 physiological measures during the subjects' daily lives. The hypothesis is that these physiological measures could be used to predict future cognitive states by allowing users to train a system to categorize historical data, physiological data, and movement data. To train the system, users needed to label their cognitive state. The system uses the KNN and random forest (RF) algorithms to create models with the measures obtained 1030 minutes preceding a label. With this approach, they predicted cognitive states with a mean accuracy of 61.3% for RF and 57% for KNN.

Galán and Beal (2012) used an EEG headset to capture estimates of attention and CL, while students solved math problems to predict the success or the failure at solving those problems. The results, obtained from a support vector machine (SVM) model, indicate that by combining indicators of attention and CL, the outcomes of the learning exercises can be predicted. Their results varied from 57% to 87% and were more accurate when predicting the outcome of easier exercises.

Although wearable devices are not being widely used for the prediction of CL, it is clear from the study of Galán and Beal (2012) that wearable devices can replace other types of equipment (e.g., use wearable EEG device instead of EEG sensors) and ease the data collection for the purposes of prediction, allowing new uses for those models. More advantages of using wearable technologies for measuring and predicting CL are discussed in the next section.

5 Opportunities, Challenges, and Limitations of Wearable Technologies

This section describes the opportunities offered by wearable technologies to measure and predict CL (Sect. 5.1) but also describes some challenges and limitation in their use for these purposes (Sect. 5.2).

5.1 Opportunities

Perhaps one of the main advantages of wearable technologies is that they are usually much less expensive than the preexisting equipment to collect similar data (e.g., EEG machines). In particular, this means that physiological and behavioral measures of students' CL can now be made at a much lower cost. Moreover, data collection is much less obtrusive. For instance, wearable technologies do not require to attach multiple sensors to the body. On the contrary, they are designed to not limit the movements of the person who is wearing them. For that reason, wearable technologies can actually be used in several contexts, including in the classroom, and allow to capture effort-related data in real time.

Real-time data collection can be useful for adaptive systems that aim to reduce the experienced CL. According to Schultheis and Jameson (2004), it is desirable to have time-specific CL estimation to allow the system to quickly adapt to a change in the users' state. For instance, Opperman et al. (2000), Chang et al. (2008), and Schultheis and Jameson (2004) attempted to develop adaptive virtual learning environments. Real-time data could also be used to provide real-time feedback to the students, helping them to self-regulate their learning process by alerting them that they should take some rest when identifying the student executed too much tasks and is tired, or move to less challenging tasks when identifying the student is experiencing overload due to task difficulty.

This ease of use also means that new types of data can be gathered. For instance, the health data gathered through wearable devices could be exploited to know more about how students' health increases or decreases their effort. Another benefit of wearable technology is that they can be easily used on a daily basis for long periods by many more subjects, gathering a much larger amount of data. Having more data available allows to develop new tools, such as adaptive systems, intelligent tutoring systems, recommendation systems, and automated feedback systems. It also allows to have more accurate predictive models, as more records are available to train them, and to periodically update these models, which is important as the factors that led to some predictions might change over time.

By having real-time and more fine-grained data, larger datasets, and more information about the students' cognitive and physical states, we can have better CL measures and prediction models. The more such additional information is available, the more accurate the predictive algorithms can be. For instance, if a student wears a smartwatch that monitors sleep-, health-, or mood-related information, then a predictive model can better estimate the required effort for a particular task by taking this information into account. However, to the best of our knowledge, no research has been made that explores this possibility.

5.2 Challenges and Limitations

One of the difficulties of using wearable technologies comes from the fact that they can be used in real-life situations instead of controlled experimental settings as almost all the measurements described in Sects. 3 and 4. Real-life situations present a variety of possible contexts, and all those different contexts can interfere with the collected measures. A student is likely to exert less effort in a quiet place than in a noisy place. A different pupil dilation may be observed depending on whether a student is in a well-lightened place or in a dark place. A student may have a lower heart rate if she/he is well rested than if she/he just made a physical activity.

This poses technical and scientific challenges when analyzing the data: we need to be aware of how environmental and personal conditions and also previous activities affect the effort measures obtained through wearable devices. Fortunately, as already mentioned, these devices also gather information related to those contextual factors, which can be explicitly taken into account in the measurements. For instance, fitness tracker data might be used to know that a higher heart rate is related to physical activities and not to a higher CL.

One related problem is that the information that can be collected by these devices can sometimes only be collected under specific conditions. For instance, if a student is focused on a learning task but motionless, movement sensors would not provide data related to his CL (Lu et al. 2017). This can also happen if students forget to use the wearable device, if the battery ends before they finish the task, if they do not want to share their data, if they do not have a given sensor in their wearables, etc. In general, the data collected by wearable technologies can be very noisy and incomplete. However, this limitation can be reduced by using multimodal measures, already cited as a way of achieving more accuracy (Chen et al. 2016; Mulder 1992). With respect to multimodal data gathered through wearable technologies, Lu et al. (2017), as mentioned in Sect. 2.3, already gave a first step toward this goal.

It is important to consider the reliability of the measurements gathered through wearable devices. There are several different devices manufactured for the same purpose – for instance, we can buy smartwatches from Apple, Samsung, and Sony – and their reliability has been questioned by researchers in contexts like sleep (Mantua et al. 2016; Rosenberger et al. 2016; van Wouwe et al. 2011), heart rate (Wallen et al. 2016; Dooley et al. 2017), and physical activity monitoring (Dooley et al. 2017; Rosenberger et al. 2016; Kooiman et al. 2015; Ferguson et al. 2015; Guo et al. 2013). Those studies compared different wearable devices on the mentioned contexts to see how accurate they are for their purposes. Their results show differences between devices, and some acknowledge what was the more accurate device for their purposes. The difference between devices should also be explored in the context of CL, to understand if they are reliable for measuring CL. Additionally, if we have a system that collects data from users' devices (that have different brands and models), the reliability of the results obtained with this data must be evaluated.

Using this technology in educational contexts also raises specific concerns: students' safety (data exposition, radiofrequency exposition, or even self-esteem), security and privacy, classroom limitations (a wearable device can be used for purposes other than learning and disturb the class), digital divide (the devices can be too expensive for some students), and dependence on outside vendors (Borthwick et al. 2015). Those concerns affect how wearable technologies can be used to measure and predict students' effort, and represent an important challenge that must be addressed in order to provide a safe environment to students. Some limitations related to those concerns are already addressed by the Family Educational Rights and Privacy Act (FERPA) in the United States (U.S. Department of Education 2015) and by the General Data Protection Regulation (GDPR) in the European Union (European Commission 2018) as they provide guidelines of how to use users' data.

