Framing Gamification in Undergraduate Cybersecurity Education

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***Abstract*—Gamification presents potential benefits in courses that traditionally require the comprehension of complex concepts and a high level of technical and abstract thinking. Courses in Cyber Security Operations (CSO) undergraduate education meet these criterion.**

This research evaluates organizational constructs that have been applied to gamification applications (GAs) in CSO education. It utilizes framing theory and frame-reflective discourse analysis to outline frames based on engagement levels and analyzes the current distribution of GAs.

The following organizational constructs for GAs in data structures and algorithms education apply to CSO education: Enhanced Examination (EE), Visualization of Abstract Ideas (VAI), Dynamic Gamification (DG), Social and Collaborative Engagement (SGE), and Collaborative Gamification Development (CGD). Three additional frames are identified: Missions and Quests (MQ), Simulations (Sim) and Aspirational Learning (AL). MQ GAs have process-driven quests, stories, and/or descriptive scenarios to augment engagement. Sim GAs use environmental immersion to demonstrate real world problem solving while allowing freedom of movement. AL GAs use goal-based designs like Capture The Flag (CTF) missions to enhance engagement.

Twenty-seven existing CSO GAs fit within the MQ frame as CSO education lends itself well to these types of experiences. Seventeen CSO GAs fall within the AL GA frame, many of these manifesting as CTF missions. Seventeen CSO GAs fit in the EE Frame due to their optimization in the analysis of learning progress. Nine Sim GAs were successfully deployed in CSO education, followed by 4 VAI, 3 SGE, and 3 DG GAs.

***Keywords*—Cyber Security Education, Gamification, Framing Theory, Game-based learning, Pedagogy**

I. INTRODUCTION

Gamification is defined by Deterding et al. [1] as the use of game elements in non-game environments. This can take a wide variety of forms, but each exhibits game-like characteristics such as leaderboards, badges, competitive elements, cooperation, communication, and advanced computer imaging [2]. Gamification refers to the use of game elements and game design techniques to augment or improve learning [3]. Most significantly, gamification as a practice demonstrates a notable increase in student engagement and motivation when implemented correctly [4]. Due to this increase in student engagement, gamification finds itself at the intersection of many fast growing, technological fields, such as cybersecurity operations (CSO).

According to the Bureau of Labor Statistics, cybersecurity related occupations are slated to increase as much as 33% between 2020 and 2030 [5]. As networks get bigger and faster, as social media sites become more comprehensive, and as our world becomes more digitally connected, cybercrime and the need for professionals tasked with keeping it at bay will continue to grow at incredible rates [6]. As it stands, the number of CSO professionals is woefully under populated. According to the Information System Security Association [7], the CSO skills crisis is now entering its fifth year, and the outlook isn't improving.

II. STUDY DESIGN

In an effort to better improve and streamline CSO education in gamification to meet industry demands, a framing of existing gamification applications (GAs) used in CSO undergraduate education can provide essential insights into the health and state of gamification in cybersecurity as a whole. This research seeks to organize the comprehensive set of GAs evaluated for use in undergraduate CSO education summarized in [8]. This study also seeks to identify common characteristics of GAs in undergraduate CSO education for the purpose of: 1) understanding the value each GA added to the educational experience and 2) framing CSO GAs accordingly. To achieve these goals, we establish the following research questions:

- **RQ1**. Organizational Constructs. What constructs exist that help identify and organize intrinsic characteristics of GAs for CSO education?
- **RQ2**. Characteristics. What characteristics naturally provide order and structure for CSO GAs?
- **RQ3**. Framing. For each CSO GA identified, within which identified frame does it fit?

III. ORGANIZATIONAL CONSTRUCTS

Organizational constructs are those structures that add form and arrangement such that complex systems and domains can be better understood. This includes classifications, taxonomies, and other hierarchical organizational structures [9]. Classifying and organizing items into categories is an important scientific endeavor for describing and understanding related items. For example, in 1735, Linnaeus wrote the Systema Naturae [10], which was indispensable as a foundation zoological nomenclature. On a much smaller scale, this research seeks an organizational construct for the set of GAs evaluated for use in undergraduate CSO education. The intended purpose of RQ1 is to: (1) study existing schematic systems, (2) identify a system useful for describing CSO education GAs, and (3) modify this system as emergent characteristics appear.

