Department of Digital Systems
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A Novel Cybersecurity Gamification Model

MASTER THESIS
M.Sc. Digital Systems Security

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1 Abstract

Gamification frameworks in cybersecurity training often encounter significant challenges, impeding their adaptation and effectiveness. This work proposes a model that addresses these challenges by providing a structured approach to developing a gamified learning experience. The methodology presented in the gamification model guides the transformation of cybersecurity training resources into a gamified format that engages and motivates participants to learn by playing. This is achieved by employing game mechanics customized to the educational goals and aligned with the desired learning objectives of the course, while also considering the behavioral core drives of the learners. The model aims to streamline the process of gamifying cybersecurity educational resources into an evolving gamified learning environment.

2 Introduction

In the evolving landscape of cybersecurity, the importance of well-trained professionals capable of safeguarding the digital cyberspace cannot be overstated. Traditional methods of teaching cybersecurity often struggle to engage learners and provide hands-on experience in real-world scenarios [1]. Participants are more likely to retain knowledge when they are engaged in practical problem-solving game situations, especially when that experience is enhanced with progress tracking for skill development and rewards for incentivization [2] [3]. Gamification frameworks in cybersecurity training face certain challenges that hinders their effectiveness, one such key issue is the lack of alignment between the gaming elements and the specific learning objectives. Many existing frameworks focus primarily on superficial rewards and badges without considering how they relate to the core educational goals [4] resulting in a disconnection between the gameplay and the desired educational outcomes and reducing the impact on knowledge retention and practical application. Additionally, another issue lies in the absence of ongoing motivation and long-term engagement where the frameworks fail to sustain participants' interest and enthusiasm beyond the initial stages [5]. To overcome this, it is essential to incorporate a sense of progression, challenges, and a captivating storyline narrative that continually evolves throughout the training process [6]. Moreover, incorporating social elements into the framework, such as collaborative gameplay and leaderboards, can foster healthy competition and peer-to-peer interaction, further enhancing engagement and motivation. Strategically merging gaming mechanics with educational objectives to create a gamified version of the resources, the novel gamification model presented aims to provide the guidelines for properly choosing, designing, and building relevant game mechanics to employ. Ensuring a direct correlation between the gaming mechanics and the cybersecurity skills to be acquired, participants are more likely to engage and develop a deeper understanding of the subject at hand. By carefully aligning game mechanics with specific learning goals, tailoring experiences to individual learners' needs, incorporating adaptive game elements that provide personalized challenges, feedback, and knowledge progression, the proposed model can be used to create an effective gamified community environment. This ensures that learners are not only engaged, but also motivated to actively participate, allowing for a deeper integration of gaming elements with the educational content.

The gamification model introduced aims to streamline the process of gamifying cybersecurity educational resources and ultimately enhancing the knowledge retention and practical application of cybersecurity knowledge. The structure of this work is as follows: Section 3 examines modern cybersecurity gamification frameworks and game engines, providing a comprehensive overview of the existing landscape. Section 4 presents the methodology of the novel gamification process, offering a step-by-step guide for implementing the model effectively. Section 5 concludes the work of this thesis with use-cases of the gamification model, including future developments and improvements.

3 Gamification in Cybersecurity Training

Gamification refers to the usage of game-based learning techniques and elements in education and training programs. It is a process that involves the application of game mechanics and artefacts into non-game environments, with the purpose of enhancing the learning experience and practical knowledge gained [7]. The effectiveness of such an approach was evaluated early on in [8] and [9] where the contexts of several non-game environments were studied and their implementations analyzed, showing positive effects and promising results, specifically in the area of education in terms of motivation and enjoyment over the learning task. More modern studies conducted [10] [11] [12] on the behavioral and habitual aspects of cybersecurity training show that this approach could make learning the various topics of cybersecurity more approachable, interactive, and enjoyable. Gamification can be an effective way to engage and motivate learners, particularly when traditional forms of cybersecurity training are perceived as hard to follow or dull [13]. Current gamification strategies in cybersecurity education involve using simulations and interactive exercises to teach security concepts or incorporating game elements of competition and collaboration into training programs [14].