6 Conclusions

In this chapter, we reviewed the existing means for measuring and predicting student's effort while emphasizing how promising wearable technologies are for these matters. After discussing some definitions of effort, we proposed to rely on the concept of CL and presented a brief overview of the existing wearable technologies.

We showed that wearable technologies allow the data collection through several sensors (e.g., accelerometer, gyroscope, magnetic sensor, GPS).

Next, we focused on the existing means for measuring CL. Although directly measuring it is still not possible, relatively accurate estimations can be obtained using subjective, performance, behavioral, and physiological measures as proxies. Unlike subjective and performance measures, physiological and behavioral measures can be made during the execution of a task and we think they are particularly suitable to make estimations of the CL experienced by students.

We then discussed how predictions of effort can be inferred from the available data about the learning resources, the students and the effort they put in their previous learning activities. We think wearable technologies offer promising opportunities for that task, as they allow us to obtain particularly useful information about contextual factors that may influence the effort. However, to the best of our knowledge, no research exists that addresses this matter.

Finally, we discussed the changes induced by the use of these technologies in the context of learning, namely, their ease of use, unobtrusiveness, and relatively low cost that allow to gather a large amount of information about a large number of subjects in real-time and in a variety of real-life scenarios. Those changes provide several research opportunities, as they allow us to explore the measurement of the CL experienced by students' in different contexts (e.g., classroom, virtual learning environment, library), the factors that can interfere with their effort (fatigue, environment, health), the factors that can interfere with the measures taken (e.g., physical activity can change the heart rate, lightness/darkness can change the pupil size, a fever can change the body temperature) and to provide new tools to be used in classroom and in virtual learning environments (e.g., feedback systems, recommendation systems, adaptive learning environments).

However, they also induce new challenges on which future research should focus, such as finding appropriate methods to compensate for the noise and lack of completeness of the collected data, combination of measures obtained through different devices, assessing the reliability and accuracy of data gathered through different devices/sensors (i.e., in real-life scenarios different users will have different devices with different sensors resulting in different measurements), and also developing policies to deal with safety, privacy, and ethical issues.

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Wearable Technology in a Dentistry Study Program: Potential and Challenges of Smart Glasses for Learning at the Workplace

Eva Mårell-Olsson and Isa Jahnke

1 Introduction

Wearable technologies, such as smart glasses, are not really a new concept. Steve Mann, often called the father of wearable technology, has been developing and conducting research on wearable smart glass for a long time. He mentioned in an article that he has been living with wearable technology in one way or another over the last 34 years (Mann 2012). Even if the increasing development of eye-based human-computer interaction goes back to the early 1990s (Bulling and Gellersen 2010), it is still not common to use wearable technologies in higher education or workplace learning.

Further, using computers and other technologies as learning tools in medical and dental study programs is not new. In fact, these date back to the early 1970s, but the real increase of the use of digital technology in dental education came with the introduction of personal computers in 1981 (Grigg and Stephens 1998). Computers and audio-visual aids were back then seen as possible means for supporting dental education needs, and several simple programs were available for dental students. The students welcomed computer-assisted learning in the form of instructions, video recordings, and the possibilities to answer simple multiple-choice questions (Stephens and Dowell 1983).

In a study comparing traditional lecturing and e-learning as pedagogies in dentistry, Browne, Mehra, Rattan, and Thomas (2004) found that for technology-

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inexperienced staff there are more benefits of face-to-face interaction with students, but the opposite occurred for the experienced staff where benefits were seen related to the manageability of learning through digital technologies. Their findings also showed the need for improving the interactions between dental students and teachers when using such technology for communication purposes.

Since that study, technologies have developed significantly, and there have been many advances in how information and materials are presented to a user (Grigg and Stephens 1998), and instead of being an expensive piece of equipment, devices such as computers or tablets are now quite affordable. Moreover, the use of technologies in education has been seen as a catalyst for changing pedagogies toward meaningful learning (Howland et al. 2012) and CrossActionSpaces (Jahnke 2015) – and enhancing teaching and learning in dental education is no exception (Brown 2006).

Schönwetter, Reynolds, Eaton, and De Vries (2010) argue that dental education is in an ever-changing, competitive, challenging, and complex environment and that there is a need to develop new dental schools globally. Further, they argue that technological changes in society create new demands for all those involved in dental education. The challenge concerns either moving forward to embrace the full potential of what technologies can afford or allowing fears to lead us to withdraw to the comforts of previous teaching and learning experiences (Schönwetter et al. 2010). Even if teachers see the value of using technology for teaching and learning purposes in dental education, many are challenged by what is seen as a cultural shift from traditional teaching methods to the "constructivists and resource-based approaches" to teaching (Reynolds et al. 2008a, b; Eaton and Reynolds 2008). Further, the challenges also concern an unwillingness to change teaching methods or to adjust to what is perceived as new and complex technology (Eisenstadt 1998; Gupta et al. 2004; Eaton and Reynolds 2008; Wagner et al. 2008; Kay 2014).

When we got a chance to explore smart glasses through the Glass Explorer Program (Google Inc. 2013), a lot of questions were raised on what the requirements and challenges will be for a device like smart glasses in dental education regarding facilitating the communication between the teacher and students during their clinical practice. Moreover, the potential of using smart glasses and how they might affect the design of teaching in dental education have remained unexplored.

2 Augmented Reality: Applications in Medical Education

In the beginning of 2013, Google released a head-mounted voice-controlled device called Google Glass that is worn by the user like a pair of glasses. The device has much the same electronics as a smartphone, including a battery, a speaker, two microphones, a camera, a Wi-Fi antenna, Bluetooth, a gyroscope, a memory chip, an accelerometer, etc. Graphics-supported information is projected through the prism over the right eye. In other words, the person sees the real world and in addition to that some additional information, or *augmented* information. For instance, the user sees a street and the name of the street is shown in the smart glasses. It is also possible to take pictures, capture videos, send messages, make phone calls, take notes, read and reply to emails, search for information, conduct video calls, etc., all with voice commands. One advantage with using this type of technology by commanding it with the voice is that the hands are available for doing other things than managing the technology. The device is also meant to deliver additional information just in time for the user. For example, emails are pushed to the device when they are delivered, but it is not possible to browse through old emails. In 2013, the device was not for sale to the public, and the first users who were able to try out this device, called Glass Explorers, were selected through a competition. The Glass Explorer Program was shut down in 2015, and the Google Glass project was moved out from Google X and turned into a standalone project called Glass at Work with five partner companies certified to make business or professional apps for Glass. One of these partners, Augmedix, has specifically focused on delivering solutions for the healthcare sector. These types of smart glasses are often referred to as augmented-reality smart glasses (AR-glasses).

