

# Cyber Taxi: A Taxonomy of Interactive Cyber Training and Education Systems

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**Abstract.** The lack of guided exercises and practical opportunities to learn about cybersecurity in a practical way makes it difficult for security experts to improve their proficiency. Capture the Flag events and Cyber Ranges are ideal for cybersecurity training. Thereby, the participants usually compete in teams against each other, or have to defend themselves in a specific scenario. As organizers of yearly events, we present a taxonomy for interactive cyber training and education. The proposed taxonomy includes different factors of the technical setup, audience, training environment, and training setup. By the comprehensive taxonomy, different aspects of interactive training are considered. This can help trainings to improve and to be established successfully. The provided taxonomy is extendable and can be used in further application areas as research on new security technologies.

**Keywords:** Capture the flag · Cyber Range · Cybersecurity · Cyber Defence · Cyber Education.

## 1 INTRODUCTION

With increasing digitalization and the integration of computers into the daily life, the number of threats is also rising. The amount of sophisticated attacks is increasing every year and poses a challenge in terms of efficient detection and countermeasures. At the same time, the required technical knowledge of an intruder decreases with the development of more automated tools [27, 6]. The defence against these attacks is based on the continuous use and monitoring of security tools. Well-trained personnel is required for this. However, current statistics show a global shortage of approximately four million information security professionals [17]. In recent years, many different training systems have been developed with focus on cybersecurity. Companies have emerged offering new certifications and universities are developing cybersecurity degree programs. Interactive training systems are further approaches that follow our motivation

as cybersecurity trainers: Theoretical knowledge is good, practical proficiency is better. These systems utilize gamification and playful scenarios to train participants in specific topics [1].

Interactive training systems offer the opportunity of real-time feedback and specific education. The focus is on instructing the participants with an efficient method and the desirable knowledge. These systems create awareness for security threats and the resulting impact in real life. In order to provide an overview of a large range of practical possibilities, we present a taxonomy to structure interactive cyber training and education. This overview allows universities, companies, and other institutions to

- identify gaps in their training system.
- improve existing training systems and intensify the training.
- provide a guideline for establishing new training possibilities.

The taxonomy includes surrounding aspects, e.g., training of teamwork, communication capabilities as well as reporting processes. As far as we know, there is no holistic taxonomy for practical and interactive cyber training and education. Such a taxonomy is mandatory to support education, structure the entire area, and accelerate further research. It enables a comprehensive evaluation of interactive training systems and the visualization of the requirements gap.

The paper is structured as follows: Section 2 establishes the requirements for a taxonomy. In the following section, we briefly discuss related approaches with their advantages and disadvantages. In Section 4, we describe our taxonomy in detail. Afterwards, we classify other examples with our taxonomy and show the practical benefit. Beside this, we discuss the presented aspects on our case study. Finally, we conclude the paper and give future directions.

## 2 DEFINITION OF TERMS AND REQUIREMENTS

We define *Interactive Cyber Training and Education* (ICTE) as follows:

**Definition:** ICTE is a comprehensive set of hands-on approaches in a secure and observable environment that enables participants to become engaged in learning and practice their cyber skills and to acquire new skills.

For a better understanding of the following taxonomy, a common basis of definition is mandatory. In general, a taxonomy structures a knowledge field to provide an overview about a specific area and its possibilities. It divides the topic hierarchical into main groups and subcategories. A taxonomy should focus on the following, ideal properties [24, 26]:

- The categories have to be mutually exclusive, i.e., no overlapping between the categories.
- Clear and unambiguous classification criteria.
- Comprehensible and useful as well as comply with established terminology.

Beside the requirements for the taxonomy of ICTE, there are the following demands on systems:

- What are the optimal approaches and motivation for developing new cyber skills?
- What skills and competencies in security are required to move to a more proactive position?
- Which kind of training system requires which functionalities and possibilities?
- What changes in terms of process, technology, and staff are required in the operational environment to support new abilities?
- What are the business objectives and strategic goals of an organization from a security point of view?

Furthermore, there are the following assessment criteria to further evaluate a classified training system. These criteria follow the National Institute of Standards and Technology (NIST) [31], which developed the cybersecurity workforce framework for the National Initiative for Cybersecurity Education (NICE). The requirements are tantamount to the ISO/IEC 25010 [19] and ISO 9126 [18] standards, which focus more on system and software quality properties. These are also valid to our scenario.

