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Design of a Virtual Cybersecurity Escape Room

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Abstract. As cybersecurity education and training methods endeavor to build a skilled workforce to meet the growing demands of government and industry, it is important to craft training exercises to build and assess a learner's understanding of cybersecurity topics in a fun and meaningful way. To meet this need, we designed a concept map and virtual model of a collaborative, virtual cybersecurity escape room. Escape rooms, which are a form of serious games intended to increase knowledge and skills or measure learning outcomes, are scenario-based and interactive in nature. The artifacts described align the serious gaming elements with elements associated with the learning experience to assist game designers and educators in addressing the need for a collaborative virtual space where learners can practice skills associated with cybersecurity in a gamified manner.

Keywords: Cybersecurity · Escape room · Game · Virtual · Education · Training

1 Introduction

This research furthers escape room design, specifically related to cybersecurity in a virtual setting. It describes two artifacts: a concept map and a model of a collaborative cybersecurity virtual escape room. The concept map outlines the relationships of gamification, escape rooms, and learning skills to help future researchers transition content to virtual escape room environments. The map provides a way to represent meanings and ways the meanings are connected [1]. In this particular case, the concept map ties actions in the room to learning skills, enabling designers to adapt future models for a variety of cybersecurity-related learning outcomes.

The prototyped model incorporates the cybersecurity-related skills of social engineering, password security, and binary to create a collaborative virtual experience; therefore, the prototype provides a cybersecurity escape room model that can be used to teach key cybersecurity concepts. The mental map and prototyped model demonstrate how to create a learning experience to support cybersecurity education.

1.1 Motivation

Gamification, which is the use of rules and game design as a motivator to increase learning, has been adopted into a variety of areas, including training and education [2].

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It revolves around taking a task, such as learning, and making it more attractive to users by structuring it as a game [3]. Building on gamification is the concept of serious games, which are specifically designed to build knowledge, skills, and competencies and have focused learning outcomes. These games can be formatted as board games, strategy games, or action games (games of emergence), or they can require players to follow a set of predetermined actions to complete the game (progression games) [2].

Both games of emergence and games of progression are being adopted to teach cybersecurity-related skills. These games include capture the flag, cyber competitions, and board games [4]. The games have been both physical and virtual and teach topics from binary to phishing [5, 6]. Additionally, game based learning methods have been shown to be well received by students and instructors, as they provide immersive, learner-centered experiences [7].

One of the physical, progression games that is currently in use for cybersecurity education is escape rooms. The approach centers on problem-solving, where students resolve problems posed by the teacher, with the problems framed in the context of a story. The problems are often challenges or riddles, and the learners usually work collaboratively for a specified amount of time [3]. For example, researchers note using a physical escape room as part of their "teach then do" model, where they teach a skill and then have students show their understanding through escape room challenges [8]. This strategy was used to access student understanding of cryptography, data security, wireless protocol manipulation, and embedded systems attacks [8].

1.2 Problem Description

While the escape room game format is popular, the physical escape rooms are challenging to design, difficult to setup, and time consuming to reset. There is also the issue of creating rooms that are sturdy enough to handle multiple uses yet are not too costly to make [9].

Another problem with physical escape rooms is they require players to be in the same physical location. However, learners may be distributed across long distances [10]. One solution is to convert an escape room to a virtual environment. A virtual room would alleviate the need to reset the room, negate the issue of wear and tear on the props, and would allow distributed users to enjoy a collaborative experience.

This brings about the question of how to design a virtual cybersecurity escape room. The purpose of this paper is to first offer a concept map for a virtual escape room design and then utilize this mental model to create a model of a virtual escape room to be used for collaborative cybersecurity training and education. Models for educational simulations, including physical escape rooms, have been documented in the past; however, the proposed artifacts are concerned with maintaining the engagement and problem-solving aspects of physical escape room models while moving the game into a virtual, collaborative setting. The virtual model focuses on cybersecurity content, as the supply of skilled cybersecurity workers is very low [11]. Since one way to build cybersecurity talent is through education, a virtual escape room provides a means to educate learners while building interest in the field [12].