2.1 Augmented Reality Technology (AR)

AR is a technology that enhances the real world by adding virtual objects that the user can use, for example, by wearing special glasses projecting the virtual objects (i.e., AR-glasses). The technique affords the ability to overlay images, text, video, and audio onto the existing reality. By merging the materialized real world with virtual objects, the use of AR has many potential applications in education and product development (Wang et al. 2018). Currently, there are three main types of AR technologies: (1) head-mounted displays and wearables, (2) mobile handheld devices, and (3) pinch gloves (gloves that allow a user to "pinch" and "grab" virtual objects or to initiate actions). Mobile devices are easily integrated into learning settings, and most of the AR applications used in education today rely on mobile applications. Google Glass belongs to the first category, head-mounted displays and wearables. Novak, Wang, and Callaghan (2012) describe head-mounted displays as complex technological devices that allow a user to see computer-generated images overlaid onto the real world via a digitally enhanced viewfinder.

AR technology is used in different areas and for different purposes, for example, using mobile and AR application as an indoor navigation system to show available routes for a wheelchair user (de Oliveira et al. 2017), for museums to include those who are hearing impaired (Baker et al. 2017), for displaying nutritional information on various foods (Butt and Navarro 2016), and for helping patients with diabetes with their diet and physical activities (Rollo et al. 2016).

2.2 The Use of AR in Education

In healthcare, AR is applied in a wide range of topics. Kamphuis, Barsom, Schijven, and Christoph (2014) present different applications of AR in medicine study programs. The first is the use of AR to simulate human organs and their placement inside the body when learning anatomy. Such education is currently provided through the use of human cadavers, which is very expensive. However, there is not enough empirical evidence to completely replace the use of human cadavers, and more research needs to be done. Another application that uses AR is for training in laparoscopy. AR offers realistic haptic feedback, which is essential for the transfer of laparoscopy skills to the work environment. Such applications also eliminate the need to have an expert on-site to observe or guide the trainee. Kamphuis et al. (2014) argue that the use of AR is promising for facilitating meaningful learning and that it might offer organizational advantages because the AR learning environment might provide the necessary variations in the training task, including collaboration, which supports authentic learning. Also, Zhu, Hadadgar, Masiello, Zary, and Hochheiser (2014) found that AR technology is perceived to be useful in medical education, and the acceptance of using the technology was also high among learners. However, most of the reviewed studies reported on early prototypes and the designed AR applications lacked an explicit pedagogical theoretical framework.

2.3 Study Goals and Research Questions

Few studies have focused on the use of AR in dental education (e.g., Juan et al. 2016). This book chapter presents the user perspective with regard to the use and adoption of AR-glasses, more specifically, how AR-glasses might contribute to communication, coordination, and cooperation between students and teachers during clinical practice in a dentistry program.

1. How can communication among users (learners, teachers) be facilitated through AR-glasses in a workplace learning setting?
2. What potential and challenges are there and how do these inform future designs?

3 Theoretical View: Learners "In the Field" – Digital Workplace Learning

Teaching and learning concepts in formal education, schools, and higher education make up a well-known research area that spans didactic, pedagogy, and instructional design (e.g., Hudson 2008), including technology use (e.g., Mårell-Olsson and Hudson 2008). With the shift into the digital age, concepts that focus on learning *from* technologies are not very useful for learners (Shapiro et al. 2017) because while this concept supports "memorizing facts", it does not enhance deep learning. As such, a new concept is needed that enhances learning *with* technologies (Jonassen et al. 2003), and different sets of elements can be considered when studying and designing for meaningful teaching and learning. Jahnke (2015), for example, suggests the following five elements:

- Clear and visible teaching/learning goals (intended learning outcomes)
- Meaningful learning activities for students
- Process-based assessment (feedback and guided reflections)
- Social relations (dynamics of social roles; learners are producers, not consumers, of information)
- Technology integration (learning *with* technologies)

These elements, however, might be not useful, or only partly useful, for other learning fields outside formal education (Norqvist 2016). Research in the use of digital technology in clinical practice and learning in the workplace seems to be a rather new field (Ifenthaler 2018; Goggins and Jahnke 2013; Goggins et al. 2013). The main difference compared to earlier research is that in formal education the primary activity is "learning", while in workplace settings the primary activity is conducting a task, *to do the job*. However, if the task cannot be conducted at all or not in a timely manner, the person will need to learn how to actually do it or how to improve their performance on the task (Mørch 2013) – learning is only a secondary goal. Learning in organizations was studied at length in the 1990s leading to the well-known concepts of *knowledge management* (Nonaka and Takeuchi 1995), *organizational learning* (Brown and Duguid 1991), and *communities of practice* (Wenger et al. 2002). Goggins and Jahnke (2013) give an overview of how these fields are connected and how they inform digital workplace learning today. They suggest a distinction between *learning* and *work* and suggest that workplace learning follows a different logic of learning. While in formal education the teacher designs for learning, where a correct answer is known, workplace learning faces the challenges of the answer to the problem not being known or it being unclear which person has the answer. The workplace learner tries to create or find a useful solution to an arising problem in order to continue his or her job task.

A promising approach for workplace learning was developed by Yrjö Engeström, entitled *activity theory – expanding learning*, that acts as a framework for analyzing and redesigning *work* (Engeström et al. 1999). Newer studies focus on linking learning and work, including the seminal paper *Between School and Work: New Perspectives on Transfer and Boundary Crossing* (Tuomi-Gröhn and Engeström 2003). Moreover, Mørch and Skaanes (2010) made the case for designing a workplace that fosters learning across sites. Their studies demonstrated concepts for linking pedagogy and work practices with boundary-zone activities (Lee 2007) that describe the role of boundary-negotiating artifacts. We argue later in this paper that augmented information delivered on AR-glasses is such a boundary-negotiating artifact. New showcases of digital workplace learning have emerged that have dissolved the boundary between work and learning (Fischer 2013). As Goggins and Jahnke (2013) showed in their studies of digital workplace learning, learning already happens *across established* organization boundaries and learners create new *CrossActionSpaces* (Jahnke 2015), and learning also occurs in unexpected and unusual online places. Learning in such settings is much more personalized than in traditional classrooms. However, using online information needs critical users who know how to identify misleading from useful information. Furthermore, digital personalized systems can lead to an illusion of serendipity (Erdelez and Jahnke 2018). When workplace learners use information and feedback from diverse sources (e.g., people, videos, materials), research is needed to explore if learners are aware that they get some sort of pre-selected information based on their online search behavior and to determine how this affects their learning and perception of encountering *happy surprises* (p. 2). To study digital workplace learning, three elements might be useful to start with. These elements have been derived from a model developed by Jahnke et al. (2010) and Jahnke and Koch (2009) from their studies of engineering learning.