- **Functional Completeness:** The degree of realization to cover all the specified tasks and user objectives.
- **Functional Correctness:** The degree to which the cyber training system provides the correct and reproducible results with the needed degree of precision.
- **Learnability:** Efficiency to achieve the specified goal of learning individual and as cooperative team.
- **Operability:** The difficulty to run the training.
- **Accessibility:** Amount of expertise to be successful in a scenario.
- **Adaptability:** The degree to customize the scenarios to the expertise of the participants.
- **Portability:** The degree to transfer scenarios from an education system to another.
- **Maintainability:** Difficulty to operate the system and to fulfill a training session.
- **Modularity:** Possibility to adapt and extend the system to current needs.

### 3 RELATED WORK

Several different taxonomies were developed, e.g., taxonomies for *Computer System Attack Classification* [2, 32, 29, 51, 23, 47, 14]. These list a comprehensive set of attacks and focus on a structural overview of attacks. Jouini et al. [21] classify security threats in information systems by threat source, agent, motivation,

intention, and impact. Easttom and Butler [12] describe a taxonomy of cyber attacks based on a modified McCumber cubes. Amongst others, they classify the categories transmission, storage, technology, policy and practices, education, training, and awareness. Simmons et al. [39] propose a taxonomy of cyber attacks called AVOIDIT, classifying attack vector, operational impact, defence, informational impact, and target. All these taxonomies can be used to develop security challenges, such that a wide spectrum of knowledge is necessary to solve them.

Different approaches focus on *Cyber Range Training*. ECSO explains cyber ranges in their WG5 Paper [13], but neither a definition nor a taxonomy is given. Priyadarshini [34] analyses and classifies existing cyber ranges based on infrastructure association, cloud usage, teams, and deployment. Other aspects are left out. Yamin et al. [52] build a taxonomy based on literature review. The taxonomy includes scenarios, monitoring, learning, management, teaming, and environment. Based on the taxonomy the authors describe several tools used within cyber ranges. The taxonomy is specific for cyber ranges and does not take target audience, proficiency level, and scoring, amongst others, into account.

Several papers describe *Cybersecurity Exercises*. INCIBE [11] analyses cyber exercises and builds a short taxonomy based on the factors focus, model, vertical sector, scope for participation, and dissemination of results. It has a rough structure and a high level focus. The perspective is only for coverage of subject areas and educational view. Beyer and Brummel [4] describe different factors for effective cybersecurity training. Kick [22] depicts playbooks in detail. Others analyze different environments for cyber training [42, 44, 48, 3, 28]. Different papers relate to aspects of gamification, serious games, and education [43, 20, 45, 25]. As a result, a holistic taxonomy for the management and organization of ICTE is missing.

## 4 TAXONOMY

Within this Section, our taxonomy for ICTE and its components is described in detail. Figure 1 provides an overview about the taxonomy. During the design, attention was paid to the complete coverage of all necessary capabilities with regard to the cyber exercise life cycle [22] and training competencies [31].

### 4.1 Technical Setup

The technical setup consists of environment structure, deployment, and orchestration. These are described in detail in the following.

**Environment Structure:** The environment structure refers to the basic characteristic of the event. This characteristic is composed of the following sub-characteristics:

- **Tabletop Style:** A session that involves the movement of counters or other objects round a board or on a flat surface.

