A Tailored Model for Cyber Security Education Utilizing a Cyber Range

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Abstract: The threats posed by the digital space are a challenge for businesses, organisations and people that can no longer be met with pure knowledge. For this reason, all individuals have to demonstrate not only knowledge but also skills and competences in the field of cyber security. However, this presents an enormous challenge to higher education institutions (HEI) in terms of how to teach these competencies and skills to their students. In this paper, we present a new teaching method for cyber security (CS). It is based on the requirements and needs of educators and learners and integrates existing methodological approaches. This teaching method is complemented by the use of a cyber range as a central teaching tool to make the education more realistic. The method is not only applicable to technical programmes, it is applicable to all programmes and the focus is on cross-disciplinary training. This ensures that the teaching not only meets today's requirements but also those of the future in the field of education.

1 INTRODUCTION

Industry and society are facing major challenges in the context of digitalisation. Cyber threats are becoming more target-oriented and sophisticated, resulting in them being identified at a late stage. (Onwubiko, 2017) This is reinforced by the fact that many businesses require qualified IT employees who are equipped with the necessary skills and competencies. Furthermore, there are not enough graduates with this kind of profile in higher education.

Cybersecurity is no longer only a problem of the IT-department, it affects the whole enterprise. This results in drastic consequences: for example, the identification and response to ransom demands and similar software can take an average delay from 90 minutes to 6 days (ENISA, 2019). This period increases by a multiple in the case of Advanced Persistent Threat (APTs), because of their specific nature and the methods used; it takes an average of 90 to 180 days for them to be recognised (ENISA, 2019). This situation is made significantly worse by the near absence of digital investigation knowledge. With regard to CS training, in particular problem-based teaching, there is currently inadequate capacity in most HEI, as well in private CS training programmes. (Crumpler, 2019)

Existing training programmes also do not sufficiently address the problems and needs of businesses. More specifically, the existing programmes are designed in a way that the education is primarily theory-based, with limited or no practical elements. Also, the number of specialised graduates is too small to meet the growing demand for CS in terms of awareness, threat prevention and response. In practice, this leads to a further aggravation of the shortage of specialists and a lack of expertise in CS. For this reason, future training programmes must be designed in an interdisciplinary way with a Cyber Range (Leitner and Frank, 2020) to prepare non-technical students, and the higher education sector must offer content and exercises that address current and future problems, as well as needs. In order to achieve this, education must change fundamentally, away from a lecture-oriented approach to a more experience-oriented and collaborative environment.

The majority of knowledge transfer in adult education at HEI, educational establishments and institutions either use traditional or purely digital teaching methods. For both methods typically teaching lectures, case and literature analyses are used. The advantage for the lecturers is that they only create

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course materials once and the preparation time can be reduced to a necessary minimum. Subsequently, the materials created in this way are mostly used over a relatively long period of time without or with only minor adjustments. (Kebritchi, 2017)

However, there are a series of shortcomings with these teaching approaches in the context of conveying CS competencies to a wider audience: The knowledge imparted does not correspond to the current situation in practice, leaving a gap in terms of future-proof competences and qualifications that can achieve immediate practical impact in the industry. (Millis, 1997) The method of education is centred on the lecturer, and thus the needs and abilities of the learners cannot be considered in the lessons to the necessary degree. Practical exercises or realistic exercises are only rarely integrated into the training and if they are, only a relatively small part of the content is covered. The acquired knowledge is based on theory with minimal or no relation to actual conditions. Digital methods are mostly used as teaching support. They range from the distribution to permanent storage of materials or as an easy way to submit assignments in a centralised way. Collaborative problem solutions are only partially possible. (Yijun, 2011)

It requires a high level of self-organisation and know-how from the learners, since tools that would make it possible are in most cases not offered. Hybrid approaches would be a solution for teaching in response to current and future needs. This requires not only the adaptation of lessons and materials, but also the adjustment of didactic methods regarding new conditions and the provision of necessary infrastructure. Digital and traditional teaching methods can then be used in a complementary way, provided that teachers and learners are coached according to their needs. Educational concepts, must be structurally redesigned to integrate both target groups and to achieve a more holistic approach. (Vasiliev, 1996)

The work presented in this paper aims to overcome the gaps between theory and practice in CS education in higher education. For this purpose, a teaching concept for CS with a cyber range as a central educational element is introduced. The different requirements and needs from educators and learners were incorporated and embedded into the design. In this way, it is ensured that a holistic picture of CS can be conveyed. To reduce the complexity and narrow the focus on the concept and its application, the other actors involved in education, such as HEI or national regulators, but also international regulators, were not included in the assessment. The concept proposed here is primarily intended to be used in higher education, but with adaptations it can also be used in adult, education and training.

The paper is structured as follows: In section 2 we present the general requirements for a teaching concept in the field of CS. Based on the results and the surveys, the developed teaching model is presented in the chapter 3. We show the characteristics of the model and the advantages which can be achieved with the model. The performance and evaluation of the model can be found in section 4. In section 5 the discussion of the results is presented and section 6 provides a summary of the proposed concept and an outlook on future work.

2 TEACHING CONCEPT REQUIREMENTS & RELATED WORK

An educational concept must be able to react dynamically to different input parameters in order to identify all the needs of learners and teachers and be able to meet these needs later more effectively. For this purpose, the authors in (Flechsig, 1996; Meyer, 2005) show the three dimensions (personal, informational, organisational) that hold a central role in education and learning. These are connected with a central Axis, which ends with the learning objectives and the learning success (Figure 1).