Different pedagogical-sociotechnical designs support different kinds of learning. In this chapter, we focus on meaningful learning *with* technologies. Table 1 shows the pedagogical-sociotechnical elements for digital workplace learning with wearables.

4 Study Description, Scenario, and Methods

We had the opportunity to conduct a Google Glass study because Google chose one of the authors as a Glass Explorer for their Glass Explorer Program 2013. As part of the program we began to integrate AR-glasses as a device in the dentistry education program at Umeå University in Sweden. The course in the dentistry program in which we integrated Google Glasses is a work-related practicum and can been defined as a type of workplace learning. Students worked with actual patients. In particular, we focused on those activities where dental students had their clinical practice with patients and were required to frequently communicate with the teacher and patients.

4.1 Scenario: Students with Patients – Before and with AR-Glasses

Before smart glasses The dental students worked with patients in the student operatory in a large hall. When a student needed help or approval from the teacher during treatment of the patient, they wrote the number of the operatory they were located in with their patient on a whiteboard. Using this routine the teacher would know, looking at the whiteboard, that a student needed help with something. During this phase, the teacher had to keep track of the whiteboard and usually had to run

Table 1 Pedagogical-sociotechnical design for meaningful learning with wearables

ID	Design of/for	Sub-category	Description
1.1	Technology support	Communication support	Synchronous or asynchronous communication support
1.2		Information management support	Learners collect, co-write, and annotate information The design helps them to learn how to evaluate sources and assess information quality (useful vs. misleading information)
1.3		Network management support	Learners (re)find other learners and experts to connect across traditional borders and (temporarily) include them within learning communities The design helps them to stay informed about the activities of the people in their own network and to spontaneously build and enhance learning communities
2	Social relations	Roles	Places workplace learners in new roles, not only as consumers of finding the solution, but as producers of evaluating solutions, as designers of developing solutions, and as identifiers of new problems
3	Pedagogical elements	Process-based sharing of solutions, reflective feedback	Encourage workplace learners to share solutions to a problem as well as to reflect on the process The design includes constructive feedback to workplace learners in the form of smaller nuggets of process-based assessments that can be adopted from mobile microlearning (Khurgin 2015)

back and forth to see if there had been any changes made or not. According to the teacher, this routine was very stressful because it was hard to know if many students were waiting for help or approval. According to the students, they and their patients spent a lot of time waiting to get help or approval to continue with the treatment.

With smart glasses The dental students had patients in the student operatory. The students used mobile devices, in this case media tablets (e.g. iPads), and the teacher used Google Glass to communicate with the students and vice versa (see Figs. 1 and 2). The students sent emails or Google Hangout messages to the teacher and described the problem, location (where they were in the operatory), and what they needed help or approval with. The teacher received a notification through a sound while wearing the AR-glasses. The teacher was able to read the message through the AR-glasses and could reply to the student by a voice message no matter where the teacher was or what she was doing; for example, when the teacher was using her hands to help another student in treating a patient, the teacher could still reply to the other students via voice message (e.g., voice to text message).

Fig. 1 The teacher is wearing AR-glasses to communicate with the students

Fig. 2 Dental students in the operatory using tablets to communicate with the teacher

4.2 Data Collection

This study was exploratory in nature and included aspects of a design-based project (Wang and Hannafin 2005). It was conducted in the second semester of the 2013–2014 academic year. A total of 18 dental students (8 male and 10 female students) and one female university teacher participated. Data for the study were collected through observations, group discussions with students, student video-recording reflections (using interview questions), and an interview with the teacher. The interview with the teacher referred to the teacher's experiences of designing the teaching in a clinical setting with the support of AR-glasses. The teacher interview took around 60 minutes. We applied the digital didactical design approach to study the designs for teaching. Interview questions focused on pedagogical, technical, social, and dental-specific issues such as (1) possibilities and challenges when using AR-glasses for communication, (2) their use in other areas than the student clinic, (3) ethical considerations concerning patient security, and (4) future development for dentists and other medical professionals.

In addition, during the clinical sessions we performed four observations of 4 h each. The observations focused on the working process and the communication between the students and the teacher, for example, if students had to write on the whiteboard instead of communicating with the teacher through the device, or if messages were not delivered through the different communication channels. At the end of each session, the students reflected through video recordings on their role as a future dentist concerning both dental and technical issues. The interview guide addressed issues of (1) dental perspectives of positive and negative experiences during the clinical work, (2) the experience of using the technology for communication, (3) suggestions for improving the concept, and (4) the use of AR-glasses as a future dentist (wishes, needs, developments).

4.3 Data Analysis Method

We analyzed the empirical material through thematic analysis (Ely 1991) based on the Activity Theory of Leontiev (1986), in which teaching is seen as a social activity, and we applied the approach of Digital Didactical Design (Jahnke et al. 2014).

Thematic analysis is a process in which the researchers construct understanding and meaning of the collected empirical data in order to identify key themes and patterns. Ely describes a theme as a definition of either utterances that all informants in a study are expressing or as a single statement of an opinion that has a great emotional or actual significance. Thematic analysis is a process for encoding qualitative data and includes two perspectives, "seeing" and "seeing as" (Boyatzis 1998). Seeing can be described as the process of searching for repetitive patterns of meaning, i.e., significance in qualitative data (Creswell 2013). The different steps of the analysis process in this study included (1) reduction of the data (coding), (2) presentation of the data (thematization), and (3) summary in the form of conclusions and verification (Hjerm and Lindgren 2010), and these steps were performed in an iterative process. As a step in making sense of the coded material, the phase of constructing meaning, or "seeing as", was carried out by searching for signs and patterns at a more abstract level of the informants' utterances. First, the data were reduced to categories, codes, and emerging patterns and then sorted into themes. Second, emerging themes were merged into a color-coded matrix for identifying relations between categories and codes within different areas. These iterative processes formed the themes in the material as presented in the next section of results. After these iterative phases, conclusions and verifications could be drawn. Data from the dentist students' video recordings and the teacher interview served to complete the whole picture.

The quotations presented in the next section serve as illustrations of the presented themes that emerged in the analysis of the empirical material.

5 Results

The incorporation of AR-glasses into education and existing study programs is not a neutral process; the device shapes the actual practice and changes or facilitates interaction and communication among participants. "First, we shape the devices and then the devices shape us" (McLuhan 1987). The study setting was not specifically made for the laboratory, rather it can be characterized as a study in the "wild" outside of the laboratory to explore what happens when teachers and students adopt AR-glasses.