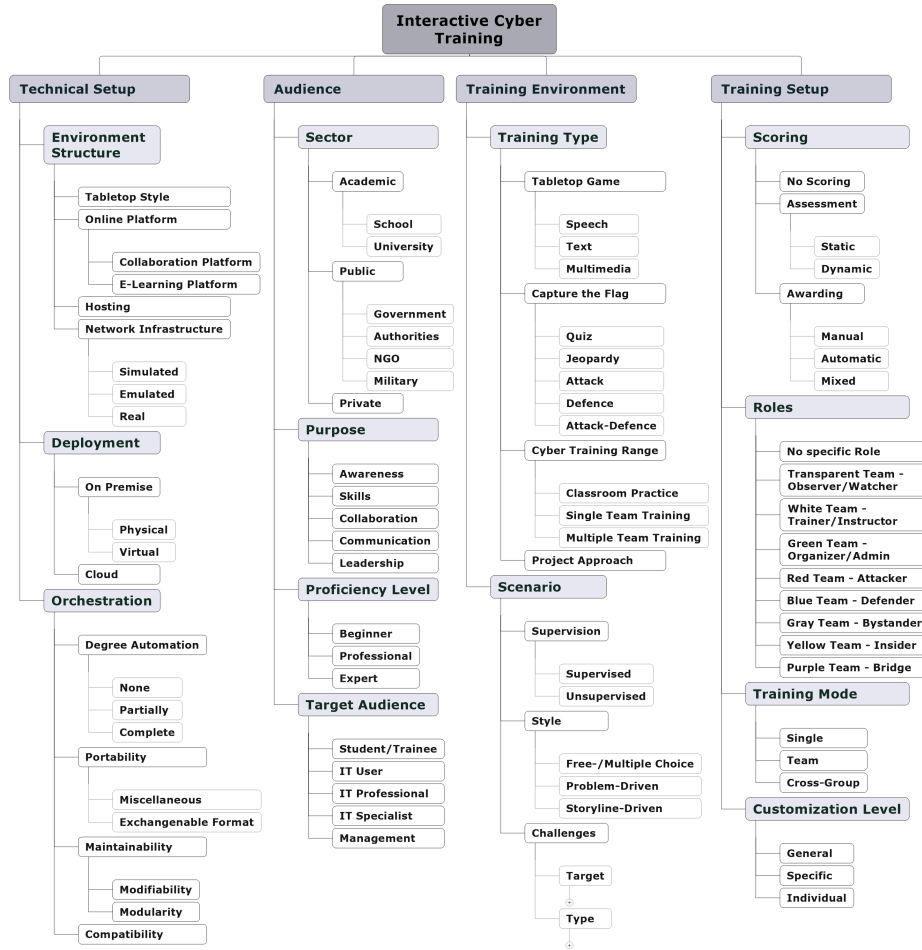


Fig. 1. Taxonomy of Interactive Cyber Training and Education Systems

- **Online Platform:** The digital service describes a wide range of interactive possibilities available on the internet including marketplaces, search engines, social media, creative content outlets, app stores, communications services, payment systems, services comprising the collaborative economy.
  - **Collaboration Platform:** The environment allows organizations to incorporate real-time communication capabilities and providing remote access to other systems. This includes the exchange of files and messages in text, audio, and video formats between different computers or users.
  - **E-Learning Platform:** A software application for the administration, documentation, tracking, reporting, and delivery of educational courses, training programs, or learning and development programs.

- **Hosting:** A cyber training based on single hosts uses primarily a personal computer to providing tasks and challenges for a user. It allows a direct interaction with the systems.
- **Network Infrastructure:** Dependent of the realization type - simulated, emulated, or real - a network-based environment consists of servers and clients, which are connected to each other in a local area network (LAN) or wide area network (WAN).
  - **Real:** Physical components are used to connect the systems and to setup a scenario.
  - **Simulated:** A simulation copies the network components from the real world into a virtual environment. It provides an idea about how something works. It simulates the basic behavior but does not necessarily abide to all the rules of the real systems.
  - **Emulated:** An emulator duplicates things exactly as they exist in real life. The emulation is effectively a complete imitation of the real thing. It operates in a virtual environment instead of the real world.

**Deployment:** The environment of cyber training can either be deployed on premise or on cloud infrastructures, as shown in the following.

- **On Premise:** The environment for the training can either run on physical or virtual machines. Either way, the data is stored locally and not on cloud; nor is a third party involved. The benefit of virtual machines is the maximum of configurability. The advantages of on premise solutions are the physical accessibility, which makes it possible to use the complete range of cyber challenges.
- **Cloud:** A training setup deployed in the cloud has on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. In contrast to on premise setups, cloud solutions are rapid elastic on request. So the training can be adapted flexible on a large amount of users and is easily usable world wide.

**Orchestration:** We understand orchestration as the composition of parts and components of a pool of tasks. The goal is to setup a holistic scenario and integrate cyber training session. Furthermore, it includes a declarative description of the overall process in the form of a composite and harmonic collaboration. A system typically exists of functions, processes, and data. It provides a common service embedded in an environment for the specified purpose. Beside this, orchestration has also a strong relation to the deployment strategy and the customization possibilities. Well known approaches are tools like Chef [7], Puppet [35], Ansible [37], and SaltStack [38].