The following requirements for a teaching concept in CS are aligned with the challenges of CS. For example, learners and teachers must be able to develop skills and competences on the social, technical, and multidisciplinary levels and to build up and maintain a holistic understanding of CS. These three areas are linked to the dimensions of the didactic octagon in order to include the external and internal influencing factors.

Social Requirements: Social learning is a process that requires interpersonal skills such as commu-

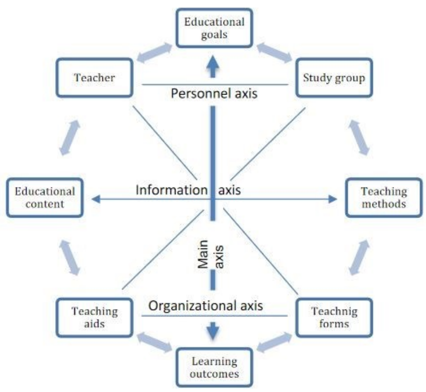

Figure 1: Didactic octagon (Andres, 2020).

nication and people-to-people interaction. Therefore, it is necessary to foster an environment, which stimulates individuals to interact. The teaching concept must allow learners to exchange and work collaboratively on problems on a formal and informal basis, whereas the teaching concept has to provide a mental model to achieve this. It is important that learners are never given the impression of having to deal with a problem on their own. Teachers need resources they can use to ensure an adequate learner-teacher relationship. Education is not only about transferring knowledge, but also about fostering soft skills and competences.(Motschnig-Pitrik, 2002) These are represented by two dimensions (personal, information) of the didactic octagon.

Technical Requirements: All learners across all disciplines have to be empowered with a range of technical capabilities and competences. They also need guidance to gain these competences and capabilities. The educational approach must allow learners to explore new solutions in a cyber range and allow them to learn from mistakes. The technical resources should support learning off and online to meet the various types of learners. Learners are from all social and cultural backgrounds, therefore it is important to enable all to have equal access to the same technical resources and to have equal chances to learn in general. Educators not only have to provide exercises on the technical aspect, they have to provide technical support when necessary and should maximise the opportunities offered by the digital space. They also have requirements on the teaching concept on the technical side, as the equipment needs to support the lessons and carry out trivial tasks given by them.

Multidisciplinary Requirements: Addressing the full scope of CS requires the education to provide learners with technical and non-technical content across all levels and empowering them to apply those. (Sobiesk, 2015) For this reason learners need to be taught the basics through disciplinary and interdisciplinary courses. As a minimum, learners has to develop knowledge and competences in the areas of policy, finance, computer science, and law. Educators are required to provide and deliver abstractions tailored to the target group. Learners must be offered the opportunity to specialise in individual domains through electives, but these programmes may not be pursued as a sub-subject and must be carefully considered during curriculum design. As university educators are in most cases only able to cover their own discipline, cooperation between institutes is necessary. Educators must work together and be able to exchange current and future educational resources. (Sobiesk, 2015) This is represented in the didactic octagon in the information dimension and, as outlined above, there is a link to the social dimension.

3 TEACHING CONCEPT

Teaching in the field of CS includes a wide range of topics across different disciplines. In order to be able to establish a complete teaching concept, different requirements and factors from educators and learners have to be kept in mind together with the individual subjects and disciplines reference. Figure 2 illustrates the complete teaching concept developed and the various input factors and parameters as well as the different outcomes that will be achieved.

The objective is to enable learners to unleash their full potential and to provide a practical and integrated theoretical education through a variety of methods to meet the challenges of CS. Educators will be able to use proven approaches and enlarge its own educational conception as also acquire skills and competences that are not possible with current methods.

Furthermore, the use of this method offers educators the advantage that the teaching resources and materials can be simply adapted and new assignments generated for each semester. For adaptation, the outcomes will be used, only on the organisational level, as the student groups will never be the same due to external factors.

3.1 Environmental Conditions

External factors or environmental conditions refer to all parameters that influence education beyond the scope of a educational approach and are highly sensitive to the educators and learners. In this model, four areas have been identified. Three are considered independent and one is formed by the others. These can be found in the first section of the model and are explained in more detail below. For the sake of brevity, only the essential ones are included in this example but there are many factors that need to be taken into account or that have an impact on teaching in general.

3.1.1 External Drivers

External drivers are the factors that do not come from the educators and learners but may influence them in their decisions and activities. They are generally established or enacted by external stakeholders such as HEI, legislators, employers and society and have a strong influence on education or on the target groups. The following points have been elaborated as external drivers:

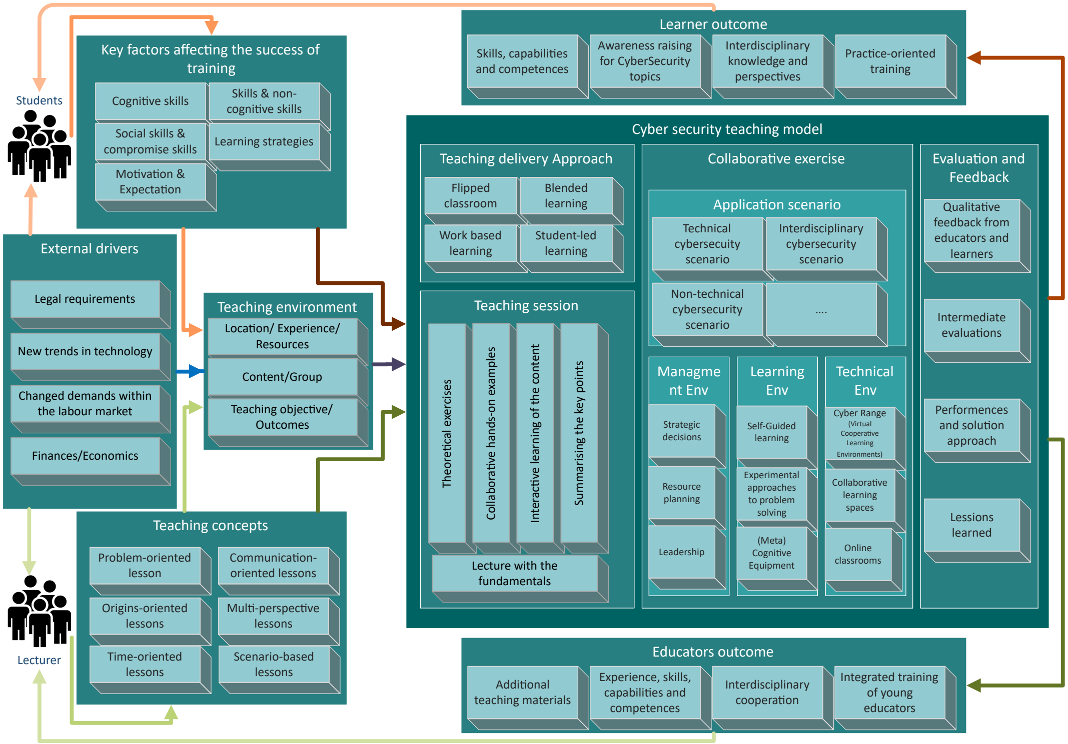

Figure 2: Overview of the teaching model.

Legal Requirements: These are defined by the legislator (European and national acts) and have different effects on the education. They have a direct impact on the teaching content through their requirements; the knowledge must be acquired by learners to be able to assess the full implications of actions and measures and to ensure compliance with the law. On the other hand, they can trigger training and further education to prepare learners who are already embedded in the world of work for the new conditions.

New Trends and Technologies: CS exists in a changing environment and is strongly influenced by new technologies and trends. This also has a strong impact on the target groups and the teaching environment. Learners are expected to be able to learn and apply the basics, including new technologies. For this reason, they also expect education to provide them with the knowledge they need. For the educators, it means that they have to continuously educate themselves to enable them to apply the new technologies to their students. An integration of these new trends has to be done continuously as the labour market expects it.

Labour Market Requirements: The labour market is always shifting and evolving in the context of technology. As a result, employers require new employees to have a set of skills, competences and capabilities and expect HEI to provide these to the learner. Employers want to keep education and training costs as low as possible for economic reasons. Learners are under strong external pressure as they fear that if they do not meet these requirements, their opportunities will be harmed. The educators and HEIs, on the other hand are divided. On the one hand, they have to provide learners a general education with the basics so the more advanced topics can be addressed, and on the other hand, not providing this education and training may lead to a reduction in the number of students enrolled and therefore a lack of financial resources for adaptation. The teaching method must be able to accommodate the changing requirements and provide them in full.

Finance/Economics: Here the different circumstances of the two target groups are addressed, but also the higher education institution as a whole, which has a direct influence on the teaching method. For learners, this factor decides whether they study full-time and focus on their degree or have to work to support themselves. In principle, there is nothing reprehensible about working alongside a degree if the learner is also active in the same field. In this way they can generate additional output that supports them in their degree programme. Another aspect is that learners need to purchase additional materials or technology to fully comprehend and complete the course content. This is a limiting factor for educators, as they have to manage teaching on a technological and human level with the resources available to them. The teaching method can only integrate new technologies or materials if the resources are available. Consequently, the teaching environment has to take this into account.

3.1.2 Key Factors of Training

The learning process depends on factors that can be directly or indirectly influenced by the educators and the learners themselves. These learning factors also influence the teaching methods applied during the learning process as well as during the preparation phase. For this work, the following key factors for successful learning were identified:

Cognitive Skills: This refers to skills that allow the acquisition of knowledge and information processing as well as being responsible for logical thinking. (Anderson, 2013) These are essential skills which not only steer learning but are also crucial in solving problems. Consequently, these skills are responsible for perception, memorisation, learning, decision-making and attentiveness. These skills are fundamental to the concept of teaching and to CS. They enable different aspects of the disciplines to be absorbed and incorporated into the assessment. This skill is important not only for CS but also for all areas of learning.

Skills & Non Cognitive Skills: These are the soft skills related to communication and cooperation but also responsible for commitment, self-efficacy and conscientiousness. (Coneus, 2009) They are often associated with the other soft skills and social skills; although for some areas this is accurate, for others they are distinct. Developing these skills will enable future leaders, but also others, to deal with situations of great stress. The teaching method itself is to foster and stimulate the development of these skills.

Social Skills & Compromise Skills: Describes the learners' ability to interact and compromise on a social level. It includes social intelligence, interpersonal characteristics, verbal and nonverbal elements and social self-regulation. (Kelly, 1982) Learning these skills is essential for achieving objectives in understanding complex topics and finding solutions. The acquisition of these skills is a major challenge in education. To enable this and to further develop existing skills, the teaching method provides the collaborative area which can be adapted to suit at any time.

Learning Strategies: These are action patterns to regulate the learner's own learning. These are either conscious or unconscious and vary according to the requirements and the situation. (O'Neil, 2014) The learning strategies used by learners can be classified as follows, according to (Shi, 2017):

- Cognitive strategies: The development, structuring and use of knowledge.
- Repetitive learning strategy: A strategy of reviewing information and knowledge in order to transfer it into the long-term memories of the learners.
- Development strategies: Combining existing knowledge with prior knowledge to abstract complex problems to familiar problems.
- Organsational strategies: Establish a relationship between acquired knowledge in order to develop a consistent picture.

