LEARNING CYBER SECURITY: TEACHING TECHNICALLY CHALLENGING TOPICS WITH GAMES AND VIRTUAL LABORATORIES

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Abstract: The learning trends are going towards the application of Internet, where the students learn by autonomous self-study approaches. In future, the need for constructing a sufficient learning environment to support the technically challenging topics is almost mandatory for developing a curriculum, which caters to the pedagogical needs and practical requirements. In this paper, we present our initial results, designs and a proposal for a learning environment, which combines games, virtual communications laboratory environment and a traditional self-study course into a framework, which enables the students to learn and practice cybersecurity with varying degrees of tools. These tools vary from games, which teach the fundamental aspects, to a full virtual laboratory, which allows realistic exercises and simulation of attack scenarios.

Keywords: Long-distance learning, cybersecurity, virtual laboratory, technically complex learning topics.

1. INTRODUCTION

Acquiring a new skill is always a difficult, especially if the skill is related to something difficult or technically challenging, such as programming or cybersecurity [1]. In addition, in some occasions it is impossible for the students to actually be present at the teaching events, meaning that in addition of needing to learn the complicated new concepts, the students also have to learn them via some form self-study approach. Some topics, such as the cybersecurity, may require physical hardware, which is beyond the means to be acquired by the students themselves, or require a laboratory where the hardware is physically available.

To replace these with online-enabled tools, we need to develop a virtual version of the learning environment. The development of a learning tool or a long-distance learning environment by itself is by no means a novel concept; the first learning tools were developed in the 60's and 70's to assist studies in computer science [2], with different types of simulators even preceding those systems. In our work, we aimed to develop a set of tools and a framework on which to add modules which introduce the different cybersecurity concepts via online games, video lectures, tutorials and virtual network laboratory system to replace the teaching hardware. In this paper, we introduce our preliminary results with the initial game designs and present our proposed framework for offering engaging long-distance education. In short, our research questions were "*what type of design issues there are in the technical construction of a virtual learning environment intended for teaching complex topics*" and "*how can we utilize the games in learning of cybersecurity issues*".

This paper is continuance to our previous work on learning environments, pedagogical tools, and course curricula in general. In our prior works, we have conducted studies on the application of the video material on the long-distance learning [3], tailored gamification to improve the user motivation [4] and a study on how organizations and users learn and adopt new skills and practices [5]. In technical side, our team has studied for example the development of a virtual laboratory for learning network communications with minimal amount of physical hardware or face-to-face teaching events [6].

The rest of the work is structured as follows: In Section 2, we discuss the current situation and related works, while in Section 3 the data collection and applied analysis methods are introduced in detail and the framework of our study is described. In Section 4, the results from the usability trials are presented, while Section 5 discusses these findings and their relation to the prior work. The paper is closed with a short summary and concluding remarks in the Section 6.

2. RELATED RESEARCH

Like every other software service or product, the aspect of usability "hygiene factors" [7], intuitivity, immersivity and usability are important for the efficiency of any learning system [8]. In a larger scale of usability studies, there is also the concept of "user experience" [9], which does not only cover the topics of how to complete tasks with the system, but also for example assess how the user expectations are fulfilled. This aspect of measuring the user experience has also been studied extensively, for example, in the development of recommender systems [10] or in videogames [11], where providing the expected user experience is a central aspect of the design.

However, especially in long-distance services the user interfaces may suffer from the simple problem that the customers simply are not aware of all of the modifications or activities which can be taken [12], possibly because they find forced tutorials or help systems sessions irritating. The users may also simply lack the computer skills to independently learn to use anything more complicated than simple websites and simplified services [13].

In the construction of gamified or game-like elements for the learning environments, de Freitas et al. [14] presents a summary of three gamified learning platforms. Their results include three observations: 1) the gamification can enhance the competitive and collaborative aspects of the student interactions, but to achieve this 2) the service requires a visually stimulating environment, and 3) to apply a challenge-based approach. In the observed systems, these were implemented mostly with points, achievements, leaderboards and other similar gamification approaches. Following the principles presented by for example Werbach and Hunter [15], these are rather common solutions to enhance the user participation, retention and motivation levels.

Finally, on the application of games and competitive aspects, Arnab et al. [16] observed a group of students which were instructed to use the gamified online learning environment with the different biases on the given information and types of expected activities. Their results indicate that the most successful test user group were the “competetive” test group, being given information on how they fare against the other users. The other groups, collaborative test group who were given information on how much they participate, and the control group, which was not offered any biased information, completed the assignments with the worse overall results.

