Gamification in Cybersecurity Education; the RAD-SIM Framework for Effective Learning

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Abstract: The effectiveness of gamification in educational technology and digital learning environments has been the subject of research for over a decade. Gamified interventions encourage active learning by promoting role-playing, mentalisation, and experimentation. Learner-centred approaches have been shown to increase learning outcomes compared to traditional methods in some domains. Although the behavioural drivers associated with gamified learning are now well documented, practical advice for game designers who produce workplace training is much less common. This paper proposes the RAD-SIM framework for behaviourally effective cybersecurity games design, whereby psychological and behavioural principles are combined with learning theories to facilitate practical game-based learning. Using the framework will increase the engagement and retention of knowledge of the end-user. Although designed with cybersecurity training in mind, there are implications for educational game design in general. Future avenues for research, including potential case studies in practice, increasing the customisability of gamified interventions, and utilising natural data from organisations are considered.

Keywords: learning, gamification, cybersecurity, games design.

1. Introduction

Over the last three decades, digital technology has grappled to find its place as an educational tool. Although it has clear educational benefits, a trial-and-error approach has led to misguided application. Game-based learning (GBL) has been shown to increase reported enjoyment and engagement with educational content across domains, which is often the first hurdle for successful learning. There has been a particular focus on engaging children and young people by using GBL approaches (e.g., Gros, 2007; Hamari, et al., 2016; Miller, 2015; Ott & Pozzi, 2012), but there is a growing literature which supports their use with older audiences (Charlier, et al., 2012; Wang & Burton, 2010; Whitton, 2011). Furthermore, GBL can increase problem-solving abilities and promote faster knowledge acquisition, compared to traditional teaching methods (Perrotta, et al., 2013). A recent literature review of 24 empirical research papers found that GBL may also increase both the quality and quantity of data available to researchers in this area, as well as facilitate the learning process in content-heavy subjects such as science and mathematics (Kalogiannakis, et al., 2021). The review found that GBL in science education can have a positive impact on academic performance more broadly, suggesting a permeating effect of gamification across different contexts.

However, the evidence that GBL is an effective method of teaching is inconsistent and often unreliable, in part because of a reliance on small sample sizes and a focus on undergraduate and WEIRD populations (Alwi, et al., 2017; Kebritchi, et al., 2010; Kosa, et al., 2016). Evaluating GBL in organisational settings can help fill the gaps resulting from this imbalance. Creating a broader understanding of the behavioural mechanisms associated with GBL by examining its effect on adults of all ages will provide a much richer understanding of the behavioural drivers of learning in general. Since learning is a ubiquitous feature of all domains, creating an evidence base which documents the pitfalls and potential of GBL interventions is valuable to practitioners of all professions.

GBL approaches are increasingly popular in the field of cybersecurity, perhaps because of a growing consensus that cybersecurity is not just a technical specialism. As such, organisations need a training medium that is not only effective but also well-received. This has resulted in a wealth of literature on GBL cybersecurity interventions, with a target population of varying abilities, contexts, learning preferences, motivations, and social environments. This plethora of scientific and industry material presents an opportunity to investigate the behavioural drivers and contextual factors associated with GBL across several fields, such as criminal justice, healthcare, education, and psychology. Building upon a literature review focused primarily on gamification in the field of cybersecurity, the RAD-SIM framework is proposed as a practical guide for training designers to follow when creating gamified interventions. The RAD-SIM framework combines practical elements of gamification (behavioural response, perceived attack, and game design) with the behavioural principles of sociality, incentivisation, and mentalisation to promote more effective gamification in cybersecurity training.

2. Method

2.1 Research Questions

The overarching question of "How can gamification best support the training of users against socially engineered cyber-attacks?" was separated into three targeted research questions for literature review:

1. What gamified training works best for who, how, and why, to protect against different types of socially engineered cyber-attacks?
2. What empirical evidence supports these claims?
3. What types of gamification have been developed for other sectors that may be relevant to this area?