The teaching method allows each learner to apply their own strategy to achieve an optimal learning goal. The intention is also to enable learners to expand their horizons and apply new strategies in order to achieve the objective more effectively.

Motivation & Expectation: Learners have different motivations and expectations in a subject area. Learners may be highly interested in a subject area, and the wrong methods can reduce their motivation. Learner expectations can be difficult to meet in most cases. For this reason, it is important that courses are described explicitly so as not to disappoint motivated learners. Motivated learners are supported by the teaching method through self-directed methods of the learner and other learners can develop their own interest through the method.

3.1.3 Selection of the Teaching Concept

The following teaching methods have been selected to ensure a deep understanding of CS. This is based on the problem-based approach, which allows teachers to create exercises that enable learners to develop solutions and work collaboratively. The purpose, according to (Hu et al., 2018) and (Lehmann, 2008), of problem-based learning is achieved when the following points are met:

- In the first phase (identification), learners need to understand the problem in all details. They need to observe the problem from all perspectives and comprehend the nature of the problem before moving on to the next phase.
- The second phase (analysis and collaboration) requires the learner to analyse the problem in order to solve it. They have to examine the problem in comparison with the current situation and the initial situation and compare them with similar problems. They can receive assistance from the teacher in order to design a solution through cooperation with other learners.
- In the penultimate phase (evaluation and reflection), learners have to review and evaluate the knowledge acquired in the context of the problem once it has been

solved. To do this, they reflect and expand the problem-solving process to other domains with equivalent challenges.

- The last phase (knowledge enhancement) consists of developing new possibilities for solving complex problems based on achieved results and considering the advantages and disadvantages of the identified solution including alternative methods.

This central approach is extended with the approaches listed in Table 1

Table 1: Teaching Approaches.

Communication oriented	Through this, the fundamentals will be communicated along with the theory. It also avoids misunderstandings in understanding the content and the task. Learners must further be able to state the problem at any time through communication.
Origin-oriented approach	Are integrated in order to be able to meet the requirements of all learners. This requires that the educators analyse and incorporate these requirements in a short time frame. Both have to react to the situation, however all needs cannot be met in this way.
Experiential and fact/ knowledge-based approach	Applied to facilitate and optimise the transfer of knowledge. This enables the learner to associate the individual parts together. To achieve this, a strong interaction between learner and educator, but also between learners, must be established. This is supported by collaborative exercises in the teaching method.
Multi perspective approach	The method ensures flexibility while supporting a variety of topics. It allows learners to explore solutions to problems from different perspectives of different disciplines.
Time-based approach	Exercises and theoretical teaching sessions are conducted in close time to each other in order to increase the learning output and therefore anchor the knowledge more deeply. The exercises are designed in a way that they can be finished during a short period of time. The short intervals between individual exercises make it possible to reduce the complexity and define the intermediate objectives in order to be able to carry out an evaluation at all levels.
Scenario-based approach	Specific content (theoretical and practical) is designed to tell a continuous narrative. This allows learners to relate complex content to each other, but also to link it to other disciplines.

3.1.4 Teaching Environment Factors

The last external factor that affects the teaching concept is influenced by the other three factors and correlates between the three domains. It addresses all edges of the didactic octagon and allows the teaching method to react to all impacts and factors. For this purpose it is necessary to consider the individual areas and axes that are related to the teaching unit as described in the chapter Requirements. The personal Axis is represented by the educators and the learners and both groups incorporate their requirements and factors into the teaching method. The Information Axis links the educational approaches that are presented with the content of the unit. The content is only partially filled by the external factors, while the other part is fulfilled by the teaching method which has to be coordinated in order to ensure harmonisation. The Organisational Axis is influenced by the available external resources, but the majority is affected by the teaching method. In order to connect these individual axes, the main Axis becomes operational. Here the objectives and the outcome are linked. Objectives are in part determined by external factors and in part by the teaching method. The Outcome is influenced in the same way, but can be influenced by the educator.

All the inputs are weighted equally in the teaching methodology and are handled in the same way. Neglecting or unequally weighting them leads to a disbalance and consequently to a less than optimal outcome. This is why a feedback loop was integrated into the teaching method, which allows an additional evaluation and adjustments after a run with the outcome. This is a possibility for the educators and learners, but also for the institutions, to quickly and efficiently address any shortcomings.

3.2 Cybersecurity Teaching Model

The teaching model for CS covers the theory lessons as well as the exercises. The model also includes the performance evaluation of both parts and the evaluation process regarding the skills, capabilities and competences used and built by the learners. For that reason, the model is divided into three parts, which are defined as follows:

1) Didactic Principles: These are represented by the teaching approach to teaching and the teaching session.
2) Exercise Principles: In the method, exercises are basically designed as collaborative activities, which is why this approach represents the meta-level. Within this meta-level are the application scenarios and the management, learning and technical environment conditions.
3) Evaluation Principles: They are presented in the teaching model with the coresponding area of evaluation and feedback in order to lead to an optimal outcome.

3.2.1 Didactic Principles

The didactic principles made available to educators by the teaching model are derived from the general principles of comprehensiveness, clarity, target-orientation, self-activity and topicality. (Marius-Costel, 2010) And are included in the two areas. The first area contains the methodology and approaches of how the teaching content is delivered to the learner, see Table 2. The teaching delivery approaches for the model are defined as follows:

The second section describes the various options for designing a session. The basis is a lecture with the fundamental knowledge necessary for the learners. The foundations of the teaching sessions can be extended with the following approaches to increase the efficiency of learning, see Table 3

Table 2: Methodology and Approaches.