This virtual escape room model provides a way to overcome some of the challenges of physical escape rooms, while still providing learners with a fun educational experience. Hence, we address the following research question:

How to design a virtual escape room to support cybersecurity education?

2 Literature Review

Traditional learning is often teacher centered. This results in less student engagement, as the teacher is the main participant in the learning and serves as the primary diffuser of knowledge [3]. However, one trend is to shift to a learner-centered environment by creating learning by experience, sometimes using tasks and puzzles to promote learning through exploration/experimentation and to meet learner needs [13]. This gamification of learning through serious games helps to create a shift from teacher-centered to learning-centered environments, which also shifts the learners from being extrinsically motivated to being intrinsically motivated [3].

2.1 Benefits of Gamification

Gamification helps facilitate learning, as it can be can adapted to student interests to produce an understanding of content [3]. Part of this is engaging the students in the narrative. Serious games, specifically progression games, such as those found in escape rooms, have storytelling features [2]. This storytelling element is beneficial for learning, as "the advancement in computer technology has helped us in harnessing the story-telling delivered through an interactive and gaming environment" [14].

Interactive environments, which are a part of the gamification of training and education, are also less intimidating than traditional classrooms. The challenges and tests offer the freedom to make mistakes, and the associated rewards, such as badges, are more desirable to students than traditional grades [3]. The format of gamification, which lends itself to flipped classrooms and problem-based learning, is also a benefit. These benefits combine to provide a different motivation for learning than what is seen in traditional classroom rewards. Instead of grades, an extrinsic motivator, students receive a sense of accomplishment, an intrinsic motivator [3].

Indicators of successful gamification of learning include enjoyment, absorption, creative thinking, activation, absence of negative effect, and dominance (level of confidence of the participants) [3].

2.2 Benefits of Physical Escape Rooms

The escape room format is suitable for cybersecurity instruction as it is optimal for cooperative work, e.g. fostering teamwork, creating a high degree of student commitment to meet goals, and increasing engagement [3]. Additionally, the challenges are application based, meaning students progress beyond learning through memorization. This results in deeper learning, as the experimental aspects of the challenges quickly allow students to pinpoint and correct gaps in their knowledge [6].

The format of the serious game also promotes auxiliary skills, such as time management, the ability to prioritize tasks, communication skills, and practice in coping with stress [4]. While the stress produced during play can be negative, the researchers maintain hints and partial solutions, which are an integral part of escape rooms, can offset unhealthy stress and prevent frustration [4].

Escape rooms also increase student motivation and commitment to the task [3]. Researchers contrast this with traditional teaching practices, which they state "fail to attract or motivate students." Instead, escape rooms benefit and enhance academic results.

Other escape room research supports the format's ability to improve academic results. A recent study using pharmacy students found escape room learning was preferred by the majority of students (94.7%) and a majority of students felt they learned better through the format than traditional teaching methods [15].

2.3 Benefits of a Virtual Cybersecurity Learning Environment

Virtual games, specifically cybersecurity-related games, allow for realism and offer a way to study responses [5]. Such games are viewed as immersive, creating a level of engagement that makes it easier to engage, motive, and train users. Researchers note the benefits of a customizable gaming environment, such as can be created using the escape room format. A virtual cybersecurity escape room has the potential to leverage these benefits, helping support cybersecurity education. Specifically regarding cybersecurity virtual escape rooms, Deeb and Hickey [16] found virtual escape rooms provide authentic learning and are successful in teaching computer security and cryptography to novice students. As far as cybersecurity specific virtual escape rooms, an initial study of a prototype showed overall positive feedback, though participants were only asked to evaluate the playing experience [17]. This research indicates that a virtual escape room model specific to cybersecurity education has the potential to increases student understanding and interest.

2.4 Artifact Requirements

The design research artifacts are intended to support cybersecurity education and virtual escape room design. While Deeb and Hickey provide a 3D escape-the-room game and determine the approach to be successful in providing authentic learning to novice cybersecurity students, their research does not offer online collaborative play or document a concept map of the constructs to facilitate further cybersecurity virtual escape room design [16]. Similarly, Löffler et al. focus on transforming an existing physical game into virtual prototype, with little attention on collaborative play and not allowing for distributed play [17].