A. Classification System

There are currently several classification systems based on game elements. Two such classification system examples are outlined in [11], [12]. According to Werbach and Hunter [11], the most important game dynamics are constraints, emotions, narrative, progression and relationships. Dicheva et al. [12] classified educational gamification research by game mechanics, context of applying gamification, implementation, and evaluation. During their classification process, [12] primarily used Deterding's classification [1] of game design elements. They also identified educational gamification design principles [13] such as goals, challenges and quests, customizations, progress, feedback, etc.

Monteiro et al. [14] created a framework for evaluating gamification systems in software engineering education. They found that the most common evaluation criteria in gamification lies in "engagement", "motivation", and "satisfaction".

Toda et al. [15] created an element-based taxonomy for classifying GAs along five dimensions: performance, ecological, social, personal, and fictional. The performance measures are related to the environment response which can be used to provide feedback to the learner. Multiple GAs were evaluated along these dimensions, and rated in each dimension with a 1-5 rating.

Gonzalez et al. [16] developed a classification taxonomy for cybersecurity aligned with cybersecurity training materials. Some of the resources described were designed for students; however, many were not. Because of the rapidly evolving state of gamification in cybersecurity education, many of the resources listed are no longer available while many new applications have been developed. Similarly, Chattopadhyay et al. [17] reviewed several popular cybersecurity educational games as they relate to the coverage of CSO curricular guidelines [18]. However, no classification system was presented in either of these.

Petri and Wangenheim [19] identified and evaluated seven different approaches to systematically evaluate educational games. Three approaches present a framework, including a framework to "identify what can potentially be evaluated in a GBL application", a framework to "help tutors to evaluate the potential of using games and simulation-based learning in their practice", and a framework to "assess the efficiency of GBL focusing on engineering education". They identified two approaches that present a scale, one aimed at selecting good educational computer games and another to assess "user enjoyment of e-learning games to help developers to understand strengths and weaknesses from the students' perception". The final approach was a "comprehensive methodology for the research and evaluation of serious games", which "assesses serious games in three different moments (pre-game, in-game, and post-game)." While these approaches provide ways to evaluate aspects of individual GAs, they do not provide an organizational construct system for ordering GAs into groupings.

Carvalho et al. [20] presented Activity Theory-based Model of Serious Games (ATMSG) which has the objective of "supporting the analysis and design of serious games when a thorough understanding of the characteristics of the game is needed". Based on ATMSG, Karagiannis et al. [21], present the COFELET ontology as a way to describe the *key elements that such approaches should embrace to assimilate well known cyber security threat analysis and modeling standards as the means to create interesting educational experiences*. The COFELET ontology was extended with *the additional elements of learning objective, grade scheme and role* in [22]. While the ATMSG model, the COFELET ontology, and similar models, provide good ways to evaluate aspects of individual GAs, they do not provide an organizational construct system for ordering GAs into groupings.

Spanier et al. [23] reviewed eight data structures and algorithms (DSA) GAs and created a systematic characteristic-based organizational construct for DSA GAs. Rather than using the sum of game element performance as in [11], [12], [23] provided a holistic and qualitative approach to organization based on emergent characteristics of GAs. The system presented in [23] consists of five categories: 1) Enhanced Examination (EE), 2) Visualization of Abstract Ideas (VAI), 3) Dynamic Gamification (DG), 4) Social and Collaborative Engagement (SCE), and 5) Collaborative Gamification Development (CGD).

B. Framing Theory

Mayer [24] explains that providing clear definitions and/or developing classifications or taxonomies is challenging in emerging interdisciplinary research areas, such as gamification, and can *"kill innovation because new combinations cannot be boxed"*. Instead of classifications, Mayer [24] uses framing theory [25] and frame-reflective discourse analysis [26] as a better way to *dissect how to define serious games and the effect they have on the broader discussion of the issue. Framing is the act of attributing meaning to events and phenomena; a way of creating order out of chaos by providing a critical analysis of the multiple, often conflicting, ways in which we perceive and discuss the utility of games* [24]. Frames are defined as *definitions of the situation [that] are built up in accordance with the principles* *of organization which govern events—at least social ones—and our subjective involvement in them* [25]. Similar to [24]'s framing of serious games, frame analysis is useful to answering RQ1 and providing structure to CSO gamification usage, as it provides a distinction between the interpretation of what is going on while a student is using the CSO GA, and the interpretation of the phenomena behind these experiences.

IV. CSO GAMIFICATION FRAMES AND APPLICATIONS

To understand the current state of gamification in CSO education, a comprehensive study of existing gamification implementations in CSO coursework was completed [8]. That study found 74 primary studies that used and evaluated GAs in undergraduate CSO education. Some publications discussed multiple GAs, resulting in a total of 80 undergraduate CSO GAs to be evaluated.