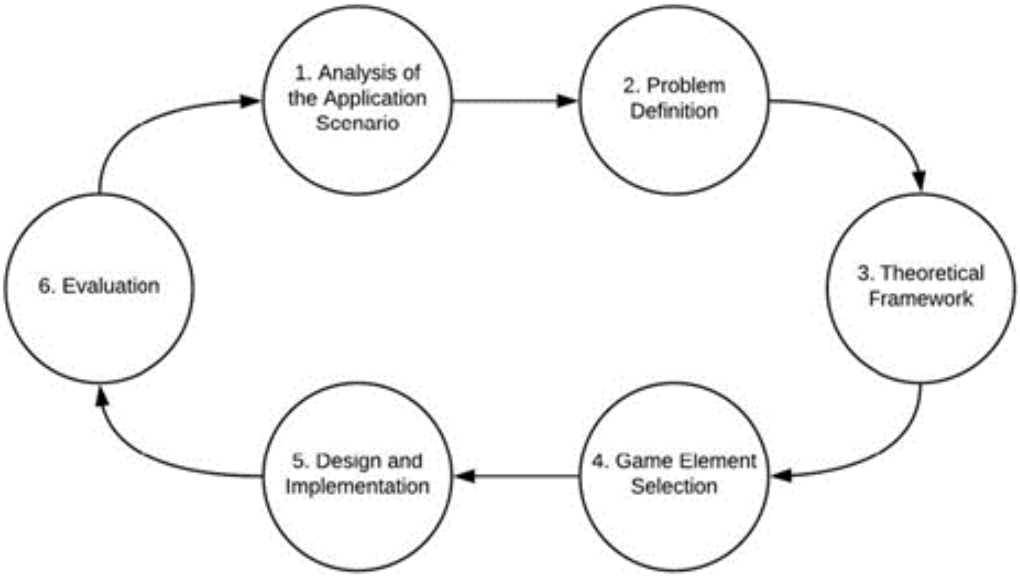

Figure 1: *Gamification Design Process*

3.1 Gamification Frameworks

To apply the process, a clearly defined strategy and well structured documentations are vital in producing a successful and effective gamified product [15]. Many of the existing frameworks are general in nature and cannot be tailored to specific domains, limiting their effectiveness. There are frameworks that have been developed and reviewed over the years in [16] and [17] that apply human-focused design principles, putting the individual as the main goal of the design and customizing the game experience based on their behavior and core drives. The main issues identified for these frameworks are the absence of clear guidelines on how to apply the gamification process, making it difficult for developers and educators to easily create gamified training programs and cources, there is the lack of proper evaluation methods, which in turn make it difficult to properly measure the outcome of the gamification process and identify the areas that need improvement, and finally the absence of ongoing motivation and long-term engagement, as frameworks often fail to sustain participants' interest and enthusiasm beyond the initial stages. There are also more technical matters such how the the game mechanics are employed, how the user interacts with them, and how the individual is actually motivated to engage in the activity [18] .

3.1.1 Serious Game Design Framework (ENISA)

Introduced in [19] and [20] the "Serious Game Design Framework" was developed by the European Union Agency for Network and Information Security (ENISA) to provide a structured and systematic approach to design and develop serious games for cybersecurity education and training, it includes the following six stages:

- Learning Objectives and Target Audience. The educators and trainers define the specific learning objectives and identify the target audience for the training program to ensure that the game is designed to meet the specific needs of the target audience.
- Game Rules and Mechanics. This stage involves defining the rules and mechanics of the game, such as the objectives, gameplay, and rewards with the purpose of creating a game that is engaging and challenging for the target audience.