The goal of the research is to produce a model for a collaborative cybersecurity virtual escape room that retains the positive elements of a physical escape room while incorporating the benefits of a virtual platform. To reach this goal, we use design science research methodology (DSRM), meaning we identified the problem and motivation, defined objectives for a solution, and designed and developed a solution [18]. The design requirements are

- A virtual game that provided an escape room experience.
- A collaborative experience for distributed learners.
- An artifact that supports cybersecurity-related learning objectives.
- An experience that promotes the positive categories of activation (motivation, action, and reward).

- A tool that alleviates a time-consuming reset of the room, negates the issue of wear and tear on the props, and is cheaper than buying and maintaining props.

This research first involves the development of a virtual cybersecurity escape room framework that includes educational and gaming alignments and a primitive prototype of the game.

3 Artifact Design and Development

Our research approach to designing the virtual cybersecurity escape room seeks to satisfy the guidelines for design science in information systems research set forth by Hevner et al. [19]. We began with a survey of the elements of educational game design. In addition to focusing on educational gamification in general, we examined the elements of successful escape rooms and virtual games and the potential problems associated with both. Next, we determined the requirements of the artifact, designed and developed a construct map, used this map to develop a model specific to a collaborative cybersecurity escape room experience, and used virtual prototyping to determine the model's feasibility [18]. This process is based on Peffer et al.'s [18] nominal process sequence, meaning we identified the problem and motivation, defined the objectives of a solutions, designed and developed the artifacts, created a working prototype for demonstration, and defined possible pathways for evaluation and communication.

3.1 Virtual Cybersecurity Escape Room Concept Map

When examining the elements of successful escape rooms and virtual games, we listed relevant constructs and arranged them into a concept map [18]. As Hay et al. [20] note, mapping of relevant constructs and theories is useful in making comparisons and synthesizing information. First, we sought constructs related to activation. Activation is "participation of the learner in the learning process by learning something new" [3].

To build proper activation and promote learning, designs need a motivation, action, and reward. Motivation is defined as the incentive that draws learners into the game. Action is the activities or challenges the user is asked to complete, and the reward is when the learner completes the action and receives the incentive [2]. We added those constructs first to our concept map of processes and structures (see Fig. 1) [21].

Since escape rooms are a form of serious gaming, designers should take into account purpose, content, and play [20]. These elements align with the areas of mentioned by Marín-Vega et al. [2], with motivation mapping to purpose, action mapping to play, and reward mapping to purpose. Content, while not having a direct mapping, has ties to the three. These were added to the map. Eukel and Morrell [13], researching escape room design, describe the learning format as a game loop of overcoming a challenge, finding a solution, and obtaining a reward. Again, there is a relationship among these components (see Fig. 1). We combined the constructs to create a mental model of a virtual cybersecurity escape room.

This simple game loop, along with the additional contributions of Harteveld et al. [22] and Marín-Vega et al. [2] serve as the initial mental model for the virtual cybersecurity

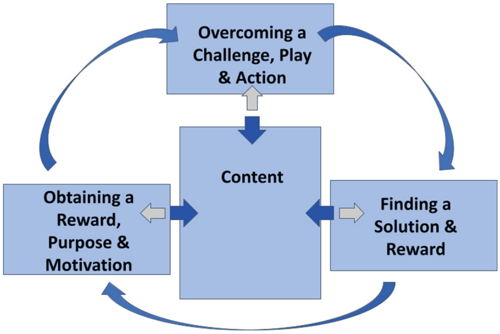

Fig. 1. Virtual cybersecurity escape room concept map.

escape room's design and requirements. Content, which includes the setting, characters, and in the case of serious games, the subject area, impacts the staging of the other elements in the loop. All of the elements and their relationships with each other must be considered in development.

3.2 Design/Refine of a Mental Model

While the concept map provided a scaffold for a virtual escape room, there are other elements to the escape room experience that must be included in the virtual design. Those include characters, a story line, environment, puzzles, hints, rules, distractors (red herrings), participant roles, and time limits.