A flexible concept for orchestration and maintainability is important for the administration of the cyber training system. Especially, the possibility of a fast troubleshooting in case of live events is mandatory. Nevertheless, it also has an impact on the participants in relation to user experience and quality of service in providing a training with adequate atmosphere.

The criterion orchestration is further divided in the degree of process automation, portability, maintainability, and compatibility.

- **Automation:** It specifies the automation of processes and the amount of human interaction with the system to maintain and administrate, especially for repetitive exercise. Subclasses for automation are non-automation, partially-automation, and full-automation.
- **Portability:** The possibility to exchange data, challenges, or entire scenarios to other environments or locations. The portability can be separated in miscellaneous approaches and the usage of common data format for exchange like YAML, Extensible Markup Language (XML), and JavaScript Object Notation (JSON) [41, 16]. The objective of future research direction is an exchange format for entire cyber scenarios to flexible deploy these in different environments and locations.
- **Maintainability:** Maintainability represents effectiveness and efficiency with which a session can be modified or adapted to changes. A modular concept has advantages in reusability and combinability.
- **Compatibility:** The Compatibility deals with the technical interaction possibilities via interfaces to other applications, data, and protocols.

## 4.2 Audience

The target of cyber training and education is the audience, which is further characterized in the following. The audience has the characteristics sector, purpose, proficiency level, and target audience.

**Sector:** The sector from which the audience comes determines the nature of the training. The following categories can be distinguished [5, 8].

- **Academic:** This includes universities and schools. The focus is on the principles underlying cybersecurity, ranging from theoretical to applied.
- **Private:** The private sector and industry focuses more on protecting its investments. The effectiveness of security mechanisms and people are more important than principles they embody.
- **Public:** This includes amongst others Government, NGO, and Military. Cybersecurity is seen as tool to protect the public interest. Hence, it emphasizes on developing policies and systems to implement laws and regulations.

**Purpose:** Purpose answered the question for which reason trainings should be used. Training can address different objectives which are listed in the following.

- **Awareness:** To raise the awareness in multiple and different security threats.
- **Skill:** To recognize the different skill levels of the participants so that can they be improved in a targeted manner.
- **Collaboration:** To improve the cooperation within a team or beyond.
- **Communication:** To increase the efficiency of internal and external communication in case of an incident.
- **Leadership:** To improve the management and coordination of the responsible entities.

**Proficiency Level:** Proficiency describes the knowledge of users and what they are able to do. The proficiency is grouped into three different levels.

- **Beginner:** The lowest level. Beginner are limited in abilities and knowledge. They have the possibility to use foundational conceptual and procedural knowledge in a controlled and limited environment. Beginners cannot solve critical tasks and need significant supervision. They are able to perform daily processing tasks. The focus is on learning.
- **Professional:** The mid level. Professionals have deeper knowledge and understanding in specific sectors. For these sectors they are able to complete tasks as requested. Sometimes supervision is needed but usually they perform independently. The focus is on enhancing and applying existing knowledge.
- **Expert:** The highest level. Experts have deeper knowledge and understanding in different sectors. They complete tasks self-dependent and have the possibilities to achieve goals in the most effective and efficient way. Experts have comprehensive understanding and abilities to lead and train others. The focus is on strategic action.

**Target Audience:** Target audience describes the audience, which is targeted by the training. This can be condensed to the following.

- **Student/Trainee:** Student and trainees have little to none practical knowledge. Training can be used for students and trainees, to enhance their knowledge and to practice theoretical courses, see [43, 20, 45, 25].
- **IT User:** IT users use the IT but have little to none knowledge about IT security. Users can get trained to understand principles of IT security and to grow awareness.
- **IT Professional:** Professionals have little to medium knowledge about IT security. Their professional focus is in specific sectors, therefore, they receive IT security knowledge for their sectors.
- **IT Specialist:** Specialists already have a comprehensive knowledge in IT security. Therefore, the training is focussed on specific aspects.
- **Management:** Management has little knowledge about IT security, but a broad overview. By the training, management can understand changed settings better.

### 4.3 Training Environment

The training environment details the environment around the training, consisting of training type and scenario. Both characteristics are described in the following.

**Training Type:** Education in cybersecurity follows different approaches [53]. The level of interaction and hands-on experience distinguishes different types of training. For interactive cyber training, the following training types exist.