The results section is organized along the five themes of (a) communication support, (b) coordination support, (c) information management, (d) technical challenges, and (e) future designs for learning. The themes illustrate that the device has the potential to meaningfully facilitate the coordination and communication of the participants, which can lead to improvements in the quality of learning. We present the results first, and then below we discuss them in the Section Discussion and Implications, specifically how the results are related to the pedagogical models that we described above, especially workplace learning, and the role of the five themes for (workplace) learning.

5.1 Theme 1: Faster Communication Support

Both students and the teacher expressed that the communication between them was better facilitated through the integration of media tablets and AR-glasses. The students in the clinic with patients expressed that it felt good *not* to leave the patient alone when they needed help from the teacher and had to leave the operatory to write on the whiteboard. Through the use of Google Glass, the students communicated directly with the teacher and left messages, for example, when they got stuck or had unusual problems during their work with the patients.

> When I need to ask the teacher something or I want the teacher to check something I've done, it feels good not to leave the patient alone in the operatory just to go and write on the whiteboard. (Student 5)

Students also mentioned that they got help faster than before, and specifically they got in contact with the teacher faster because the teacher was able to reply to the student messages directly from the AR-glasses regardless of where in the clinic the teacher was. The teacher replied immediately with a short notice and the students knew if they could expect help soon or if they had to wait while the teacher was helping other students and could go on doing something else. In previous courses without Google Glass, students just had to wait for their turn not knowing for how long until the teacher had finished with the previous students in line.

5.2 *Theme 2: Improved Quality of Coordination*

The teacher in this study pointed out that when using the AR-glasses, it was possible to prioritize which student needed help first based on the content of the messages sent. Before, when only the operatory number was written on the whiteboard and not what kind of help the student needed, it was not possible for the teacher to prioritize.

> The students also started to write what they needed help with or what they wanted me to do. Then it was possible to prioritize things when I got several messages at the same time. (Teacher)

The teacher also stated that it was possible to know if another student wanted to be in contact with her because a notification alert was sounded when a message was received. This was perceived as especially helpful when she was occupied in an operatory. She did not have to worry if students had written their operatory number on the whiteboard and were waiting in line for her.

5.3 *Theme 3: Information Management – Using Pictures to Express the Problem*

The students expressed that with Google Glass it was possible to attach an image to the message and that the teacher could more easily understand the student's problem. For example, when the student made the decision to take additional x-rays of the patient's teeth but needed approval from the teacher. However, the media tablets were perceived as a bit too big and clumsy for taking pictures.

> It's good to be able to send a picture. Then the teacher can look at the picture and make an assessment and reply about what is needed to be done even if she is somewhere else. (Student 2)

5.4 Theme 4: Challenges – Technical Problems Make Students Feel Uncertain

Even though the students and the teacher reported that the AR-glasses had facilitated faster and better communication, there were some challenges.

First, sometimes when a student sent a message to the teacher, it took longer than expected for the message to be delivered to the AR-glasses. These delays made the students feel uncertain and made them wonder if the teacher had gotten the message or not. Therefore, it was important that the teacher replied to the students as soon as a message was received.

> We had some trouble with the Wi-Fi, and if the teacher didn't respond right away I wasn't sure if she got the message or not. Sometimes there was a delay and it took a long time for the teacher to receive the message. That was a bit annoying. (Student 1)

Second, both the media tablets and the AR-glasses were in great need of a wireless network. When the signal fluctuated, the messages sometimes were not delivered. Sometimes the messages were not delivered even if the Wi-Fi was working properly, and the students mentioned that it was often easier to send messages via Google Hangout.

Another thing the students reflected on was how to keep the device clean and hygienic. Every time they needed to send a message, they had to remove their gloves, type the message, and then clean their hands and put their gloves on again. Therefore, they suggested that a device used for communication purposes in a dental clinic should be protected or wrapped in plastic in some way to keep it clean. Another possibility they mentioned was to use voice-controlled devices for everyone, both students and the teacher. However, in this project there were limitations to accessing AR-glasses for everyone.

Another challenge the students sometimes perceived as annoying was that it was impossible for them to know how many of the other students were in line waiting for help. This made it impossible to know the actual waiting time to get help from the teacher. Before, when they were writing the operatory number on the whiteboard, they saw just by looking at the whiteboard how many of the other students needed help. So, one design recommendation was to create a virtual whiteboard for the students to be able to get information about how many students there are in line.

Now with the Google Glass, when they were using electronic communication, they were also expecting the teacher to reply immediately even if she was in the middle of a conversation. When she did not answer right away, they felt a bit uncertain about what to do next and whether they should send the message again or just wait for her to come to their operatory. This can lead to the design recommendation to communicate that different expectations might occur.

5.5 Theme 5: Future Designs for Digital Workplace Learning

When looking into the future, both the students and the teacher saw several possibilities for using the system for developing new areas regarding information management, network management, and social elements. For a dentist it would be good to have access to notes while treating a patient or the possibility of taking notes via voice commands (information management, Design Element 1.2 in Table 1). It would also be easier to ask a colleague for advice just by sending a message or making a video call without leaving the patient alone in the room (communication support, Design Element 1.1 in Table 1). For dental education, the students mentioned that it would be good when a teacher could use the AR-glasses to record a demonstration and to project it onto a screen so it would be easier for them to see the demonstration and be able to discuss it (communication support and social elements, Design Element 1.1 and 2 in Table 1). The students also mentioned the possibility of using AR-glasses in surgery and either making a video call with Google Hangout during the surgery for synchronic teaching or recording during surgery so the students can watch the operation afterwards (communication support and social elements, Design Elements 1.1 and 2 in Table 1). Another possibility they mentioned was that it would be useful to have access to instructions in front of one's eyes while treating a patient (information management, Design Element 1.2 in Table 1).

6 Discussion and Implications

The results of this study point to challenges and problems, but also to advantages with the use of AR-glasses in the dental clinic. The implementation and exploration of how this type of technology can be used might have a meaningful impact on re-imagining and re-designing the transition between formal education and digital workplace learning. Table 2 connects the empirical data to the pedagogical-sociotechnical design as described above.

As described in Table 2, one advantage with AR-glasses is that they are voice-controlled and the dentist's hands are available to do other things while being online at the same time. This offers the opportunity for a teacher in dental education to perform ordinary activities using their hands and to communicate with students at the same time. This could be compared to what Jahnke and Koch (2009) described as *communication support* where learners are given the opportunity to communicate with others synchronously or asynchronously (Design Element 1.1 in Table 1 and Table 2).