Also, there are elements needed for a successful virtual gaming experience, including methods to denote achievements and feedback. Examples of these are scoring, progress bars, and timers, which are rewards and indicators of goal attainment [2].

To determine the best path forward, we grouped these elements into categories using the Virtual Cybersecurity Escape Room Concept Map. The goal was to align the items to the elements in the existing model and decide how they relate to a learning experience and a virtual environment. Here, we related content to characters, storyline, environment, distractors, and participant roles; as those elements promote interest and engagement but are not fundamental to the skill being taught. Rather, they contribute to the narrative of the story. For example, to assess a student's understanding of cryptography, the skills could be framed in a narrative centered around either WWII or outer space. These content-related items dictate the framing of the narrative (the setting and characters in the game), but the items do little to impact or assess the learner's understanding.

Puzzles, time limits, and rules are associated with overcoming a challenge. These elements are defined by the skill being taught. The puzzle must assess the knowledge of the skill, while time limits and rules determine the depth of knowledge expected. For example, a beginner may get more time and more lenient rules, but an advanced student might have time drastically reduced or have to adhere to more stringent rules. These items also impact virtual design as these indicators need to be included.

Hints are tied to finding a solution. This aspect assesses the learner's understanding of the task and ability to do the skill. At this point, the game design involves creating a productive struggle without pushing students to the point of frustration [3]. Well-timed hints assist with this.

Finally, obtaining a reward is associated with feedback. Whether a score, progress bar, or a badge, these gauge the learner's understanding of the skill (see Fig. 2). Feedback must be included in a virtual escape room. These skills were applied to the concept map, creating a mental model for future design. This map is a possibility of an outcome and provides a picture of reality to anticipate events [18, 23].

Fig. 2. Virtual cybersecurity escape room concept map with educational and gaming alignments.

As seen above, the educational aspects of the game fell in the outer rings (gaming loop) of the concept map, while the story aspects, which are more flexible and not associated with the specific learning skills, fell into the center (content) section of the frame, inside of the gaming loop. This informs the design as it applies to a virtual setting. Since the center of the mental model is flexible, it can be changed based on the desired theming of the game. However, the outer portions of the mental model should be customized based on skills and student ability, since these areas are tied directly to learning.

This is different than a physical escape room, where designers must consider available resources (props tied to the content/environment) in additional to educational objectives and game goals [13]. The use of a virtual environment lessons the impact of content on game design, as props to create an environment is no longer an issue. This is accounted for in the Virtual Cybersecurity Escape Room Concept Map through larger and darker arrows, representing that a virtual escape room is more skill-driven than narrative-driven. The smaller arrows, pointing away from the content, note that the content can have some impact on game design, but it is less than in a physical environment.

Skill-Driven Elements. As the game is for cybersecurity education, the design is driven by the skills being taught. Therefore, we listed skills that related to cybersecurity. We took into consideration how the skills would fit into a narrative and how easily they could be converted into an online puzzle. Using these as our criteria, we chose pretexting, password security, and binary.

Next, we mapped these skills to puzzles in a virtual space. For pretexting, students find hints in the room that indicated a person's likes or dislikes, which are used for social engineering. For password security, students use the pretexting information they found to answer common password recovery questions. For the last puzzle, they convert a base-10 number to binary, again relating back to a password recovery question. The hints are limited to how to find the needed information in the room and a time limit of 20 min is appropriate for the skills.

For motivation, the game relies on the satisfaction of accomplishing the task and a positive message when students discover the right answer. However, other rewards, such as a digital badge, could be added.

Narrative-Driven Elements. For game design involving a story element, Harteveld et al. [22] outline three steps: 1. Create characters and setting, 2. Create a visual narrative 3. Organize these in the form of dialogue, choice, action. To achieve a virtual escape room, we incorporated these steps in the room's design.

For characters and setting, we needed at least one hero and one villain. We determined the setting should be an apartment in modern times. For, the narrative, we endeavored to answer the questions who, what, when, where, why, and how to weave together a story. The *who* was hero Rush Walker, and the villain organization was the Silent Hand. The *what* was the evidence to help defeat the Silent Hand. The *when* was a 20-min time frame before the participants lost the game. The *where* was an apartment in modern times. The *why* was to save Rush Walker and help find evidence to bring the Silent Hand to justice. The *how* was finding the PIN to unlock the safe deposit box.