- **Table Top:** This type is a lightweight, but intellectually intense exercise. In this setting, the involved teams or participants focus on opposing missions. On a theoretical basis, the teams develop different strategies and countermeasures to explore the offensive cyber effects on operations. Table top trainings could be based on speech-only, text-only, or multimedia [46, 22].
- **Project Approach:** In this type of training, hands-on projects are to be completed during the training. Thereby, the participants learn and understand the basic concepts of security. During the projects, the teachers can intervene and control the learning process [53].
- **Capture the Flag:** Capture the Flag (CTF) is a well-known cybersecurity contest in which participants compete in real-time. Several distinct kinds of CTF have evolved in the recent years, including quiz, jeopardy, attack-only, defence-only, and attack-defence [9].
- **Cyber Training Range:** A cyber range provides an environment to practice network operation skills. It should represent real-world scenarios and offer isolation from other networks to contain malicious activity. In this training type, complex attacks take place in a simulated environment. The participants perform diverse educational hands-on activities according to their role. Possible trainings are classroom practice, single team, and multiple team trainings. In these trainings the roles that are not covered by participants are simulated or covered by the instructors [10, 48].

**Scenario:** The scenario is a main component of cybersecurity training. Scenarios are needed to reach the goal of the training and are described by the following characteristics.

- **Supervision:** Either the training is supervised or unsupervised. Cyber range trainings are typically supervised, while jeopardy CTFs are unsupervised.
- **Style:** The style describes how the different challenges within the training are setup. Free-/Multi Choice can be the case with CTFs. Other directions are problem-driven and storyline-driven, if the challenges are arranged around a problem or a central storyline.
- **Challenges:** The challenges are the content of the training. These are defined by target and type. The target of the training can be a network, host, application, protocol, data, person, or physical. For solving the challenge types, foot-printing, scanning, enumeration, exploitation, pivoting, privilege escalation, covering tracks, and maintaining access may be needed. Souissi [40] and Lehto [25] use similar characterisations for attacks respectively competence areas.

#### 4.4 Training Setup

The training setup further describes the training itself with the scoring, roles, the training mode as well as the customization level.

**Scoring:** Scoring is an important component of a cyber training. Depending on the purpose of the training, the scoring provides means to motivate the participants and a way to give feedback. It is also used to track the progress during a training. For competition-oriented trainings, like CTFs, a scoring is necessary. The scoring can be based, but is not limited to monitoring systems, defined objectives, or over-the-shoulder evaluation mechanisms.

- **Awarding:** In this variant of scoring, participants get awards for predefined actions or achievements. These awards can be granted both manually and automatically. Furthermore, a mixed approach is possible, e.g., by automatically giving awards for general objectives and manually giving awards for outstanding achievements. In general, awarding has a lower granularity than the detailed assessment and requires less administrative effort, but gives reasonable feedback and motivation for the participants.
- **Assessment:** This scoring variant is more complex than awarding and allows to assess participants and compare them to each other. The assessment scores can be assigned in different ways. One type is the static setting of different scores for tasks and objectives. In order to distinguish it from awarding, the degree of difficulty can be included here. Furthermore, the scores for different tasks can be set dynamically using mathematical functions. But also other dynamic methods, such as the Elo Rating System [33], are covered by this variant.
- **No Scoring:** Depending on the training, a scoring is not necessarily needed.

**Roles:** Participants in a training are split in different teams, according to their skills, role, and tasks during a training. For the identification, each team has a color assigned based on its role. The following teams are commonly used in cyber trainings and exercises [22, 49].

- **Green Team:** The operators that are responsible for the exercise infrastructure build this team. Before a training, this team sets up and configures the environment and takes it down afterwards. During a training, it also monitors the environments health and handles problems that may arise.
- **White Team:** This team consists of instructors, referees, organizers, and training managers. They design the training scenario including objectives, rules, background story, and tasks. During the training, this team controls the progress and assigns tasks to the teams. These so-called *injects* also include simulated media, operation coordination, or law enforcement agencies. Giving hints for the training teams could also be part of this team.
- **Red Team:** This team consists of people authorized and organized to model security adversaries. They are responsible to identify and exploit potential vulnerabilities present in the training environment. Depending on the training environment, the tasks can follow a predefined attack path.
- **Blue Team:** The group of individuals that is responsible for defending the training environment. They deal with the red team’s attacks and secure the compromised networks. Guidelines for that team are the training rules and local cyber law.