Another advantage is that introducing technology that has not been used earlier helps to reflect on established working routines and supports the development of new didactical designs for teaching toward learner-centered approaches (the learner as prosumer). Jahnke et al. (2010) described these as *pedagogical elements.*

Table 2 Pedagogical-sociotechnical design connected with the empirical data

ID	Design of/for	Sub-category	Empirical data
1.1	Technology support	Communication support	Voice-controlled and hands-free wearables gave the opportunity to showcase solutions in real time and to communicate with learners at the same time
1.2	Technology support	Information management support	Future scenario: As designed in this study, AR-glasses did not help learners to collect or annotate problems and solutions; however, the user presented several ideas: Access to digital notes while treating a patient and the possibility to take notes via voice commands Record a live demonstration with AR-glasses and project it onto a screen Use of AR-glasses to make a live video call with Google Hangout during surgery to show students an operation Access to instructions as augmented information in front of one's eyes while treating a patient
1.3	Technology support	Network management support	Wi-Fi issues made it difficult to create social networks. Teachers/students needed quick technical support. Lack of support can mean that users will not adopt wearables. The design supported students in finding experts and teachers in order to receive immediate feedback, and it helped them to stay informed about on-going activities
2.1	Social relations	Roles	It took time to practice and become comfortable using wearables, and the user perceived it as time consuming. This runs risk that old routines will appear to be easier to stick to
2.2		From old to new work routines	The AR-glasses served as a mediator to reflect on existing practices and to develop new and meaningful learning practices. The AR-glasses helped to reflect on established working routines and supported the development of new teaching designs
3.1	Pedagogical elements	Process-based sharing of solutions, reflective feedback	The system's design encouraged students to share problems with the teacher during the process of treating patients and to try to find solutions via asynchronous communication support
3.2		Clear purpose, added value	The teacher and students needed to have a clear purpose and added value for AR-glasses in terms of how they would support or facilitate a specific learning activity. The teacher used the AR-glasses for communication purposes and created new feedback channels that were not available within previous learning settings

Depending on the design, the teaching method might encourage the workplace learner to share their reflections on the learning process and design solutions (Design Element 3 in Table 1 and Table 2).

A challenge that arose in this project was the Wi-Fi. Wearable technologies are in great need of wireless networks in order to work properly. Therefore, a long-term strategy for the infrastructure in higher education is very important. Teachers should be able to rely on the technology working well or at least have access to quick support so that they can design their teaching around the technology. A lack of support runs the risk that the teacher will choose not to use the technology. This could be seen as *network management* (Jahnke and Koch 2009) and is shown as Design Element 1.3 in Table 1 and Table 2. This means that teachers need to find experts (i.e., technology experts) and temporarily include them within the learning community. They need to be informed about on-going activities so that teachers are able to enhance the learning community with technology.

The results in this study also indicate that it takes time to practice and become comfortable using new types of technology (e.g., using voice commands on AR-glasses). This can be perceived as time consuming, and there is a risk that old routines will seem easier to stick to even if the teacher is experiencing the benefits of wearable and remote-controlled technology. A teacher needs to have a clear purpose for the use of the technology in terms of what it will support or facilitate in an activity when designing the teaching activity. A specific technology needs a clear benefit within a teaching and/or learning activity. Such a benefit might be that teachers or students see that learning can happen across established communication boundaries and can create new CrossActionSpaces. As this study demonstrated, workplace learners used such new communication and feedback channels that were not available within previous learning settings (Design Elements 2 and 3 in Table 1 and Table 2).

These issues and benefits illustrate that the future teacher might need to be more flexible and might have different solutions available when problems arise. The future teachers will be jugglers of different design elements – including social, didactical, and technical solutions. This is in line with what Goggins and Jahnke (2013) suggest, that there is a need to create and study new pedagogical and technological designs or re-designs. As the results show in this study, teaching support is desired in order to prepare teachers when bringing new forms of technology into existing working processes because such technology can generate the need to change old routines and/or adapt the working processes to new ways of working and new ways of designing teaching and learning in higher education. This is something that is not always easy to manage. Changing known routines or working processes can be perceived as very challenging, time consuming, and sometimes very stressful. This in turn, if technical support is not offered, can lead to holding on to old routines even if improved routines with better effects are obtainable with the support of technology.

Figure 3 is our suggested pedagogical-sociotechnical design for meaningful digital workplace learning with AR-glasses. We assume it can be used for other wearables too. From our study with dental students, we learned that AR-glasses are a

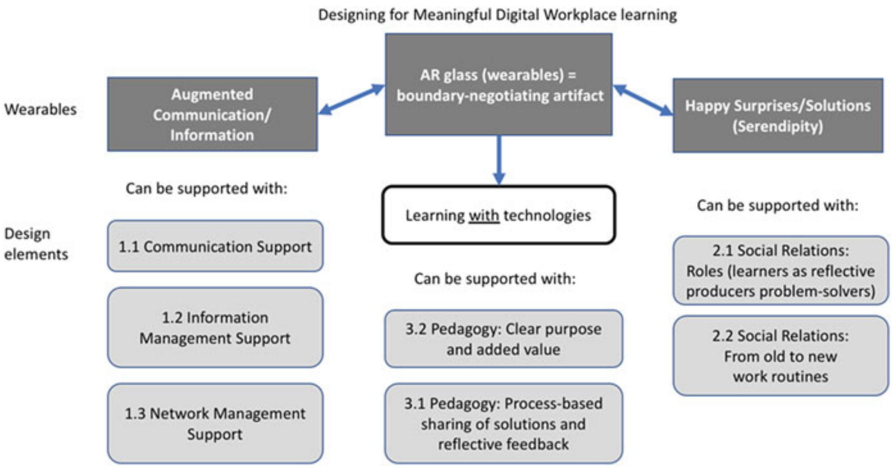

Fig. 3 Pedagogical-sociotechnical design for meaningful digital workplace learning with AR-glasses

boundary object between, on the one side, augmented communication or augmented information, and on the other side, serendipity, happy surprises, and unexpected solutions for learners who are trying to find a solution to a workplace-related problem in order to carry out their job. The figure also includes how augmented communication and happy surprises can be supported with different pedagogical or sociotechnical design elements (1.1–3.2), which are described in detail in Table 2.

7 Conclusion

The findings presented here reveal a richness of both challenges and advantages using wearable technology such as AR-glasses in higher education. The adoption of AR-glasses provides beneficial communication support between workplace learners in a dentistry program in a new way. This might support learning and lead to different digital designs for meaningful learning. However, it is still a surprise that it is not possible to rely on wireless networks working properly. In this case, there is a risk for teachers or students being unwilling to develop new teaching or learning methods using these technologies.