Combining the Elements. These elements combine to form the model for the virtual escape room (see Fig. 3). This model demonstrates the relationship of cybersecurity virtual escape room elements, as it shows the relationship among the constructs and how to they relate to cybersecurity virtual escape rooms [24].

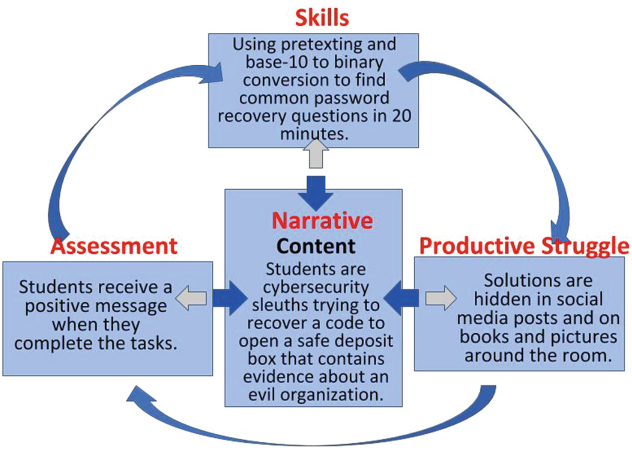

Fig. 3. Virtual cybersecurity escape room model using the concept map.

After populating the mental model with elements for the specific learning model, we created a puzzle chain for the room. This progression chain demonstrates how the narrative-driven elements in the room interact with the skill-driven elements in the room to create a series of puzzle to assess learners' skills (see Fig. 4).

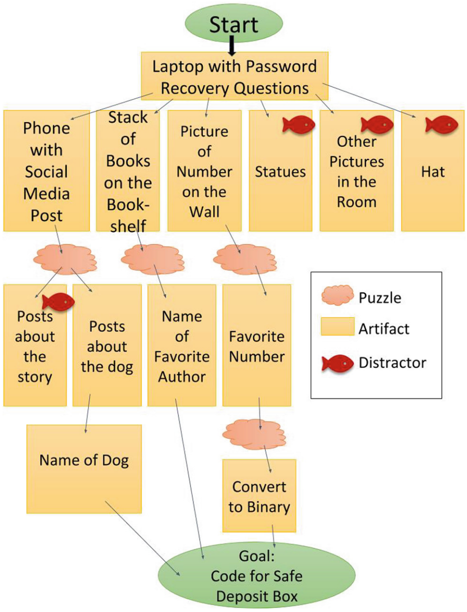

Fig. 4. Puzzle chain.

The puzzle chain is a guide room design in the virtual setting and is an answer key for teachers or others who may be facilitating the play inside the virtual space. The puzzles were arranged in a hybrid fashion, but the design could be adapted to be path-based or sequential, depending on the training needs [9].

3.3 Model Prototyping

To determine if the design could meet the requirements, we prototyped the room in virtual Mozilla Hubs. Mozilla Hubs is a browser-based collaboration platform that allows designers to create and customize virtual environments [25]. This strategy is similar to that of Harteveld et al. [22], who used paper prototypes to create "quick-and-dirty mockups to get quick feedback on design ideas from users without needing to fully implement them." The Mozilla Hubs environment serves as a mockup of a virtual escape room. Link: https://hubs.mozilla.com/jjnf73F/the-silent-hand.

From the existing Mozilla Hubs rooms, we selected one resembling an apartment and began populating the room with items in the puzzle chain. Figure 5 is an example of how the room looks upon entering. The storyboard is in a prominent location to serve as a starting point for play [2].

Fig. 5. View upon entering the room.

Due to the room's limited functionality, we added work-arounds to mock-up the interactive aspects of the room. For example, for the users to see the password reset question, we had to embed a link for a Google Form, which opens up a new tab and takes them outside of the Hubs room.

We repeated this strategy for the mobile device that was designed to display a social media post. For it to work, we embedded a link to another site, which we used to create a fake social media post. This post was needed to test social engineering pretexting skills, as the students would have to read the post to find the dog's name for the password recovery question.