- Game Story and Scenario: This stage involves developing the story and scenario of the game, which will help to provide context and relevance for the learning objectives.
- Game Visual and Interactive Elements. This stage involves designing and developing the visual and interactive elements of the game, such as the graphics, user interface, sound effects and images.
- Game Implementation and Pilot Group Test: This stage involves implementing the game and testing it with a pilot group of users. This will help to identify any issues or problems with the game before it is released to the public.
- Game's Effectiveness Evaluation. This stage involves evaluating the effectiveness of the game in achieving the learning objectives and meeting the needs of the target audience. This will help to identify any areas that need improvement, and to make any necessary changes to the game.

Figure 2: *Serious Game Design Assessment Framework*

3.1.2 Gamification Design Framework (NCFTA)

Another well-structured framework identified in [21] for designing gamified applications through model-driven engineering mechanisms is the "Gamification Design Framework", developed by the National Cyber-Forensics and Training Alliance (NCFTA) and it consists of five stages:

- Learning Goals and Target Audience: The game's educational goals must be set to appeal to the target audience.
- Game mechanics and rules: This stage involves defining the rules and mechanics of the game, such as the objectives, gameplay, and rewards. This will help to ensure that the game is engaging and challenging for the target audience.
- Design the game's story and scenario: This stage involves developing the story and scenario of the game, which will help to provide context and relevance for the learning objectives.
- Create the game's visual and interactive elements: This stage involves designing and developing the visual and interactive elements and content of the game.
- Evaluate the game's effectiveness: This stage involves evaluating the effectiveness of the game in achieving the learning objectives and needs of the target audience. It will aid to identify any areas that need improvement, and to make any necessary changes to the game.

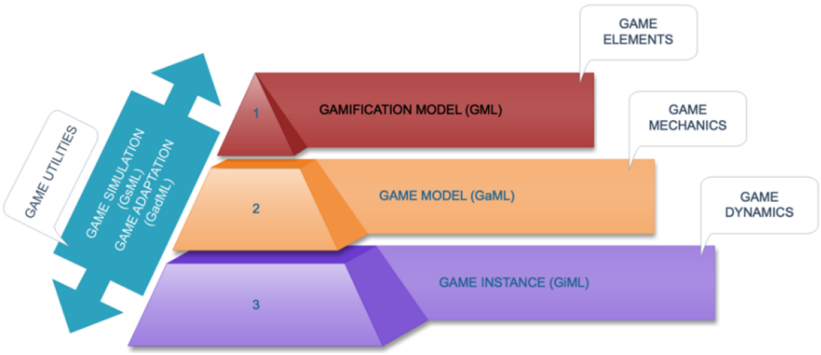

Figure 3: *Gamification Design Framework Architecture*

This framework is intended to help educators and trainers create interactive and engaging cybersecurity training programs that effectively meet the learning objectives and target audience. It is very analogous to the "Serious Game Design Framework "developed by ENISA in the sense that both have similar stages but differentiate in the way they are defined. While the NCFTA Framework is more focused on the evaluation of the game's effectiveness the ENISA framework is more focused and detailed on the implementation and testing phase of the game.

3.1.3 Octalysis Framework

The Octalysis Gamification Framework is a framework developed by Yu-kai Chou to help design human-centered gamified systems with the purpose of being engaging and effective. The framework is based on eight core drives that motivate human behaviors these are the following:

- Meaning and Calling: The drive to feel that one's actions have a greater purpose or meaning.
- Accomplishment and Development: The drive to improve one's skills and achieve goals.
- Ownership and Possession: The drive to acquire and possess virtual or physical objects.
- Scarcity and Impatience: The drive to obtain something that is scarce or in limited supply.
- Avoidance and Loss: The drive to avoid losing something of value.
- Unpredictability and Curiosity: The drive to explore and discover new things.
- Social Influence and Relatedness: The drive to interact and connect with others.
- Empowerment of Creativity and Feedback: The drive to express one's creativity and receive feedback on one's actions.