An overall discussion about the integration of web-enabled technology, or information and communication technology, in the transition between higher education and workplace learning in the long run is urgently needed for developing and preparing higher education and students for the future. Although this is an old demand, we argue here that the technology alone should not be at the center of the discussion. The different concepts that, for example, Goggins and Jahnke (2013) highlight might be useful when incorporating new technology and for showing how such technology supports or hinders learning. Based on this study, and our results from other studies, we argue that taking different aspects into consideration, e.g., social, pedagogical, and technical issues, is necessary and that teacher support is required for unexpected problems that might arise when designing lessons and preparing for future education using wearables.

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Part VII
Synopsis

The Bigger Picture

John Traxler

1 Introductory Remarks

All of the topics in this chapter form a contextual and critical framework for wearables and learning and drive questions about equity, innovation, sustainability and education but are written from the perspective of a generalist outsider aware of the capacity of education and of technology for good or ill. So, approach the following remarks with caution, and adapt and adopt only the ones that seem to work. I am very conscious and fairly critical of the history, priorities and trajectory of mobile learning and its research community, so I come at the wearables research community, if there is now such a thing, with baggage, perhaps insights and perhaps prejudices but mostly as an outsider. To be more specific, my history over the last two decades has been—apparently, not my words—that of a pioneer and thought leader in mobile learning but one increasingly disturbed by its research community's inability to adapt to the evolving impact and significance of mobiles across our societies. So, the following remarks may be variously highly insightful and stimulating critical thought or completely irrelevant, wholly inaccurate and stimulating dismissive disregard.

2 Trends and Fashions

Starting with the more tractable topic, it is easy to identify a handful of emerging *edtech* trends in formal education, such as micro-learning (Job and Ogalo 2012),

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learning analytics (Siemens and Long 2011), the flipped classroom (Bishop and Verleger 2013), open educational resources (OER) (Butcher 2015; Atkins et al. 2007), mobile learning (Traxler and Kukulska-Hulme 2015), augmented reality (Wu et al. 2013; Lee 2012), virtual reality (Christou 2010; Allison and Hodges 2000; Javidi 1999), massive open online courses (MOOCs) (initially pedagogies but now mostly platforms) (Conole 2014) and maybe other or more recent ones, and put these alongside established trends and players such as the virtual learning environment (VLE) (e.g. Canvas, Blackboard or Moodle), plagiarism detection and lecture capture. We must then ask whether learning with wearables should compete, combine, co-opt or collaborate with these, whether there is synergy or overlap in the race for resources and research, whether all their various underlying pedagogies are compatible and complementary or whether these pedagogies make them profoundly different. This of course assumes that somehow specific pedagogies are hardwired into specific technologies, but having seen most of the world's ostensibly social constructivist VLEs used as repositories for slide decks and handouts, this is probably not the case.

These questions are however not purely academic or pedagogic since universities, schools, colleges and research institutes continue to operate within the wider economic, social, cultural and political environments.

Amongst other pressures, they must, for example, respond to the call for 'job-ready' graduates whilst also responding to calls for 'lifelong learning' (Atkins 1999). In the current context of wearable technologies, this tension may mirror or echo a wider one between, respectively, specific concrete IT skills and overarching digital literacy.

There is however also an underlying tension in looking at all such trends and fashions, namely, do they reform and reinforce the established institutions, professions, curricular and vested interests of formal education or is their status, visibility and application outside these established entities in empowering users' cognitive lives such as to challenge these established entities? To put it another way, do these trends or fashions represent opportunities to create, shape and share learning as well as to consume it? And can users appropriate these technologies to create new forms of knowledge and learning (Lai 2011)?

In answering these questions, we must be aware that there is ostensibly a benign argument, copied from the rhetoric of the mobile learning research community, that wearables promote the liberation of learning from the classroom, the campus and the textbook, experiencing the contingent mess of reality instead of the sanitised and managed version presented on campus by teachers. (There is almost the possibility that these two alternatives faintly capture concepts that might be called *modern learning* and *postmodern learning*—a proposition that it might be interesting to explore.)

Wearables, in this context, may actually be tethering rather than liberating (Traxler 2011; Cecchinato and Cox 2017), just as mobiles are, tying learners back to old forms and formulations. By this we mean, the ways in which these technologies seem to free learners from physical presence, on campus, for example, but actually managing and monitoring them remotely, subject still to the earlier hierarchies and relations.

This is complicated by the argument that wearables, even more than mobiles, are becoming prosthetic, embodied, *part of us*, only more so (Koefoed Hansen and Kozel 2007; Cranny-Francis 2008). Do we want the education system to be *part of us*? Maybe not.

Moreover, arguing that learning with wearables enables contextual, personalised or spontaneous learning only works when contrasted with the non-contextual, impersonalised and scheduled learning often experienced within formal education and its institutions. If users with wearables are their own or each other's teachers, even if *or especially if* they do not even conceptualise it in that way or do not see the activities as teaching and learning, this argument is rendered null—there is nothing to contextualise or personalise learning *from.* Perhaps this, the union of the personal and the digital, is the pretext for a radical reconsideration of the relationships between education and society, for *deschooling* and starting again (Illich 1973; Selwyn 2012).

Wearables insert a powerful new variable across the whole spectrum of learning. Whilst we can identify the constraints and incentives that might drive this in the case of formal learning, beyond this we have a variety of definitions, such as informal learning, non-formal learning, incidental learning and self-directed learning, that must strive to capture the breadth of possibilities (Schugurensky 2000; Malcolm et al. 2003). One line of thought has documented and analysed the 'learning projects' of individuals (Tough 1979), namely, those significant events of self-directed learning in the lives of adults; and this might offer a way forward by working from the bottom-up, in terms of activities, rather than top-down, in terms of definitions. It does make learning both pervasive and trivial whilst constraining it to knowledge acquisition rather than knowledge discussion—and that would also be true of micro-learning (Bruck et al. 2012). Wearables, as another connection to people, context and the environment, might however provide extra and random stimuli that could provoke reflection and thought. Perhaps it is far too early to predict the impact of wearables on any learning outside the formal and only experience, and evidence will eventually underpin new understandings.

And this takes us to a different perspective, that is, the place of wearables in a world outside formal education where personal and social digital technologies enable people and communities to produce, share, discuss, transform and discard ideas, information, images and opinions, learning from each other and the environment, learning in groups, in communities and in isolation. This not only challenges formal education but also places wearables, being personal and physical, in some kind of relationship with the Internet of things (IOT). Suddenly the world becomes a richer and more informative place, and the possibilities explode. We are obviously only at the beginning of the beginning in this respect.