Flipped Classroom	Lessons are designed to improve the quality of teaching through a learner-centred approach. It requires learners to independently prepare for the lesson and work on a problem within the sessions. (Ozdamli and Asiksoy, 2016)
Blended Learning	A combination of offline and online resources are used. It allows learners to control the time, place and pace of learning. This also requires that educators and learners are in physical contact with each other however face-to-face practices are enhanced by digital based activities in terms of content and delivery. (Graham, 2006)
Work based learning	Is a strategy that allows learners to have real-life experiences. It is a combination of theoretical and technical skills and is usually linked to business practices. (Boud and Solomon, 2001) It is not possible at the higher education level - here the cyber-range environment is applied. This provides learners the opportunity to work on real systems and to develop topics that are otherwise only available in business.
Student-led learning	The responsibility for the teaching experience rests with the learner. Knowledge acquisition is facilitated as learners interact with a peer-to-peer process. (Marvell, 2013) In the model, this approach is fundamentally used in exercises to provide learners with all the opportunities and in order to strengthen skills.

Table 3: Type of Sessions.

Theoretical exercise	During the lessons, exercises can be performed where theoretical topics are elaborated. This means that learners have to deal with the content of the lessons. This is similar to the lessons that children receive to learn mathematics.
Collaborative hands-on examples	Learners have to work together on abstract and real examples in the sessions. This allows for immediate assistance in case of problems and enables timely preparation of results for all learners. The complexity of the exercises is variable and always depends on the level of knowledge and skills of the learners.
Interactive learning of the content	Use of specific tasks and questions to encourage learners to participate in the lesson without communicating directly with the lecturer. This should reduce the barriers and lead to a new teaching experience.

3.2.2 Exercise Principles

The exercises represent an extension of the theoretical lessons and should serve to consolidate the content. The exercises are therefore important as they are not isolated and follow the same narrative. Therefore, the principles of the exercise follow the didactical guidelines. During the exercises, the learners work collaboratively together, so it is on the meta level.

An application scenario represents the first part of the exercise that needs to be prepared. The exercise topic and the individual focus points will be determined and different storylines will be generated. A storyline deals with a specific CS challenge, e.g. ransomware, APT, etc., or a storyline pushes the scenario ahead to guide the learner to the desired objective. Storylines can also be incorporated to increase the difficulty of the scenario and produce background noise in order to disguise the attacker's actions. For this reason, the Table 4 contains scenarios that support this model and can be built upon. There are three dimensions in the concept to adapt the exercise to the different conditions of the environment, enabling all teaching concepts to be addressed. To do this, educators have to address the three dimensions of **management**, **learning** and **technology**. The first dimension is the management environment, while the role assignment belongs to the learners. The characteristics of the dimension are shown in the Table 5.

Table 4: Application scenarios.

Technical cybersecurity scenario	This kind of exercise involves a strong technological component. In order to design this type of exercise, an infrastructure (Cyber Range) has to be integrated into the training where learners will be able to work with the scenario and repeat the scenario if necessary in case the chosen solution does not lead to the desired result.
Non-technical cybersecurity scenario	Represents the logical opposite of the technical scenarios. In this type of scenario, technology can and will be used, but the aim is not that learners develop a solution that focuses on the technical level. The aim here is rather to focus on the non-technical areas such as risk management etc. that can be developed without the use of technical resources. Purely non-technical exercises are the preliminary stage of the interdisciplinary exercises and are designed to evaluate learner procedures and processes.
Interdisciplinary cybersecurity scenario	The storyline approach can be a combination of technical and non-technical exercises with the integration of different disciplines or a pure exercise where learners from different disciplines work on the same challenge. Storylines must therefore be planned in a way that all learners can contribute their strengths and pass on their knowledge to other learners by working together.
Other scenario	This teaching method also allows other types of scenarios for integration. The educators have to make sure that all parameters can be implemented and that the learning objectives and the expected outcome are properly defined.

Table 5: First dimension.

Strategic decisions	Learners have to make decisions in order to succeed in the exercise and therefore in the scenario. The decisions will change as the information content evolves. It is very important that the decisions are documented and on which basis they were taken. It prepares learners for future leadership roles.
Resource planning	Learners need to consider resources that are supposed to be lacking in the exercise, like money, human resources etc. It prepares learners for future leadership roles.
Leadership	It is essential for future decision-makers to build up competences and skills in this sector. This is often neglected in education and training programmes or reduced to the transmission of soft skills.
Other	Additional management duties can be added to the exercise, depending on the scenario.

The second integrated environment that is supported and embedded by the model deals with the topic area of Learning with Application. In this field, competences and skills are addressed that are used and acquired. The following strategies of this dimension are listed in the Table 6.

Table 6: Second dimension.

Self-Guided learning	Combines learning organisation, learning goal identification, learning control and learning outcome monitoring. Learners are stimulated to learn by their own and educators provide the environment. (Kraft, 1999)
Experimental approaches to problem solving	Enables learners to independently develop solutions based on experience and acquired knowledge. In the exercise, these solutions are evaluated and in case of a failure, the learners are forced to reconsider the solution and develop a new approach to the problem.
(Meta) Cognitive Equipment	Firmly anchored in the teaching method in order to guarantee the processing of information on the different dimensions and to enable learners to acquire new knowledge and is linked to the logical thinking.

The last environmental dimension which is integrated into the teaching concept as a fixed element is the technical dimension, see Table 7. The exercise methodology is provided and carried out with technical resources. The different exercises in the sub-

Table 7: Third dimension.