Additionally, there are further roles involved in training, which are summarized in the following teams [50, 52].

- **Transparent Team:** Members of this team observe the training. Usually, these people have a defined purpose, but have no influence on the training itself. Possible purposes are learning about the training topic and roles, studying strategies of participants, or supervising employees.
- **Yellow Team:** Members of this team perform not only tasks like generating legitimate network traffic and user behavior but also perform erroneous actions that lead to vulnerabilities and attacks. This team can also include the regular system builders, like programmers, developers, and software engineers and architects.
- **Purple Team:** In a training, this team is a bridge between red and blue teams that helps to improve the performance of both. Through joint red-blue activities it improves the scope of the training participants. Goals are to maximize the Blue Teams capability and the effectiveness of Red Teams activities.
- **Gray Team:** Bystanders of a training form this team. They do not necessarily have a specific intention or purpose, but an interest in the training event itself. It is also possible that this team interacts with participants and thereby unintentionally influences the training.
- **No specific role:** Individuals who do not fit into the defined teams can be assigned to this role.

According to [50], the orange team completes the so called Color Wheel. This team is of special importance in a holistic system development process.

**Training Mode:** Training mode defines the mode in which the training is accomplished. The training mode has three different alignments.

- **Single:** A single player plays against others. Others can be real persons, but also scripted opponents.
- **Team:** A team plays against others. In this alignments, each player can bring its expertise into the training, focussing on different aspects. Examples are Blue and Red Teams.
- **Group:** A group plays against others. In this setting, the group members might not know each other. Example are CTF competitions and training for the entire organization in a breach scenario.

**Customization Level:** Depending on the goal of the training, the training setup can be customized. A distinction is made here between three variants.

- **General:** A general purpose training setup is not, or only little customized. This variant is suited for an entry level training or to learn about general processes without regard to the underlying setup.

- **Specific:** The training setup can be customized for a specific training goal or target audience. Examples for this variant are specific trainings within the High School education [15] or for the health sector [36].
- **Individual:** The most tailored variant is an individual customization. Hereby, the training setup corresponds to a real environment in the best possible way. Exemplary uses of this variant are the training of teams in their environment or the training of new expert-level employees.

## 5 EXAMPLES AND CASE STUDIES OF CYBER TRAINING AND EDUCATION SYSTEMS

A tailored modification of a CTF for educational purposes is described by [28], named Class CTF (CCTF). The idea behind this approach is to maximize the learning outcome and minimize the time spent for a CTF event. They observed a higher motivation of their students helping each other solving the challenges. Also much more interest in learning and practicing skills during hands-on exercises was noticed. This seems to be a usual behavior if changing the learning setup to more hands-on exercises. Nevertheless, this approach can be categorized in our taxonomy as follows: The training setup is based on Red and Blue team roles. To give all participants the same chances, the presented scoring is based on fixed solutions for every challenge and, therefore, static. CCTFs follow a team based approach and are designed for students in universities to improve their skills and foster communication and collaboration abilities. The proficiency level starts from beginner level and can evolve during a series of CCTFs.

The presented taxonomy progressed during our own Capture the Flag experiences. Whereas this taxonomy was very basic during the first phase of our initial CTF in 2015, it evolved further during the next events. Table 2 summarizes our past events with some details. In the next section, our CTFs are categorized based on the taxonomy. This is followed by our experiences during the organization of various CTF events.

Year	Title	Duration	Teams	Attendees	Challenges	Tracks
2015	The Beginning	9 h	11	31	34 + 1 Easteregg	Beginner, Advanced
2016	A New Hope	8 h	14	49	18 + 2 Eastereggs	Beginner, Advanced, Professional
2017	24: The Revolution	24 h	18	69	48 + 2 Eastereggs	Beginner, Advanced
2018	Dark Fiber	18 h	24	92	39 + 3 Eastereggs, 3 Scenarios/Maps	Jeopardy, Attack-Defence
2019	The 5th Element	18 h	29	129	50 + 2 Eastereggs	Jeopardy

**Fig. 2.** Overview of accomplished CTF events. Each session consisted of an additional Online-Qualifying over one week.