The use of these elements could create a problem for learners who have never used this type of virtual environment, as they might have trouble finding and using the open link button for the two props. These elements will be corrected for the game's final design.

Another problem with the mock-up that detracts from the realism of the game is the timer. The only way to embed a timer into the mock-up that would start automatically was to use a GIF. This limits the functionality of the timer, as it only counts down for a few seconds. This is an element that will be corrected in the final game design.Even with the limited functionality of the protype's environment, we were still able to populate the room in an effort to see if the design could meet our requirements.

Aside from work-arounds, the room is indicative of the design. We had no trouble adding the other clues needed for the password recovery questions and hints and rules as specified by our design.

4 Demonstration and Evaluation

Demonstration, which is presenting the artifact in a manner to determine its use for solving one or more aspects of the problem, can involve strategies such as simulations or proof of concept activities [18]. This could be using a workshop to determine the feasibility of an artifact or recruiting stakeholders for expert review, both examples of using demonstrations to determine how well an artifact aligns to design requirements [26, 27].

For the demonstration phase, we will utilize a workshop approach to determine the feasibility of the artifact. A survey will be sent out to 10 high school educators who teach cybersecurity, inviting them to explore the virtual escape room through a link. The survey will consist of questions centering around the initial design requirements. The following questions will be used

- Is the virtual environment similar to an actual escape room?
- Can multiple users enter the space and effectively communicate through audio and chat features; thereby supporting collaborative distributed play?
- Does the design support the skills of pretexting (social engineering), password security, and binary?
- Does the design promote positive categories of activation (motivation, action, and reward)?
- How does the game compare to the physical escape room in regard to alleviating reset of the room, wear and tear on props, and cost of buying and maintaining props?

Open-ended questions will be added to allow participants the opportunity to explain their answers. The responses will be collected using Google Forms, with respondents being asked to rate the degree of their response using a Likert scale ranging from 1 to 5, with 1 being *Does not meet the requirement* and 5 being *Highly meets the requirement*. The scale is intended to assess the degree that respondents feel the artifact aligns with each of the design requirements [28].

Provided that the demonstration indicates the artifact satisfies the design requirements, we will follow Peffer et al.'s [18] DSRM Process Model by having students evaluate the model. This will determine how the game impacts the intended audience.

After comparing various evaluation models, including those by Su et al., Lopez-Belmonte et al. and Hogberg et al., we determined that Su et al.'s framework provides a better coverage of the topics being evaluated and will be used as a guide for developing an evaluation [3, 29]. Additionally, as demonstrated by Couceiro [30], we determined to capture content-related knowledge gained from the activity. This will be achieved using a pretest and posttest.

The demonstration and evaluations will be completed during the next phase of the research.

5 Contribution, Limitations, and Future Work

The use of a virtual platform, as described here for a cybersecurity escape room alleviates a time-consuming reset of a physical room, negates the issue of wear and tear on physical props, and is cheaper than buying and maintaining props.

Aside from making escape room facilitation easier, the research furthers escape room design, specifically in a virtual setting. For example, the concept map informs researchers and game designers on a mental model for a cybersecurity-related, collaborative virtual escape room. It outlines the relationship of gamification, escape room components, and learning skills to help researchers transition content topics to a virtual escape room environment. The concept map also ties actions in the room to learning skills, enabling designers to adapt future models for a variety of educational outcomes.

The research furthers the knowledge of moving the escape room format into a virtual environment by incorporating the skills of social engineering, password security, and binary and making it a collaborative experience; therefore, the cybersecurity content specific prototype provides a virtual cybersecurity escape room model that can be used to teach students social engineering, password security, and binary in a distributed, yet collaborative, format. The game can be utilized in classrooms for training environments to assess learner understanding and promote interest in the field. The prototype demonstrates that such a learning experience is possible to support cybersecurity education.

As the research only allowed for primitive prototyping, future research will involve transitioning the game to an insanitation for further evaluations. Additionally, the future work should evaluate the user and hosts experiences to determine its degree of usefulness in supporting cybersecurity learning outcomes.

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