Cyber Range	Is a virtual infrastructure that can be adapted according to the requirements of the challenge. Physical components such as operational technologies (OT) and Internet of Things (IoT) can be integrated, to bring the experience more into the real world.
Collaborative learning spaces	Software module that allows learners to collect information and share it in a centralized way and refer to it as a ticket system when new information is available. In the European project ROUTE-TO-PA (Palmieri, 2021) an open source and publicly available tool was developed that fulfills these requirements.

ject areas also require a variation of technical exercise techniques and methods.

3.2.3 Evaluation Principles

The evaluation of the theoretical and practical part of the training is important for the assessment, but also for the development of skills. The assessments, however, also support the trainers on the organisational level. They receive feedback and can adapt exercises and teaching to improve quality or to better meet learners' needs. Learners can be motivated by high-quality feedback at every stage and work more intensively on the content. For this reason, different approaches have been integrated into the teaching method to support teachers, and they follow the following principles in Table 8.

Table 8: Integrated methods of evaluation.

Quantitative feedback from educators and learners	In this variant, it is possible for learners to receive feedback from educators, learners but also experts. This allows learners to understand which errors they have made during the session and which competences and skills they need to further improve. In this way it is also possible to ensure assessment with points.
Intermediate evaluations	Exercises take place in a constantly changing environment. This makes it difficult for teachers to understand the decisions and the solution. Evaluation of tasks at regular intervals is therefore essential. This makes it possible to guide and intervene in case of problems.
Performances and solution approach	The assessment of individual learning must be carried out by deriving the overall solution, thus ensuring that learners receive the assessment that corresponds to their performance. This is made possible by using this approach. In an exercise, the technology allows the individual learner's performance to be tracked and assessed.
Lessons learned	It is a repetition of the learning objectives in connection with the knowledge and skills that have been obtained. The purpose of this is to show the learner how the steps relate to each other and to support the learner to use this knowledge in similar cases in the future or to integrate it into new approaches.

The components and individual approaches presented in this model are designed to support teachers in their educational activities. For learners, the model provides a practical education with the integration of disciplines that are not part of their studies. The implementation of the model is a process that needs to be carried out over a longer period of time. However, it is important that both target groups find their requirements and needs reflected in the teaching method.

3.3 Outcomes Addressing the Target Groups

The focus of teaching is always on transferring knowledge, skills, competences and reaching objectives. That is also the case in the developed model for CS education. In this model, not only learners reach objectives and outcomes but also educators gain knowledge and competences. Consequently, this model can also be seen as a method of life-long learning. This means that through each iteration of the model, the educator's development is enhanced and can be better tailored to the requirements of the learner. The results of both target groups are presented below.

3.3.1 Learner Outcome after a Session

The methodology focuses on the holistic understanding of CS as well as on the personal and methodological development of the learners. The following points describe only a part of the outcomes that the learners achieve, but these are crucial.

Skills capabilities and competences: Through the exercises and the various theoretical teaching options, the model offers learners the creation and further improvement of skills, competences and capabilities in the field of CS, but also in associated subject areas. The application also strengthens the learners' confidence on their own capabilities and leads to higher quality results in more in-depth training programmes. Therefore, learners are constantly challenged to apply these skills.

Awareness raising for CS topics: For future employment it is essential that all learners, not only computer scientists, are aware about CS topics. The model actively supports this by focusing on interdisciplinary approaches and by providing a framework for the development of a CS awareness among all learners. Guiding learners to the topics and involving them more in the teaching leads to a lower threshold and awareness raising and therefore to an overall increase.

Interdisciplinary knowledge and perspectives: The integration from disciplines which are not related to computer science and the integration of learners from this discipline in the exercises ensures that both sides acquire knowledge from the corresponding discipline. This is supported by the joint elaboration of solutions and the integration of the individual specialist knowledge into the solution.

Practice-oriented training: A fundamental component of the model is the practical exercise and elaboration to solve problems. The harmonisation of theoretical lessons with the scenario-based approach enables the use of various exercises. In this way, the proportion of practice sessions can be increased and current topics can be integrated into the programme. These practical exercises foster the development of skills and capabilities and increase the understanding.

There are other outcomes that can be achieved in the area of learning, these have not included in the list because of the prioritisation process.

3.3.2 Educators Outcome after a Session

The model provides educators various opportunities. It is essential that educators embrace the process and overcome barriers in order to collaborate more and obtain outcomes.

Additional teaching materials: Teaching materials have to be constantly reworked in order to be up to date. New materials also regularly need to be generated as a result of the changes in the programmes. The model supports the educators in this process. Through the experiences they make, the educators receive indications of where improvements are necessary. Learners contribute to this process with their solutions. This gives educators the opportunity to incorporate solutions to show examples to other learners. On the other hand, learners contribute by producing documents. These can serve as a basis for new exercises.

Experience, skills, capabillities and competences: Teachers build experience and develop new ideas through each iteration. By designing exercises, they develop and sharpen skills, capabilities and competences as they engage with known and new subject areas and develop a new perspective. The model supports the teacher in reaching the results by requiring the teacher to actively engage in the construction of the learner's skills and competences, expanding their own as well. On the other hand, they are supported by the multiple possibilities that the model offers them.

Interdisciplinary cooperation: In the exercises, educators have the opportunity to teach across disciplines. This may lead to new collaborations, and also to cooperation with other teachers in other countries. This will also broaden their perspectives and therefore lead to an increase in personal skills. The model supports this in the sense that they are always confronted with interdisciplinary challenges and have to strategise to integrate these challenges. Educators can initiate and build up the collaborations.