3 Wearables and the Global Education Context

Wearables are, of course, at the mercy, perhaps like many innovations in educational technology, of political and economic ideologies and resources.

Since the sub-prime mortgage crisis in 2008 in the USA and its global consequences, there has been less money and more caution in both the public and private sectors, accompanied by a trend in Western Europe and the USA away from statist centre-left ideologies to neo-liberal centre-right ideologies (Altbach et al. 2009; Ball 2012). Consequently, universities globally have become more corporate and more competitive. So, wearables in education are players in this analysis and we have to ask about their value and role. Do they represent components in corporate image-building, something to feature on institutional web sites? Do they have a role in the various league tables and key performance indicators? Does the ostensible mission of each institution affect how wearables are presented and packaged in the corporate context? As part of the educational support within elite academic institutions, as part of the cutting-edge agenda for research-intensives and as part of a challenging social issue for those institutions with an inclusion, opportunity and participation mission. And how will the educational wearables community access research funding? Curiosity-driven theory-building, improved academic efficiency, external corporate sponsorship or cost-effective innovation in the hope of increased equity and social inclusion (Martin and Etzkowitz 2000)?

Clearly, researchers in educational wearable technology must position themselves astutely in the competitive market for research funding and institutional recognition. They must however also recognise the limitations of any research ethics process, for example, unfamiliarity with the possibilities of emotional or psychological harm and the potential of emerging technologies (Carusi and De Grandis 2012).

Another trend that is potentially undermining the historical understanding of the purpose of education in Western Europe and the USA (Biesta 2009) has been the ongoing ‘hollowing out of the labour market’ (McIntosh 2013), whereby those middling jobs between road sweeper and brain surgeon are progressively disappearing due to the general progress of digital technologies. This is accelerating due to the specific technologies of robotics, artificial intelligence (AI), the Internet of things (IoT) and performance support (Smith and Anderson 2014). This erodes the possibility of social mobility and erodes the role of education in delivering social mobility. Discussing education for unemployment is not politically palatable, so many education systems continue to pursue an unrealistic employment agenda and might promote learning with wearables within that agenda.

What also erodes the purpose of education, or rather the authority and relevance of formal education in the traditional institutions of education, is the universality of personal digital technologies that allow access to all the online content and communities of cyberspace and allow individuals and communities to create, share, transform, discuss and discard ideas, images and information whenever, wherever they like. Post-truth and fake news may be the downside of self-directed learning, symptomatic of a widespread slide into some kind of postmodernity. Obviously, the educational exploitation of wearable technology represents only a small corner of this change and turmoil, but one can ask whether learning with wearable technologies is not just personalised and individualised but also pathologically individualistic, contributing to separation, isolation and solipsism, the ‘quantified self’ (Swan 2012; Gilmore 2016; Lee 2013) as part of the ‘neo-liberal nightmare’, specifically that part representing unrestrained individual choice (Flew 2014). Moral panics have influenced earlier initiatives in technology and educational technology and will no doubt continue to do so (Goggin 2006) but now resonate with the changed zeitgeist (Aupers 2012).

In this shorter section, we should ask about the possible place of learning with wearables in education outside in what is becoming an increasingly homogeneous global higher education culture (Burbules and Torres 2013). It is most likely however that the same economic, social and political forces that are driving this increase and this homogeneity are also driving the development of learning with wearables, meaning that inside this is where development, deployment and research will happen and not much outside, except perhaps in the equally well-resourced environments of global corporates and businesses, delivering corporate training and performance support.

4 Wearables, Complicity and Crisis

Whilst the issues of educational technology in the context of various types of global crises may seem abstract and obtuse (Traxler and Lally 2015), there are obvious questions around involvement with military, pharmaceutical, automotive, political, corporate or security sponsorship or applications, not that these are intrinsically harmful connections but certainly they are morally complex and practically unpredictable in their implications and outcomes. These are however easy examples, and the more philosophical question is about the role of education and of technology and thus of educational technology. There is almost a default modernist liberal assumption that education and technology and certainly educational technology are unconditionally benign but they are clearly not. A more critical assumption might be that they serve someone’s interests, usually those of the powerful and the hegemonic. This assumption at least prompts us to explore each educational technology and each intervention and ask, ‘who?’, ‘how?’ With wearables, like so many other examples, the answer is not simple or clear or consistent or stable. We must hope that there is some political will for policy priorities and public resources that exploit wearable technologies within education to improve equity and social justice, for example, in the interests of people with disabilities and disadvantages and in the face of interests that maximise corporate profit or economic advantage. Cindy L. Anderson and Kevin M. Anderson discuss ‘Wearable Technology: Meeting the Needs of Individuals with Disabilities and Its Applications to Education’.

It is certainly imperative to explore any new educational technology and ask whether it amplifies, reduces, transforms or complicates existing digital divides and social or economic inequality (Van Dijk 2006).

Of course, appropriation takes place, and this works in both directions. People and communities adopt and appropriate technologies and systems away from the purposes designed into them by corporations and states, for example, very consciously, the maker movement developing its own wearables (Peppler and Bender 2013; Charlton and Poslad 2016; Kafai et al. 2014), and the reverse also happens, namely, corporations and formal institutions co-opting popular and demotic forms. And there is serendipity. No one expected the NASA space programme to produce Teflon, and 3 M were not trying to produce Post-Its (Krols 2012), thereby making any moral or political analysis less straightforward. Furthermore, 'unexpected consequences' commonly describe the outcomes of (educational) interventions in international development but should probably describe the outcomes of (educational) interventions in almost any social context or any social science (Sutcliffe 2011). All of these issues form the ethical context of wearables in education and educational research.

5 Concluding Remarks

The purpose of this contribution was, to use the English expression, *to set hares running*, not to catch or ensnare them. The subject of wearable technologies in education, like many other innovations or possibilities in educational technology, acts a provocation and a proxy for so many other wider concerns, and we hope that this contribution illustrates what some of them might be and that the other individual contributions can be read and considered in this light (Selwyn 2013).

To finish back on a personal note, in my view the mobile learning, quote/unquote, community is struggling for meaning, significance and impact, stuck in pre-2008 modalities, a ripple that's ignoring the tsunami; it should have looked forwards and outwards, not inwards and backwards. My hope is that these reflections avert something similar in the educational wearables research community. If there are specific lessons in this analysis, they might be something like'stay open, be critical, keep moving, but mostly, improve people's lives by engaging with people's lives'.

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