## 5.1 Application of the Taxonomy

Since our goal was to organize an event for the students of our university, we followed an approach to support their skills, their team spirit, and nevertheless fun during the event. That said we classify our CTFs based on our *taxonomy* as follows.

- **Audience**
  - **Target Audience:** Students and IT professionals.
  - **Sector:** Public (NGOs, government agencies), and academic.
  - **Proficiency Level:** Beginner up to expert level.
  - **Purpose:** Improve skills and collaboration abilities within the teams.
- **Training Environment**
  - **Training Type:** Capture the flag including quiz and jeopardy. In 2019, we also set up an attack-defence track.
  - **Scenario:** Storyline-driven including some free-/multiple choice questions..
- **Training Setup**
  - **Scoring:** Assessment, as it uses dynamic scoring.
  - **Roles:** No specific roles.
  - **Training Mode:** Team.
  - **Customization Level:** Individual, because the incentive is to provide an environment near to real world scenarios.
- **Technical Setup**
  - **Environment Structure:** Online platform in sense of E-Learning platform, and hosting.
  - **Deployment:** On-premise.
  - **Orchestration:** Partial degree of automation and modular approach for designing the services.

## 5.2 Phase 1: Organization and Development

In the first step, it starts with an idea to organize a CTF event. Meetings are scheduled and all participants are on a hype that the event will be a great success. But latest during the first crunch-time, the hype ends and all participants realize the hard work. Therefore, it is necessary to structure and organize the phases. Choose a project management that fits for the needs. It is important to have regular meetings, but also a ticketing system and version control for the challenges and underlying infrastructure.

During the first meetings, the audience for the event and the requirements need to be defined. We used our *taxonomy*, as shown in the previous section, to help ourselves. The classification of a planned event allows organizers to derive additional constraints, e.g., to support multiple proficiency levels based on categories or changing the level of difficulty based on successful solves of challenges. We followed an approach to support their skills, their team spirit, and nevertheless fun during the event. This includes a story-driven scenario including

some free-/multiple choice questions, e.g., eastereggs. Thereby, we develop several challenges for beginner as well as experts. In order to provide equality and increase the motivation, we provide different tracks with separate scoring based on the proficiency level. We have learned from experience that dynamic scoring makes it easier to determine the individual difficulty of the various challenges. As a result, the training setup includes our own developed scoring system. We promote no specific roles in our setup, but in the last years some teams joined the event with observer participants.

As an advice from our own experiences during the development of an event, we recommend planning sufficient buffers for unexpected issues regarding challenges and infrastructure. This saves the organizers from excessive crunch-time. Our technical setup was complex so far. It includes real network infrastructure and on-premise hardware for hosting the environment. On top of these hardware machines, we setup a virtual environment consisting of virtual machines and virtual networking infrastructure comparable to a real data centre. To minimize the workload during the event, we tried to orchestrate availability checks and restarts of vital services.

### 5.3 Phase 2: Testing and Dry Run

The main part of the second phase is testing. During this phase, all challenges are checked by an individual or small team independent from the developers of a challenge. If the event is based on a story line, all transitions to following challenges and activations of challenges after a successful solve need to be checked. Furthermore, it is necessary to keep in mind that nothing is more frustrating for participants than investing a lot of time in solving a challenge that is buggy or not solvable. Therefore, testing is more than essential for a successful event. The testing phase is also a good point in time to check the overall progress in developing challenges. To support the participants during the event, walk-throughs should be developed and tested in parallel. If a hint system is planned for the main event, it should also be checked during this phase. Nevertheless, every hint system has its own pros and cons. We did not find a satisfactory hint system for all participants so far; except for providing no hints for a single team. Finally in this phase, check the infrastructure readiness for the number of planned participants.

### 5.4 Phase 3: Accomplishment

The accomplishment phase usually takes place at two points in time: (1) qualifying and (2) main event. During the qualifying event, it is possible to gain experiences for the main event. Are the challenges too easy to solve? Is it necessary to split the participants into different tracks based on their skills? Are infrastructure resources planned adequately? Did the challenges need a supervision or are they robust enough? Taking these possible questions into account, the setup can be adjusted where appropriate. In case of different categories based

on proficiency level, the participants should decide which track to choose. Additionally, it is important to plan enough resources in infrastructure and staff for the main event. It is usual that not all challenges and storylines run as expected. Preparation should also include unforeseen events such as network and power failures, unavailable challenges or challenges that cannot be solved even if tested in advance.