Integrated training of young educators: The training of young educators confronts HEIs with specific challenges. Resources for training young educators are limited most of the time. The model provides assistance to educators and higher HEIs in this process by integrating young educators into the exercise and allowing them to develop their skills. In addition, the young educators can develop individual approaches and provide new perspectives. This leads to a situation where gaps in training can be bridged and young educators are not overwhelmed when they are first deployed.

4 EVALUATION

To evaluate the effectiveness of the teaching model for CS, an interactive lecture and an exercise was carried out concerning the topic of forensics and examined with a test. Three groups of participants were selected to be part of the evaluation. The first consists mostly professionals from the field of CS, hereafter referred to as A, who have been working or researching in the field at least for 5 years. They carried out the exercise and established a threshold. It was not expected that the other groups of participants would reach this threshold. The second group of participants, hereafter referred to as B, consists of young professionals in CS or young researchers who have just completed their studies. This represents the reference value for the third group of participants, the learners. They have received all the necessary documentation and have been supervised throughout the process. The last group of participants is made up of learners, hereafter referred to as C, from the field of computer science in the undergraduate (Bachelor's) or postgraduate (Master's) stage. Learners are selected only if they have not had any explicit lessons related to the topic in their studies. This should ensure that all learners participate in the test with the same prerequisites.

Participants from groups A (3 participants) and B (5 participants) carried out the exercise under laboratory conditions. They were observed throughout the experiment and all actions and conversations were recorded and documented with their consent. Group A carried out the exercise in 15 minutes using their knowledge and acquired skills. They proceeded methodically and goal-oriented and were thus able to work out the task quickly and answer all questions. Group B first had to familiarise themselves with the setting. They completed the exercise in 45 minutes on average. They spent a lot of time analysing individual files and had to understand the relationships. When they identified the vulnerability and researched about it, they were able to answer all the questions and complete the exercise positively.

For group C (72 participants), the interactive lecture and exercise was divided into two different modes. The participants in the first mode took part in the interactive lecture and then had to complete a test with 10 questions within 24 hours. They had 30

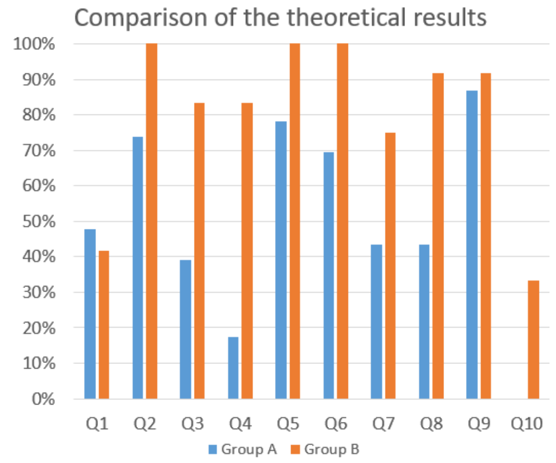

Figure 3: Test results.

minutes to answer the questions and could attend in the technical exercise after that. The participants in the second mode also attended the interactive lecture and performed the technical exercise two weeks later. After completing the exercise, the group had to answer the test with the same questions.

Results of the Knowledge Assessment: The results of the knowledge assessment are shown in Figure 3. The results of the group that performed the test after the interactive lecture are shown in blue, while the results of the group that performed the test after the exercise are shown in orange. It was possible to answer the questions correctly, incorrectly or partially correctly. Partially correct answers were marked as incorrect in the binary evaluation.

The second group performed better in 9 out of 10 questions. About 38% of the participants in this group answered the last question correctly, whereas none of the participants in the first group did so. The first question was the most outstanding; here the first group performed better. This question is directly connected to the contents of the lecture and does not occur on the exercise in this form. About 50% of the learners in the first group had passed the knowledge assessment and about 80% in the second group. An improvement of 30% appears in a practical exercise within a cyber range that also has a strong connection to the theoretical topics..

Performance in the Exercise Compared to All Participant Groups: For the practical exercise, the learners (36 participants) of group C formed teams of three individuals. This enabled the model and the participants to reach their full potential. They had 60 minutes to solve the task assigned to them. The challenge was an implementation of the CVE-2019-11043 vulnerability and the learners had to find out how the attackers got into the system, what activities they performed and which evidence they left in the system. From the 12 teams that participated, 3 teams were not able to solve the task in time. They attempted to apply the methods and strategies they had learned, but according to their own statements, their technical knowledge was not so advanced that they could have handled it better. The remaining 9 groups completed the task in time. 4 groups completed the task in 35-40 minutes. This means that they have largely undercut the reference value. The remaining groups in the exercise came close to the reference value, with an average time of 48 minutes.

5 DISCUSSION OF RESULTS

The objective of this work is to enhance CS education and training with a newly developed model that utilises a cyber-range environment as a central educational tool. For this purpose, the requirements and needs of educators and learners are collected through surveys, interviews and workshops and incorporated into the model. Educators and learners are clearly not the only actors involved in CS education which have requirements to the design of the educational programme. Therefore, also the external conditions are included in the analysis as in the model. In a second step, the teaching concept was examined in a practical setting. The objective with this step is to ensure that the model significantly improves the educational situation and that knowledge, competences and skills can be acquired. For this purpose, the learners had to work on a topic which is not part of their degree programme. A comparison between experts and learners was therefore possible and the improvement could be defined on a quantitative level.