The intended purpose of RQ2 is to understand GAs from a characteristic-based point of view. Due to the qualitative and emergent nature of RQ2, the answer evolves as CSO gamification applications are discovered and synthesized.

Like the key elements in the game-based learning evaluation model [27], characteristics that are key to formalizing the frames include: the intended purpose of the GA; the level of engagement the student can experience with the GA; the level of immersion the student can experience within the GA; the level of control the player has to manipulate or co-design the game world; the level of social interaction available in the GA; and the level of self-directedness available in the GA.

In this study, each GA discovered in [8] was evaluated and its primary characteristics identified. No judgment was made about the quality and value of the GAs, but the explanation provided for the GA and its evaluation in undergraduate CSO education were used as a means to place it into a given frame, as an answer to RQ3, as shown in [28]. The framing system used in this paper is meaningful to explain how experiences with GAs in CSO undergraduate education are organized. *Although the frames are relative, they are not irrelevant. They structure ongoing discourses about what the GA can and cannot do in terms of learning and change*. [24].

During this study, several distinct patterns emerged. Like the DSA GAs studied in Spanier et al. [23], 1) several applications added a gamified interface to a quiz or exercise program, 2) some applications utilized visualization to describe abstract ideas, and 3) some utilized ideas concerning social and collaborative engagement. These patterns offer a ready means to facilitate the evaluation of the organizational constructs identified above. Because the patterns that emerged match those identified in Spanier et al. [23], the schema defined in that study is the best answer to RQ1 and provides a starting point for RQ2. This research then applies framing theory for more flexibility in the organization and analysis of GAs.

When progressively applying the system as proposed in [23] to CSO GAs discovered in [8], many CSO GAs reveal the emergence of novel ontological characteristic patterns. These novel patterns in CSO indicate potentially missing frames required to effectively stratify CSO GAs. Upon the discovery of these patterns, each pattern received a name and was given its own unique frame. Each GA was subsequently scored based on its most significant characteristics and placed in the most applicable frame. In observing the emergent characteristics of these CSO GA orphans, this research determined that many CSO GAs fit into three additional frames: Missions and Quests, Simulations, and Aspirational Learning.

This combination provided for the sufficient stratification of CSO education GAs. The resulting scheme provides a complete answer to RQ2 and has eight frames: (1) Enhanced Examination, (2) Visualization of Abstract Ideas, (3) Missions and Quests, (4) Simulations, (5) Aspirational Learning, (6) Dynamic Gamification, (7) Social and Collaborative Engagement, and (8) Collaborative Gamification Development.

In the contextual analysis below, a brief description of each gamification frame is rendered in response to RQ2. In response to R3, GAs that fit within each frame are listed at [28]. With such knowledge, a better more generalized understanding of the state of the discipline can be achieved. Like Mayer's [24] frame analysis for serious games, the reader is welcome to find undergraduate CSO gamification examples *that fit, or do not fit, these frames, and then to come up with new, complementary or competing frames, because that is how frame analysis should work*. Rather than sum the elements of a given application to achieve a description, this research desires a holistic approach to RQ2 that examines the overarching characteristics. Table I summarizes the number of CSO GAs in each frame.

TABLE I. GAS IN CSO EDUCATION BY FRAME

Enhanced Examination (EE)	17
Visualization of Abstract Ideas (VAI)	4
Missions and Quests (MQ)	27
Simulations(Sim)	9
Aspirational Learning (AL)	17
Dynamic Gamification (DG)	3
Social and Collaborative Engagement (SCE)	3
Collaborative Gamification Development (CGD)	0
Total CSO GAs	80

A. *Enhanced Examinations (EE)*

Tests and quizzes by their very nature tend to be tedious and disengaging. EE GAs attempt to better engage students within the context of an exam, quiz, or homework by providing a graphically attractive and/or interactive interface [23]. Seventeen of the GAs discovered by [8] are listed on [28] as fitting the EE frame. For example, generalized education gamification frameworks such as *Socrative* [29], *Kahoot!* [30], *Seppo* [31] and *OneUP* [32], [33] have been applied to CSO education [34] and thus fit withing the EE frame. *UltraLearn* [35] is a platform similar to *OneUp*, designed to teach cybersecurity to learners with any background. *GamifiedLearn* [36] is a similar e-learning system.