3. DATA ANALYSIS AND INFRASTRUCTURE

As mentioned in the related research, the hygiene factors [7] are important for any type of learning environment [8]. To establish if our approach of developing games to teach the fundamental concepts was plausible, our initial testing work focused on the interface components, and the user experience aspects. The concept was to measure the user interface and intuitive attributes such as the usefulness, efficiency and likeability of the different user interface schemes, following the usability concepts by Rubin & Chisnell [17]. In addition to these, open comments and suggestions on improvements were requested.

As this research project is closely related to actual software development process work, the research project will also apply exploratory [18] case study approach. The case study includes process steps and activities, which form the general study blueprint [19]. In general, case study method is considered a valid and very suitable research method, when constructing a new solution by the means of software engineering, and studying a phenomena such as learning in its natural environment [20]. To collect information on the functionalities of the different components on our learning environment, guidelines by Fink [21] were used on the construction of the survey items, and the collected qualitative feedback was analysed and classified based on the principles of open coding by Strauss & Corbin [22]. In this study we consider our work and collected survey information exploratory, from which no mathematical or strong conclusions can be made, but combined with the qualitative data some indications and recommendations for the future work can be reported. On testing the usability aspects and the user experience, recommendations for measured items and test settings were constructed following the general principles of Dumas and Redish [8], Rubin & Chisnell [17] and Barnum [23]. The data sources, collected information, and analysis steps are illustrated in Fig 1.

The development of the gamified learning tools is also a part of a larger overhaul of the networks and cybersecurity degree program. As illustrated in the Fig.2, the game-like learning tools assisting the course are part of the fourth development step for the entire system. To build upon this foundation, our developer team has developed fully virtualized modifiable network definition tools. These tools can be used to teach design, testing and development of the data communications networks. The current system is capable of fully simulating over 1200 simultaneous devices and their connections, while also providing a simulated version of the Internet called Simternet. The usability and quality aspects of this virtual laboratory has been tested with the migration process of the local teaching events to the system in the step two of our development process. This work has been extensively reported in the publication [6].

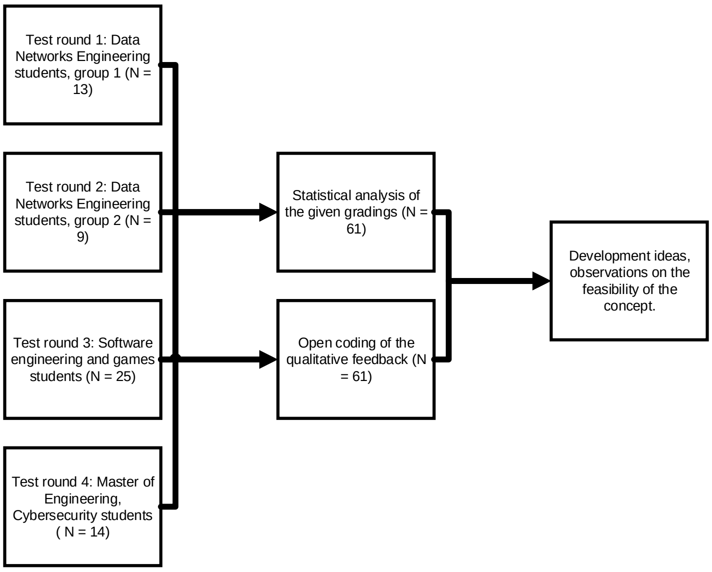


Fig. 1. Data collection sources and analysis methods of the research step

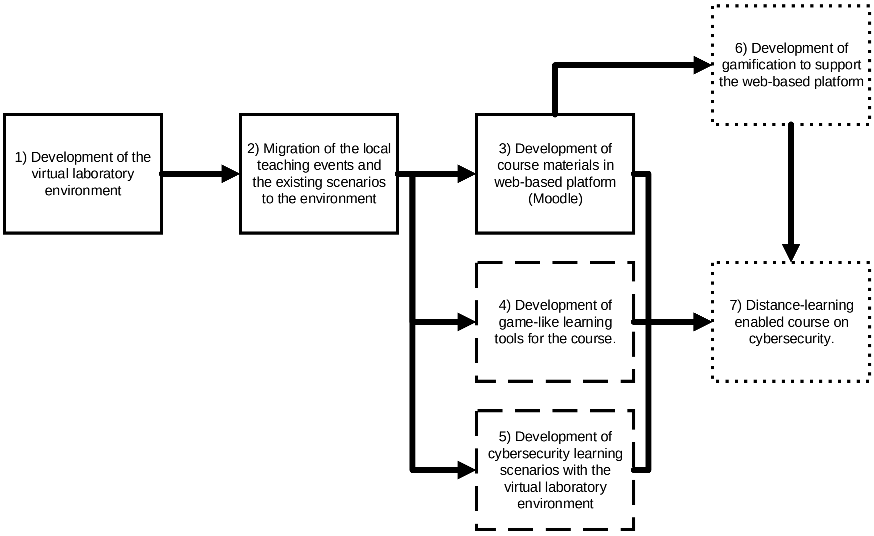


Fig. 2. Development steps for the long-distance learning system. (Dashed line components under development, dotted line components future work.)