Our evaluation of the interactive lecture has yielded the following results. The learners are much more active and engaged than in the classical lecture. It was possible to immediately verify understanding based on the learners' answers and thus to react and adjust before the learners acquired inaccurate knowledge. An important aspect for the achievement of the programme's objectives. Feedback from learners after the event was also positive. The results of the Q&A show that a purely interactive lecture is not sufficient to convey complex topics. The results can only be significantly improved by applying learning in a coordinated exercise after the lecture. With a purely interactive lecture, the percentage of correct answers in the experiment at 50%, see Figure 3 and Table 9. The combination of the exercise and the interactive lecture increases the percentage of correct answers in the experiment to 80%. Thus, a 30% increase in per-

Table 9: Performance of the participant groups "Lecture".

Type	Average of correct answers	Improvement
Interactive lecture	50 %	/
Interactive lecture with exercise	80 %	30 %

formance could be achieved in the experiment by applying the model.

A learner-centred approach including interactive components is a reasonable extension of current teaching methods. Learners are more involved and the transfer of theoretical knowledge will be improved. Educators have to invest more effort in the development of the materials. The amount of material they have to prepare is in the dual mode restricted in volume, they have to include less illustrative examples to convey the content. As educators are guiding learners in the elaboration of the content, learners have to engage more intensively with the content. Auditing and maintenance of the teaching materials is simplified due to the limited scope.

A new approach to the exercises is developed and tested during the work. The methodology for the exercise is based on existing approaches and methods. For this purpose, several approaches are evaluated. The aim here is to integrate the advantages of all approaches to overcome or mitigate the disadvantages in order to design a concept that enables all learners to learn CS. The key feature is a cyber-range environment which facilitates the construction of scenario-based content and provides realistic hands-on training with the virtualised infrastructure. The exercise is conducted in the same way as the lecture with learners and additionally with two reference groups consisting of experts and researchers from the field of CS. All groups performed the exercise in the same way, whereby the scenario was designed in such a way that theory and exercise complement each other.

The Table 10 shows the performance of the participant groups in terms of minimum, maximum and average processing time. Furthermore, the table shows the percentage improvement compared to the average reference time. The learners' results were divided into two parts. The first group of learners is below the reference time with their average processing time. The learners in this group achieved an approx. 15% better average time by completing all tasks. The second group is about 8% above the reference time. This approximation was the expected result from the model.

The experts' results were within the expected scope and provide a reference value for the other groups. The group of young researchers from the field of CS elaborated the exercise within the given parameters of the exercise. They chose and carried out a methodical approach. To do this, they used their

Table 10: Performance of the participant groups "Exercise".

Group	Max time	Min time	Avg time	Percentage comparison
Expert	16:21 Minutes	14:10 Minutes	15:15 Minutes	34.2312 %
Young professionals	47:52 Minutes	39:14 Minutes	44:33 Minutes	**100 %**
Leaner "Below the reference value"	40:03 Minutes	35:28 Minutes	37:45 Minutes	84.7362 %
Leaner "Over reference value"	58:53 Minutes	45:46 Minutes	48:24 Minutes	108.6419 %

acquired knowledge and competences and related the task to similar problems and worked out a solution approach and procedure. The learners' results range across the spectrum. However, it is impossible to expect that all learners will complete a course positively, despite the best teaching method. Each person is different, depending on the knowledge they have. The majority of learners completed the exercise successfully and were able to achieve the objectives of the exercise. Their developed solutions is based on both the knowledge gained and the knowledge learned in the interactive lecture. Some learners exceeded the results of the reference group, the majority completed the exercise in the expected range with good results.

Teachers need to restructure their course to apply the model and thus spend resources to design teaching materials, exercises and scenarios. They also have to go through several cycles to find an optimal mode between theory and practice. The central teaching tool in the model is the cyber range, so it is important to develop an EDU range which includes the limited technical resources as well as the short preparation time of the educators. The applicability of the Cyber Range must also be given to learners from technical and non-technical studies.

6 CONCLUSION AND FUTURE WORK

The digitisation process in all areas of daily life makes it increasingly important for all individuals in society to develop a general awareness of CS issues and therefore to receive training and education in CS. As a result, HEIs and Training Institutions are challenged to develop a programme that enables individuals to be trained in CS. They need to develop a programme which enables them to carry out the training. These programmes should not limit their focus on the qualification of technical staff but also include service teaching of other disciplines.

The model for CS education with a cyber range environment as a knowledge transfer method provided in this work aims to improve education as well as the transfer of skills, abilities, and competencies.

In this regard, this model puts the emphasis on integrating the requirements and needs of the educators, learners, and external factors. For this purpose, this work has evaluated different teaching approaches, the current CS environment and the requirements and needs of educators and learners, and has analysed potential cascading effects.

The survey results are used to conceptualise and implement the model, resulting in a theoretical and practical lesson. They serve to evaluate the model as well as the integrated approaches. The evaluation followed a two-stage procedure. In the first stage the acquisition of knowledge with an interactive lecture session was evaluated. In the second stage, a tailored practical teaching session with a cyber range environment was carried out in addition to the interactive session. This showed that the results regarding the learners with the exercise were significantly better than without. In order to compare the results from the learners, the exercise was additionally conducted with experts and young researchers from the field of CS. The learners achieved the similar results as the young researchers in the field of CS by using the model, and in some cases they even performed better than them.

This work provides a basis for delivering CS education to everyone. However, more broadly based surveys are still needed across all disciplines to ensure that all learners' and educators' needs and requirements are integrated. This needs to include learners of all disciplines - and the same needs to be done with educators. The assessment must include nontechnical concerns as well. This will ensure that exercises and theoretical lessons do not miss the requirements and needs of the target group. Another important aspect is that the requirements of the labour market are also included. Then the developed model will be able to cover the relevant areas and provide training in the field of CS for everybody.

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