The aim of the literature review was to construct a narrative using these questions as a guide. This resulted in a general description of GBL literature across the cybersecurity domain, with reference to other relevant fields. This formed the foundation for the RAD-SIM framework.

2.2 Generation of Coding Criteria for Literature Review

An interdisciplinary subject matter expert (ISME) workshop was conducted by a panel including an Applied Behavioural Scientist; a Senior Lecturer in Childhood Studies, an Educational Psychologist; a Social Psychologist; and a Cyber Risk Specialist. The scoping parameters and coding criteria for the literature review were identified and used to create a table of PICO search terms. This translated into search strings (available upon request) used to search PsychINFO, Web of Science, Scopus, and ACM Digital Library.

A total of 250 papers were coded for this review. Identifying information was recorded alongside details specifying focus (e.g., cybersecurity-related, or not). The 'key gist of results' was recorded qualitatively, and relevance to theory was noted. Coders used a strategy as defined in the ISME workshop, identifying themes related to user vulnerability (e.g., phishing), types of training (e.g., cybersecurity specific), different user needs (e.g., learner differences), domains of interest (e.g., online/offline training), organisational/user processes (e.g., influence) and assessing impact (e.g., evaluation method).

2.3 Content Analysis and Narrative Synthesis

Content analysis was used to identify prominent concepts/themes relevant to the coding protocol. Researchers used keywords, determined in the search protocol, to identify the frequency of themes throughout the literature by counting the number of times each keyword was used. These keywords were then clustered into broader themes using a qualitative method and discussion within the team. Clustered themes were organised into a coherent structure using narrative synthesis. By exploring relationships between themes across the literature, a logical and comprehensive description of ideas were articulated. This method allowed the research team to draw meaning from a wide range of sources and create rational answers to the three research questions.

2.4 Creating the RAD-SIM Framework

Using the findings of the literature review and a second ISME workshop, the RAD-SIM framework (Figure 1) was designed using three learning theory frameworks. Behavioural and social learning theories were considered due to their relevance to social norms and pressures in the learning process. This includes both a behaviourist view of learning, in which learners are driven to pursue rewards and avoid punishment by classical and operant conditioning (Skinner, 1957), and the perspective of Social Learning Theory (SLT), which posits that individuals learn vicariously by watching others (Bandura, 1977). The classical conditioning and trial-and-error theories of learning of Pavlov (1928) and Thorndike (1911) were taken into consideration. Cognitive Learning Theory (CLT) (Yilmaz, 2011), which proposes that learners explore their environment by building on their existing cognitive structures or schemas, was explored in relation to potential behaviours within gamified learning. CLT promotes student-led/-centred learning, rather than teacher-centred. Theories of social constructivism (SC) were evaluated in relation to game-based training. SC asserts that learning occurs when we create meaning from experience. The mind acts as a filter of information, attending to what is interesting/relevant and ignoring less salient stimuli. The SC perspective is that knowledge is socially constructed; the 'Zone of Proximal Development' (Vygotsky, 1986), is a learning environment in which individuals can build on their own knowledge using the knowledge of their teachers and peers in an environment that fosters active learning. These theories supported the foundation of the RAD-SIM framework.

3. Proposing the RAD-SIM Framework

This section proposes and explains the RAD-SIM framework, which is intended for use as a prompt when designing GBL activities. Figure 1 visualises the five key categories for consideration when designing GBL or training programs, including the subcategories which contribute to each. The framework aims to provide GBL designers with a step-by-step guide for creating GBL based on behavioural principles. The subsections below explain the rationale for each component with support from the literature, as well as some of the key points to consider when designing a game.