For the third development step, a fairly typical Moodle–based course on the cyber-security and data communications was developed to serve as a platform for the testing of the virtual laboratory long-distance assignments, game-like learning tools and gamified course contents. Out of these elements, the virtual laboratory assignments and the game-like tools were developed during the academic years of 2016-17 and 2017-18. The development and structure of this course component has been extensively reported in the publication [24].

The fourth development step consisted of designing and building the game-like learning tools to explain the fundamental aspects of the data communications, and how these systems operate. The concept was to illustrate how the system functions normally, and how the different types of cyberattacks or security breaches could in theory happen.

The first game-like learning tool was designed to present how the different types of firewalls function. The game advances from old firewalls towards the next generation systems, while adding more features which needs to be understood. The modern firewalls check all of the data packets to prevent unnecessary or high- risk traffic in the corporates network, and for example, one feature of the next generation firewalls is the capability of fine-tuned recognition of the application used in network sessions. Overall, the game is heavily simplified if compared to the real firewall systems but presents the concepts on how they work.

The player score is based primarily on the amount of errors, and secondarily on the amount of time, abstracted into a baud rate-imitating high score. The game was developed over a HTML5-based game engine PlayCanvas [25] to allow different types devices and platforms. Screenshot of the game in progress is presented in the Fig 3. Pedagogically, the concept is that after the play session, the acceptance rules should be reviewed and discussed on why they exist, and then the same firewall would be configured on the virtual laboratory. Similarly, further game-like teaching tools have been designed for example for developing new acceptance rule sets, or for finding unsecure exceptions.