B. Visualization of Abstract Ideas (VAI)

Many CSO education GAs utilize visualization to describe abstract ideas that are difficult to comprehend [23]. Additionally, visualizations effectively and flexibly demonstrate a step-by-step walk-through of abstract ideas. Four undergraduate CSO GAs found in [8] fit within the VAI frame and are listed on [28]. For example, Zhang et al. [37] created a web-based interactive visualization tool that aims to help students gain a deeper understanding of buffer overflow concepts. It is played as an online game with an analytics dashboard, leaderboards, quizzes, coins and points.

C. Missions and Quests (MQ)

To enhance engagement, several CSO education GAs add a story line and well-defined step-by-step processes that enable students to complete quests as they progressively learn content. GAs in the MQ frame derive their main characteristics from the required steps needed to take to reach the conclusion. The level of engagement, immersion, and control that the student can experience with a MQ-based GA is typically higher than EE-based GAs, even though these GAs still include a means to evaluate student learning. For example, cybersecurity virtual escape rooms provide fun MQ GAs [38]–[41]. Twenty-seven of the CSO education GAs discovered in [8] are listed in the MQ frame on [28].

Representative MQ GAs include *CounterMeasures*, a series of guided security missions [42], *BashDungeon*, an adventure inside a dungeon, aimed at reproducing the topology of a Unix file system [43], *Temple of Treasures*, a 2D game to learn Discretionary Access Control and Mandatory Access Control, where the player is in search of gold, stuck in a temple, and needing to gain knowledge on targeted concepts to unlock the doors along the escape pathways [44], and *SherLOCKED*, a 2D top-down puzzle adventure game to help students' knowledge of foundational security concepts [45].

D. Simulations (Sim)

Simulations provide environmental ambiance and context, oftentimes via immersive content, into which narrative and story are integrated to bolster engagement [46], [47]. In simulations, players are free to move around and explore the environment. Nine CSO education GAs found in [8] are listed as simulations in [28]. For example, *QuaSim* [47] is a 3D GA that poses quantum cryptographic problems developed by domain experts to students who interactively move around the environment to find the solutions. It also facilitates collaborative and competitive project-based student learning of quantum principles.

E. Aspirational Learning (AL)

In CSO education, many educators make use of goal driven simulations, test-beds and competitions to augment student learning ([48], [49], [50]). While these CSO GAs may appear similar to MQ-based or simulation GAs, GAs that fit into the AL frame are differentiated in that no predefined step-based process is required; the student simply needs to accomplish some goal in any way possible as fast as possible. Many of the GAs in the AL frame involve a Capture the Flag competition. Sixteen CSO education GAs found in [8] are listed in the AL frame in [28].

For example, two Jeopardy-style CTFs were used and evaluated in CSO education in [51]. The CTF competitions consisted of challenges covering several security topics, but did not have a specific scenario or context for the applications. Similarly, a virtual-machine (VM) based CTF framework was created by [52], for CSO students to complete Jeopardy-style CTF challenges. They also focused on technical skills and understanding and were not based on a specific scenario. For all exercises, students were required to submit written answers describing the steps they took to recover flags from the VM, and — where appropriate — a description of what the vulnerabilities were and how they worked, and an explanation of how they could be fixed [52].

F. Dynamic Gamification (DG)

DG is defined as any GA that dynamically changes according to user input throughout its gamified life-cycle. As stated in [23], *"DG would still exhibit the same sorts of game mechanics applied in other GAs (e.g., leaderboards, avatars, badges, awards, graphical interfaces, missions, objectives, etc.), but would add a layer of student-led game development"*. The student-led innovations within a given game framework provide the dynamic shift in the look, feel, game mechanics, and the overall set of characteristics exhibited by a given gamification app implementation; enabling students to take ownership of the gamification experience.

DG is a form of discovery learning that follows Bruner's Constructivism Theory [53]. Bruner's theory on constructivism encompasses the idea that "learning is an active process in which learners construct new ideas or concepts based upon their current/past experience or knowledge" and "students and instructor should engage in active dialog" [53]. Bruner's earlier work [54] established that a good teacher will facilitate the learning process by designing lessons that help students discover the relationship between bits of information. DG also provides students with a software development experience [23]. This realism can help students, not only learn the concepts, but also self-actualize in terms of seeing themselves as software developers [23].

Three CSO GAs discovered in [8] exhibit DG characteristics as listed in [28]. For example, in [55], students participate in a game-development based learning project that sees the individual create different penetration testing games. The students report they enjoyed a unique opportunity to deeply understand the topic and practice their soft skills as they presented their results. Their peers, who played the created games, rated the quality and educational value of the games as overwhelmingly positive [55]. While the application of this process sees students interacting with unrelated static gamification iterations, the game development pre-phase inherent in all DG GAs is explicitly present.