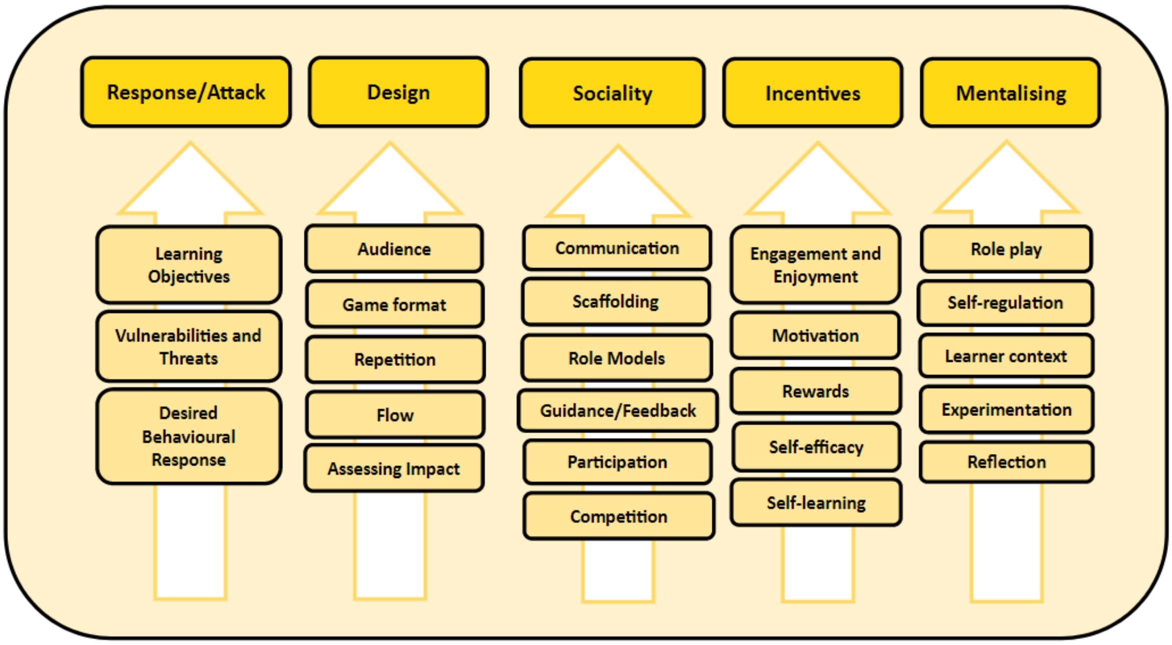

Figure 1: The RAD-SIM framework and associated sub-components

3.1 Response/Attack

The literature indicated that evaluating the success of GBL relies on the initial outlining of specific learning objectives (Silic & Lowry, 2020). Although these objectives can be differentiated for audiences/abilities, they provide an important benchmark against which to measure impact. Outlining learning objectives at the earliest stage of game design ensures that activities are geared toward helping learners achieve these goals from the outset, providing focus/direction for the designer.

This component includes consideration of desired user responses when different vulnerabilities are targeted. As the literature review focused primarily on the domain of cybersecurity, there is a focus on identifying the key vulnerabilities/threats that a user needs to be protected against in a digital context. Desired behavioural responses can then be established (e.g., recognising/eporting phishing emails); this forms the basis for determining learning outcomes/bjectives. This process can be extended to other domains.

Evidence from the literature suggests that training alone does not necessarily lead to consistent behaviour change (Salas & Cannon-Bowers, 2001). However, repeatedly targeting the same learning objectives may help to reinforce knowledge, leading to increased learning over time (Cujzek & Vranic, 2016). This variation in the effectiveness of GBL emphasizes the importance of tracking performance over extended periods. In an academic setting, this information may contribute to the current understanding of the longevity of learning and the effect of training on memory. In an applied setting, it may inform how often training must take place to maintain desired behaviour.