Figure 4: *Octalysis Framework*

The Octalysis framework helps to identify which of these eight core drives are most relevant to a given situation and to design a gamified system that will tap into those drives to motivate and engage users. This structure helps to evaluate the effectiveness of the gamified systems by identifying which core drive(s) it is tapping into and how well it is doing so. Octalysis is widely used in many industries such as education, healthcare, and business. It is a powerful tool for designing effective and engaging gamified systems for a wide range of applications, and for understanding the motivations and behaviors of users in these systems.

3.2 Game Engines & Tools

Game Engines (GEs) are software applications that can be used to create games and develop interactive applications. They provide a set of tools and libraries that can be utilized to create graphics, animation, physics, and other elements of a game. Most GEs have a steep learning curve, making them difficult for beginners to use, but several modern tools and frameworks can be used with minimal knowledge of programming. Initial factors when considering GEs are their flexibility and scalability, as some GEs are designed for specific types of platforms, a few of them are better suitable for small-scale projects and do not scale to large-enterprise levels. Other relevant considerations include the cross-platform support of the GE, with some being compatible only to certain platforms that can limit their reach and accessibility, and their support of features or technologies. It's worth mentioning that some of GEs and frameworks are more popular in the gaming industry and others are more popular in the education field, each one has its own strengths, weaknesses, and target audiences, so it's important to evaluate which one would work best for the specified use case.

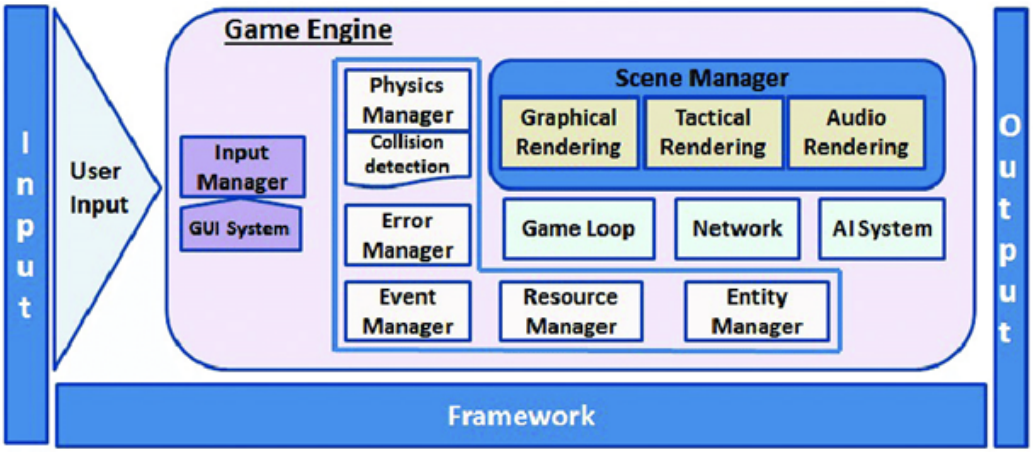

Figure 5: *Game Engine Architecture*

3.2.1 3D Game Engines

These game engines equip developers with the resources they need to make advanced, captivating, interactive 3D games and applications [22]. Creators get the ability to implement complex physics, lighting, and other effects into their 3D worlds, with highly detailed characters and objects. Some of the most well-known 3D game engines are listed below:

- Unity: A cross-platform game engine developed by Unity Technologies. It is widely used for creating 2D and 3D games and interactive applications on a variety of platforms. The game engine provides the developer with a range of tools for creating animations, physics, and other elements for building a game. Unity is known for its flexibility, ease of use, and wide range of features, making it a good option for both beginners and experienced developers with a large active community.