As another DG example, McGregor et al. (2022) present the Citadel Programming Lab which comprises a GitLab instance for simulated secure programming tasks and a tower defense game. In this game environment, students first play the tutorial level, which exposes them to the purpose of game and gameplay mechanics. This is followed by the students playing the main level, which exposes them to security metaphors, helps them develop motivation to defend their goal and allows them to earn points. Students can then spend points to unlock upgrades, which some upgrade tiers require solving a programming task and reviewing other solutions.

G. Social and Collaborative Engagement (SCE)

SCE GAs allow students to regularly and easily interact such that student motivation and engagement are improved [23]. Three CSO education GAs found in [8] exhibit SCE frame characteristics and are listed in [28]. For example, *PeerSpace* is a network based collaborative learning environment created by Li et al., [56]. It utilizes elements like peer review, project repositories, wikis, profiles, friends, blogs and discussions to build relationships and encourage collaboration between students. It also provides a game section which students can use to better understand the coursework.

H. Collaborative Gamification Development (CGD)

CGD pertains to applications that utilize collaborative student involvement in the formation of a dynamic gamification framework [23]. The development of the framework by the student participants can add another level of gamification customization and abstraction that can offer a far more accommodating and engaging environment for students. Currently [57] contains elements of CGD yet falls within the SCE frame as its primary characteristic attributes placed it within that frame.

V. DISCUSSION

In seeking a solution to RQ1, multiple gamification classification systems were identified and evaluated. While quantitative classifications based on the summation of game mechanics provides valuable insight into the inner evaluations of GAs, a frame-theory based schema focused on engagement augmented from the schema in [23] appears to fit more closely with the objectives set forth in this research.

As an answer to RQ2, this research determined that many CSO GAs exhibited characteristics that placed them naturally into the frames from [23]. Other CSO GAs exhibited characteristics that formalized three additional frames: MQ, Sim, and AL.

After observing emergent characteristics of the CSO GAs collected by [8], each GA was placed into the frame in which it best fit. This organization and evaluation by characteristics serves to answer RQ3 with a summary of GAs by frame shown in Table I and the complete listing in [28]. The most populated frame was the MQ frame, with twenty-seven existing CSO GAs, as CSO education lends itself well to these types of experiences. The next most populated frames were AL GAs (17), including several CTF missions, and EE (17), as GAs make excellent tools for testing learning progress.

In observing the relationships between the frame types examined, two emergent dimensions appear to materialize that delineate certain frames away from each other. These dimensions are: 1) Engagement and 2) Social Interaction. EE, VAI, MQ, Sim, and AL are generally motivated by a need to better motivate and engage students. SCE, DG, and CGD, on the other hand, focus more on how students engaged in Engagement-level GAs interact with each other. As the frames increase along the engagement dimension, different levels of social interactivity can be applied to them by sliding them across the social interaction dimension. These apparent dimensions allow combinations of social interaction frames and engagement frames (e.g. DG EE, SCE VAI, etc.) to be formulated for potentially more concise user outcomes.

VI. FUTURE WORK AND CONCLUSIONS

In future work, the researchers intend to focus on more concise, accurate, and comprehensive characteristic-based framing. More research is needed to better understand the relationship between engagement levels and characteristic-based gamification frames as well as engagement levels and their relation to socialization among students in GAs. Further research and development must be carried out to better understand the benefits, detriments, and functionality of these GAs frames, especially as applied to other educational domains. A comprehensive study of GAs in computer science undergraduate education is forthcoming from the researchers and seeks to discover if the framing schema identified in this paper applies.

Further work should be dedicated to creating a better understanding of the observed emergent dimensionality existing between the engagement and social interaction frames appearing in this work. By expanding and correlating the existing organization structures observed here along a two-dimensional plane, a better comprehension of how GAs can be delineated could be achieved.

As a characteristic-based organizational construct for CSO GAs, this research identified and used eight frames: (1) Enhanced Examination, (2) Visualization of Abstract Ideas, (3) Missions and Quests, (4) Simulations, (5) Aspirational Learning, (6) Dynamic Gamification, (7) Social and Collaborative Engagement, and (8) Collaborative Gamification Development.

Understanding the organizational constructs that have been used to organize GAs provides a broad overview of where effort is being placed in CSO gamification development and can help researchers better gauge which areas in CSO gamification need more attention. Using framing analysis of GAs in CSO undergraduate education is useful in determining the current state of the usage of GAs as it provides a distinction between the interpretation of what is going on while a student is using the GA, and the interpretation of the phenomena behind these experiences.

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