3.2 Design

The design component of the framework focuses on the intended audience, game format, elements of repetition, flow, and methods of assessing impact. Evidence shows that the audience should be at the centre of an intervention design to promote maximum engagement (Beguin, et al., 2019; Deeb & Hickey, 2019; Jøsang, et al., 2020; Luh, et al., 2020; Oroszi, 2019). Not only must the game be appropriate for the learner's ability (Bakker, et al., 2015; Mayer, et al., 2013), experience (Pina & Bordonaba-Juste, 2018), and context (Staller & Koerner, 2021), but the identification of these characteristics is essential for accurately positioning the difficulty of levels and the rate of progression through the game. Games that were too difficult for a player lead to disengagement (Pusey, et al., 2014), as did over-familiarity with content (Pan, et al., 2017; Zargham, et al., 2019).

As maintaining an element of challenge is key to sustaining player engagement with the intervention throughout their experience, some key questions at this stage of design are "why is the user engaging with the intervention?", "in what context are they learning?", and "how much support might the user need to participate in the game?". In response to these questions, a designer should choose a game format, for example, a simulation, card game, escape room, or capture-the-flag game. It is important to examine the practicalities of formats in relation to the end user's needs; financial cost, timescale, and remote/in-person delivery are examples of potential considerations. Two studies suggested that increased awareness of wider context might directly improve recall due to an increase in attention, leading to higher knowledge consolidation and improved memory (Williams, et al., 2014). Incorporating elements of repetition should be considered by the designer, as repetition can help improve recall (Papies, 2017). However, a designer should remember that repeated information needs to be presented in a variety of ways; direct repetition, though necessary to secure longer-lasting learning, can become monotonous.

Perhaps most importantly, a designer needs to plan the flow of a user's experience through the game. Pace will be a subjective indicator to the participant, but the designer should incorporate features such as visible/trackable goals to provide a tangible measure of progress/development. This allows users to receive feedback on their actions, providing a greater understanding of their current ability and areas for progress. Flow is an important factor in maintaining concentration and engagement, both of which are broadly demonstrated to be key to achieving positive learning outcomes across the literature.

A way to assess the impact of an intervention, based on learning objectives, should be embedded within the game. This should incorporate both performance- and practice-based metrics to capture a comprehensive understanding of learner development. Where possible, pre/post-intervention testing can help to establish the efficacy of an intervention; several studies across the literature engaged in this type of testing (Deeb & Hickey, 2019; Konig & Wolf, 2018; Mostafa & Faragallah, 2019; Raman, et al., 2014; Ross & Bennett, 2020; Tobarra, et al., 2020) but many lacked evaluation.

3.3 Sociality

Sociality requires engagement with others in group-oriented games. Engaging with others not only creates an opportunity for competition and collaboration, but also promotes vicarious learning using role-models (Bandura, 1977), and further building on this foundation by scaffolding knowledge (Vygotsky, 1986). In addition, communication and interpersonal social skills have been shown to be transferable to other contexts (Rooney & Whitton, 2016) and are therefore likely to be useful across learning environments and beyond. The most common features of sociality in the literature are communication (Yang, et al., 2012), scaffolding (Barzilai & Blau, 2014), role models (Scholl, 2019), guidance and feedback (Kumaraguru, et al., 2010), participation (Koch, et al., 2012), and competition (Alqahtani & Kavakli-Thorne, 2020; Amo, et al., 2020; Anvik, et al., 2019; Gjertson, et al., 2017; Scholefield & Shepherd, 2019). Communication provides learners with an additional opportunity to gain knowledge and should be encouraged throughout the game by encouraging collaboration or competition with others. Some participants may prefer working independently and should be given the opportunity to learn from observation rather than participation. Encouraging communication is also key to promoting scaffolding, whereby players can discuss difficulties and strategies. This allows them to help each other to improve their individual knowledge bases. By promoting active, student-centred learning, participants construct their own meaning and acquire knowledge as a group. Role-modelling should be incorporated into GBL design where possible, either by using a stronger, more experienced, or more successful 'real' player or by creating a relatable fictional character. Players learn from the examples set by role models, and role models have a great deal of normative and informational social influence.