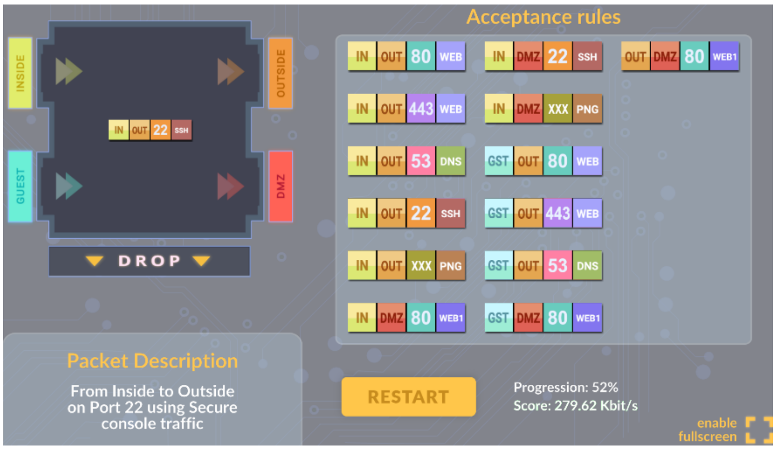


Fig. 3 Screenshot of the first learning game prototype; The firewall simulator

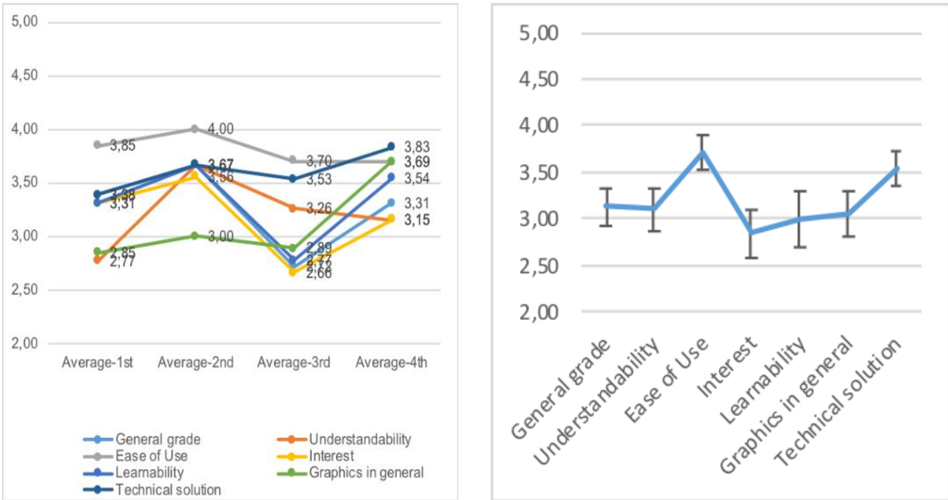
4. STUDY RESULTS

The usability and learnability aspects were investigated with four rounds of testing work. Overall, our test sessions collected data from 61 individual users involving students from three different engineering-oriented study programs: Data networks (Bachelor's level), Software Engineering and Games (Bachelor's) and Cybersecurity (Master's level). In this chapter, we present the results of these test sessions, and draw some implications from the results.

4.1. Survey Results

The alpha testing requested the participants to give grade from 1-5 for the following items: 1) overall grade, 2) understandability, 3) usability, ease of use, 4) interest, 5) learnability, 6) technical solution and 7) graphics. In addition to these, 4 open questions were asked based on the observed problems and general attitudes towards the game itself. The averages, medians and modes are available in Table 1, and the change trends of averages in the Fig 5a.

The difference between the alpha test rounds 1 and 2 was that the round 1 consisted of only single player elements, namely the core gameplay and minimal instructions. The round 2 had some simple courseware integration to Moodle and a highscore-list to enable competitive play between the different users. The round 2 interface had also some minor upgrades based on the feedback from the round 1. The rounds 3 and 4 consisted of testing the system with the same iteration of the game than round 2, with different target audiences.



(a) *(b)*

Fig. 5. (a) Average trends between the different test rounds (b) Overall grade deviation at confidence level of 0.95

Table 1. The grades from the testing rounds and total (1-5, 1 worst, 5 best).

Round 1: Data Networks Engineering students group 1				**Round 3: Software Engineering and Games students**			
N = 13	Aver-age	Me-dian	Mode	N = 25	Aver-age	Me-dian	Mode
Overall grade	3,4	3	3	Overall grade	2,7	3	3
Under-standability	2,8	3	3	Under-standability	3,3	3	3
Usability	3,8	4	4	Usability	3,7	4	4
Interest	3,3	3	3	Interest	2,7	2	2
Learnability	3,3	3	3	Learnability	2,8	2	1
Graphics	2,8	3	2	Graphics	2,9	3	3
Technical solution	3,4	3	3	Technical solution	3,5	4	4
Round 2: Data Networks Engineering students group 2				**Round 4: Masters of Cybersecurity stu-dents**			
N = 9	Aver-age	Me-dian	Mode	N = 14	Aver-age	Me-dian	Mode
Overall grade	3,7	3	3	Overall grade	3,3	3	3
Under-standability	3,7	4	4	Understanda-bility	3,2	3	3
Usability	4,0	4	4	Usability	3,7	4	4
Interest	3,6	4	4	Interest	3,2	3	3
Learnability	3,7	4	4	Learnability	3,5	4	4
Graphics	3,0	3	2	Graphics	3,7	4	4
Technical solution	3,7	4	4	Technical so-lution	3,8	4	4
Totals all rounds combined							
N = 61	Aver-age	Me-dian	Mode				
Overall grade	3,13	3	3				
Under-standability	3,10	3	3				
Usability	3,72	4	4				
Interest	2,85	3	3				
Learnability	3,00	3	4				
Graphics	3,07	3	3				
Technical solution	3,54	4	4				

The most obvious feedback was that the 3rd round game developer students were the most critical user group towards the game (overall grade 2,7, mode 3; interest 2,7, mode 2; Learnability 2,8, mode 1) whereas the data networks engineering students in group 2 were the most positive test group (overall grade 3,7, mode 3; interest 3,6, mode 4). On the general characteristics, understandability, usability and technical solution were the only areas of the product, which could be considered universally at excellent level; in all other graded areas, at least one or more groups gave below-average score. Considering the general average grades, usability and technical solution were the only graded concepts which had above average grades in average grade, median and mode. The overall grade average of 3.13 (median and mode 3) was mediocre, but on the positive side of the average grade.

4.2. Open feedback

The open feedback on the system identified issues and bugs with the game prototype. Overall, the collected feedback criticized some of the designs and the difficulty curve of the game at the latter phases, but in general the open feedback more or less confirmed the grades and their reasons. The classification of the open feedback is in Table 2.