The event should start with a short introduction about the "Do's and Don'ts" during the event. All participant need to understand that any attempt to break the infrastructure or manipulation of the scoring system leads to disqualification. Have a system in place to monitor such attempts. If photos are taken during the event or names of persons or teams are published afterwards, the participants have to be asked for consent. Consideration should be given in advance to where this information will be placed afterwards. This is necessary for the terms under which it is allowed to do so, keeping in mind regulatory requirements. Furthermore, a monitoring system should be in place to track the availability of all challenges and scoring systems. Necessary services should restart automatically in case of a failure as there is no time for manual troubleshooting during the event.

Regarding the IT security of the participants and infrastructure, the "Do's and Don'ts" are presented in the first step. Yet, various technical measures are feasible to prevent, e.g., manipulation of virtual machines, containers or network infrastructure. Virtual Machines (VMs) virtualize an underlying computer, whereas with containers the operating system is virtualized. Each way has consequences for the security, resources, reproducibility of exploits, and permissions. If a participant is able to break out of a docker container, other challenges could be manipulated in other containers or directly on the VM. Furthermore, if a participant is able to break out the virtual machine, also other VMs on the host or even the hypervisor can be manipulated. Therefore, it is vital to make even a short risk assessment of your infrastructure hosting the challenges. If a team is manipulating their own challenges and infrastructure, it might be acceptable to disqualify the whole team. However, if it cannot be determined who has manipulated a challenge or infrastructure, it may be necessary to cancel the entire event. That would be very frustrating for the other teams playing a fair game.

### 5.5 Phase 4: Cleanup and Maintenance

The last phase starts with the collection of evaluation sheets handed out during the event. The feedback of the participants is a good measure to improve the quality of a CTF and at the same time input for further events. Dependent on the feedback form and participants, it includes feedback about the difficulty of the challenges, the setup, but also about the fringe. The traffic and log files generated during the event are a good starting point for further analytics. Outcomes could include information on team strategies, toolsets used, and additional solutions to your challenges. If desirable, initiate a call for write-ups and provide a platform for the teams to share their solutions. It can be inspiring to read write-up of different solutions. Furthermore, traffic collected during the event showing various kinds

of attacks to provided services is very valuable for security research. To reuse the hosted challenges for further events, clean-up the provided machines afterwards. An easy solution is either using container or making a snapshot of all resources in advance. This enables the reset to this snapshot after the event. To keep the system save, shutdown all resources if they are not in use between events.

It must be ensured that all participants have given their consent for relevant information to be collected from evaluation sheets, log files, traffic, pictures, and team names. In case of collected data from a participant that did not give the consent, these data need to be deleted immediately. Subsequently, the data should be prepared for publishing, depending on the needs. Additionally, sponsors definitely welcome a short report about the event. Further, if the event was a success, publishing the results gives the organization and development team a good standing in organizing cybersecurity events.

## 6 CONCLUSION AND FUTURE WORK

Cyber training and education systems are an important aspect in education of different persons in each sector. Interactive training can help to improve the security knowledge in a practical way. The development of such systems as well as the extension and improvement can be hampered because of a missing general classification. This is especially the case for specific systems with focus on an individual use case.

To overcome this shortcoming, we developed a flexible taxonomy for ICTE systems. The taxonomy provides a detailed description of all components with a focus on technical realization. All phases of the exercise life cycle are covered within the taxonomy to obtain a holistic approach. It supports the education and training of different roles under consideration of the current skill level. This allows a targeted teaching in specific scenarios. In a next step, we showed examples of education and training systems, before we provided a case study based on conducted trainings. The trainings were categorized by our taxonomy. These examples further explain different training types.

In the future, we will conduct a survey about training systems, in order to apply the taxonomy to further systems. For example, we will show the fully compatibility and extensibility with the NIST NICE Framework [30]. This can help to enrich the taxonomy with more details. Further non-technical possibilities are ICTE in context of assurances and certification levels. Beside this, the taxonomy motivates the discussion and highlights the advantages of such systems. In order to improve the trainings, we will compare different types of scoring methodologies and provide a better suited one. As different scenarios are developed, a universal scenario description format or language helps to compare and exchange scenarios. This will be designed in addition.

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