Guidance and feedback are therefore vital components of the sociality aspect of RAD-SIM. Feedback can be provided by in-game characters, teachers/tutors, other participants, or the player themselves. Furthermore, receiving feedback in the form of points can help to reinforce positive/desired behaviours and guide a player through the training, creating a greater sense of flow. Feedback is useful for building user confidence and self-efficacy as it acts as a signpost to their progress within the training. Feedback and guidance help to promote greater participation by acting as an incentive. Across the literature, participation was shown to be maximised by making the game as engaging/enjoyable as possible. Competition can be used to further increase enjoyment and has been shown to make learning more effective (Sepehr & Head, 2018). However, not all individuals will be motivated by a competitive element, so competition should not usually be made a mandatory component of GBL.

3.4 Incentives

Incentives motivate players to learn and engage with the game (Alqahtani & Kavakli-Thorne, 2020). The identified subcomponents are engagement and enjoyment, motivation, rewards, self-efficacy, and self-learning. As previously stated, enjoyment and engagement are vital to creating a successful game. Players who report high levels of enjoyment participate in gamified training for longer than with traditional teaching materials, increasing their opportunity to learn (Mostafa & Faragallah, 2019). Games can be made enjoyable using compelling narratives, pleasing aesthetics, in-game rewards, and accessible game mechanics. Participation, engagement, and enjoyment influence motivation, which can either be intrinsic (e.g., they find the game exciting) or extrinsic (e.g., they want to succeed against others). Rewards fuel extrinsic motivation and utilise the natural human drive to engage in reward-seeking behaviour. Rewards can take many forms, including positive feedback, points, prizes, or increased reputation. Rewards should be used to encourage behaviours, knowledge-seeking, or longer participation.

Promoting self-efficacy and confidence drives intrinsic motivation. Learners should feel that they can progress through a game and have the capability to acquire knowledge. Players should also build confidence in their ability to recognise when to behave in a certain way or apply their recently developed knowledge base. Self-efficacy can be encouraged by appropriately targeting content to the learner's ability; starting at too difficult a level will not promote feelings of confidence or capability (Pusey, et al., 2014). Furthermore, allowing players to navigate the content at their own pace ensures that individuals are sufficiently challenged, but not pushed too far out of their comfort zone; games could be programmed to detect these changes. Designers should promote active self-learning, whereby players choose to independently seek out additional resources and experiences to improve their knowledge. There is evidence to suggest that GBL makes participants more likely to engage in further learning outside of an intervention (Huang & Hew, 2018), therefore education/training providers should make sure that there are resources available for individuals to continue their development outside of the game. It is this self-learning that is most meaningful to the learner, resulting in the longest-lasting effects.

3.5 Mentalising

Mentalising allows a learner to consider how they or others would think/act in a situation, helping them to develop a better understanding of themselves and other people. This encourages participants to reflect on their knowledge and behaviour, understanding how their mental states have an impact on outcomes (Rahim & Minors, 2003). The mentalising aspect of the RAD-SIM framework includes role-play, self-regulation, learner-context, experimentation, and reflection. Role-playing is an essential part of a learning experience and allows a learner to consider their thoughts and actions in different contexts and circumstances, thus gaining a better understanding of their own mind (Guenier, et al., 2022), whilst also providing an opportunity for practice. Role-playing prepares learners for a range of real-life scenarios, helping them to recognise real-world threats/opportunities (Rahim & Minors, 2003). Role-playing also encourages adversarial thinking, prompting them to adopt an oppositional mindset, considering how an adversary might think or act (Gondree, et al., 2013). Not only does this help the player to identify their own potential vulnerabilities, but it also promotes more advanced critical thinking and consideration (Dark, 2014). This process may help users to develop their higher-order thinking.