Table 2: The most common open feedback classification items

• Difficult to understand, needs better tutorial (47.5 percent of feedback)
• Positive comment regarding the game or the learning objectives (21.3 percent)
• Negative comment regarding the game or the learning objectives (18.0 percent)
• Button or interaction layout needs refining (18.0 percent)
• Needs quicker way to restart the session (16.4 percent)
• Last level is too difficult (9.8 percent)
• Does not work correctly or does not boot in the tested platform (9.8 percent)
• Did not like the visual style (4.9 percent)

The list includes the items which were mentioned more than once and included game-related information. Overall, the results reflect on the given grades; the most open comments complain that the game was difficult, and needed more instructions on what the player is expected to do in the game. The overall difficulty also reflects on some of the comments: the test users wanted to have way to restart their session if they got too many errors on the lower levels, since this barred them from achieving a high-score. Additionally, the highest difficulty level where the player needs to read the given package description in addition of visual clues was criticized for being a difficulty spike, along with some comments on the general user interface layout. Overall, the amount of positive and negative feedback was similar, roughly one fifth of the test users really liked the idea, and similarly roughly one fifth didn't find the game-based approach appealing.

5. DISCUSSION AND IMPLICATIONS

Based on the collected results from the test rounds, our game-like approach was not a complete success, but a starting point for developing the concept further. From the technical point of view, the tool was successful even though some students complained about issues especially with the mobile devices. The firewall game was tested with a varying groups of target audiences, and each test user was able to complete a test run with the software. This indicates that the selected platform and the game engine are sufficient for our purposes.

As mentioned earlier, we did observe that the software engineering and games – students, were very critical towards using a game-based approach. Their most common criticism was that the game basically functions as a memory game, and that the learning outcome was not very obvious. This group also gave uniformly worse grades than other test groups on almost all measured categories.

One of the possible reasons for the negative feedback could be the student-perceived difficulty and target audience for the tool. It could be reasonably expected that some students – especially those with prior knowledge on game development - can view the visualization tool as a crude game without much content. Similarly, the students with the network security background can view it as a toy aimed towards the lowest common denominator. This is a concern, but our development work aims towards general population, in which these issues should resolve themselves. In any case, the feedback indicates that the competitive aspect of the game is interesting and should be promoted, since the students commented on several occasions about the features related to a better high-score.

As for the future research on the tool, our results and literature [13-15] indicates that there are needs and opportunities for visual learning tools, especially ones enabling students to compete against each other. Obviously, some of the game elements and UI solutions need revisions. Also, the tutorial system needs development since almost half of the test users complained about confusion on their first session. As for our next practical step, we intent to test the gamification to teach cybersecurity with the game-like tools developed within the final context, and with the first group of actual long-distance students.

6. CONCLUSIONS

In this paper we present our initial observations on our development project to offer long-distance learning environment and course tools to teach cybersecurity concepts and other technically challenging topics. The developed course ecosystem is designed to include a virtual communications laboratory environment and online courses applying a number of gamified approaches.

The first game prototype was tested with an audience of 61 students with varying levels of experience on the data communications topics. These users were tasked to independently run a test session on the game, which illustrates and teaches the fundamental aspects of how firewalls function, and grade and record their opinions on a separate answer sheet. Based on their opinions and gradings, several observations were made on the feasibility and usability of these games.

The research questions "*what type of design issues there are in the technical construction of a virtual learning environment intended for teaching complex topics*" and "*how can we utilize the games in learning of cybersecurity issues*" can be answered to a certain degree by these results. First and foremost, the game design plays pivotal role on the user interest, and based on our results, the game by itself nor the ability to compete with the other students was not enough motivation for the students to engage with the tool. Similarly, even if the game promotes a fairly straightforward concept, it was criticized for being confusing and in need of better tutorials. With some test audiences, we observed things similar to Tullis and Albert [9] or Vânia et al. [13]: the students might feel that the visualizations and gamified tools are gimmicks, which do not enhance the learning outcomes.

In future, we will continue to develop our long-distance learning ecosystem, and provide more gamified content and game-like elements to the teaching tools. The next step with the game is to combine it with a virtual laboratory scenario and create a narrative to drive the learning scenario. For example, a story about an organization fighting cyber-attacks and fixing broken systems. The purpose would be to teach not only to understand the application control policies used on the firewalls, but to implement the application security policies with the modern tools.

The initial results were not overtly positive, but the approach was not completely rejected by the test users. Besides the narrative to guide the cybersecurity game sessions, our focus should generally be on the content development, providing challenging and engaging learning tools varying from simple games to teach the fundamentals, to the full-sized virtualized networks with realistic life-like assignments.

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Manuscript received on 21 May 2018