Learner context is an important consideration in GBL design and content should reflect the topics that players might encounter in real life. However, there is also a need to consider audiences' attitudes toward subjects, as gamification can provide a 'mask' which makes learning information more enjoyable by presenting it through an alternative topic (Staller & Koerner, 2021). Increased enjoyment leads to experimentation within and outside of the learning environment (Huang & Hew, 2018), leading players to use trial-and-error learning to construct their own meaning. Players should be encouraged to consider material critically and creatively to adapt to different situations; experimentation creates an opportunity to develop these skills. Mentalising can further improve a learner's ability to self-regulate their behaviour, responding rationally to different situations (Rahim & Minors, 2003). GBL gives learners the opportunity to practice responding to emotive events, giving them a certain level of inoculation against similar scenarios in the real world (Calvo-Morata, et al., 2020).

Game designers should encourage players to reflect on their experiences of the game; reflection is an important skill which allows a player to objectively consider their past thoughts and behaviour and help them to encode learning from the short-term to the long-term memory (Mitchell & Hill, 2019). This further consolidates learning and should be encouraged by presenting opportunities for discussion with other players or by creating structured, scheduled breaks for self-reflection.

4. Conclusions and Future Study

The most substantiated finding from across the literature is that GBL is useful for increasing engagement with educational content, and it is this increased attention and participation which leads to improved recall, greater awareness, and enhanced cognitive control. Although this finding was not supported in every case, there is enough variance in contextual factors to suggest that individual differences and the level of context-dependent specificity are at least partially responsible for this differentiation. This potentially indicates a lack of flexibility, adaptability, and customisability in current game designs. These features were identified in the literature review, and subsequently the RAD-SIM framework, as being necessary components of successful GBL. Whereas practitioners should seek to incorporate these elements into new or existing training structures, researchers might consider exploring the precise value of customisability in relation to other elements of the RAD-SIM framework.

Considering this finding, GBL may be particularly effective for participants who must complete mandatory learning/training in educational and organisational settings. Participants who elect to engage with GBL may already have a strong sense of motivation to engage with the materials. On the other hand, mandatory training sessions are often considered repetitive and disengaging, resulting in poor learning outcomes and ineffective learning culture (Sloman & Borattino, 2007). Although the current focus is on applying GBL to cybersecurity training, in the future it is hoped that there will be a reconfiguration of all mandatory work-based training, with the goal of increasing the retention of knowledge and promoting positive behaviour change. The latter four categories of the RAD-SIM framework (Design; Sociality; Incentives; and Mentalising) would certainly cross-apply to other professional environments, for example, diversity and inclusion training or organisational cultural development. Research must shift its focus from small scale studies to meta-analyses with a statistical focus; this review took a qualitative approach; however, it is decidedly clear that a quantitative strategy would provide more insight. A significant limitation of this review is that both the content analysis and narrative synthesis introduce a subjective component (and potentially bias) into the analysis of information from the literature. However, it is hoped that the proposal of the RAD-SIM framework and relevant themes has given enough insight to prompt further investigation in this field. Similarly, this review was somewhat constrained by time and resource budgets, as it was not conducted by an academic institution. It is hoped that there will be scope for a more quantitative approach for this work in the future. In contrast, however, taking a qualitative approach allowed the researchers to cover a broad range of papers and topics within this domain, ultimately contributing to the wider discussion of GBL training in cybersecurity and beyond.

An important benefit of using GBL approaches to education and training is the ability to collect information on the progress of individuals and groups over time and across topics. This allows training providers and educators to track the development of users and adjust to increase engagement of learners. It also provides researchers with a potential source of data. Much of the current literature focuses on lab-based interventions and self-report surveys, however, there is great potential to utilise this natural data to investigate real-world facilitators/barriers to learning. Strengthening the relationships between education, industry, and academia is a vital process which has benefits for all parties; education/industry sectors can develop more efficient, functional tools, and academia is able to make reliable predictions based on accurate real-world data. The field of GBL is an emerging catalyst for nurturing this symbiotic relationship.

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