Figure 6: *Unity Logo*

- Unreal Engine: A cross-platform feature-rich game engine, developed by Epic Games for creating high-end 3D games, virtual reality experiences, and real-time architectural visualizations. It too provides a range of tools for creating graphics and physics and it is particularly well-suited for creating high-end 3D visual effects. Considered one of the top game engines in the industry, Unreal Engine is widely used in AAA game development.

Figure 7: *Unreal Engine Logo*

- CryEngine: A 3D game engine developed by Crytek, a German game development company and it is known for its powerful graphics capabilities and is used to create high-end 3D games, virtual reality experiences and real-time architectural visualizations. CryEngine is more complex and difficult to use than some other game engines and it has a cost for licensing.

Figure 8: *CryEngine Logo*

- Godot: A free and open-source game engine that was developed by the Godot Engine community. It's built to be easy to use with many features and tools for game developers and it is designed for creating 2D and 3D games that run on multiple platforms. Godot is a good option for both beginners and experienced developers with one of its main advantages being that it's open-source and free, making it accessible to a wide range of users.

Figure 9: *Godot Game Engine*

3.2.2 2D Game Engines

The game engines presented below, provide a set of tools and features that make it easier for developers to create 2D games, including graphics, physics, input, and sound. Some of the most popular 2D game engines include:

- GameMaker: A game engine for creating 2D games with a visual drag-and-drop interface allowing developers to create game logic and behavior without writing code. It includes a visual scripting language, a built-in physics engine, and support for a wide range of platforms.

Figure 10: *GameMaker Logo*

- Construct: A game engine that is designed for developing games with minimal coding. It includes a visual editor, a built-in physics engine, and support for a wide range of platforms. It is especially well-suited for beginners and non-programmers, but it also has enough features and flexibility for more experienced developers.

Figure 11: *Construct Logo*

- Phaser3: A popular open-source HTML5 game engine designed for creating 2D web games and interactive applications that can run in a web browser. There are many resources and tutorials available online with large active community of developers.

Figure 12: *Phaser3 Logo*

3.2.3 Interactive Stories and Visual Novels

Interactive stories and visual novels are a type of digital media that allows the player to make choices and affect the outcome of the story. They often feature branching narratives, with different paths and endings based on the choices the user makes. They can be used for a variety of purposes, including entertainment, education, and marketing. There is a variety of tools available for creating these kinds of games, including text-based tools and visual tools listed below:

- Quest: A free, open-source tool for creating interactive fiction and text-based games. It features a simple, easy-to-use interface and allows users to create choice driven storylines, puzzles, and inventory-based mechanics. Its ease of use and flexibility makes it a great choice for indie game developers, writers, and those new to game development.
- Ren'Py: An open-source visual novel engine used to create interactive stories with text, images, and sound, it is popular among indie game developers and is known for its built-in editor allowing the creation of interactive dialogues, characters, and game mechanics. The engine supports a wide range of platforms and allows developers to export their games in a variety of formats.

Figure 13: *RenPy Logo*

- Yarn: An open-source tool for creating interactive fiction and dialogue-based games. It is designed to be simple and easy to use, making it a great choice for those with little or no programming experience. This game engine is a command-line tool that allows users to create interactive stories and games by writing in a simple, human-readable language called "Yarn Spinner", which supports the use of variables, conditions, and loops, making it more powerful than other text-based game engines.

Figure 14: *Yarn Logo*

- Twine: A free, open-source tool that can be used to create interactive fiction games. It allows users to create interactive stories using a simple point-and-click interface, which makes it easy to create and design games without requiring programming knowledge. Twine games can be exported as HTML files, which can be played in any web browser.

Figure 15: *Twine Logo*

4 Cybersecurity Gamification Model

In this thesis, a novel framework is introduced on how to transform cybersecurity training resources into a gamified educational platform. The purpose of this work is to develop a structured methodology to incorporate gamification principles into real-world cybersecurity scenarios, challenges, exercises, and practices to enhance the process of learning and how it is conveyed.

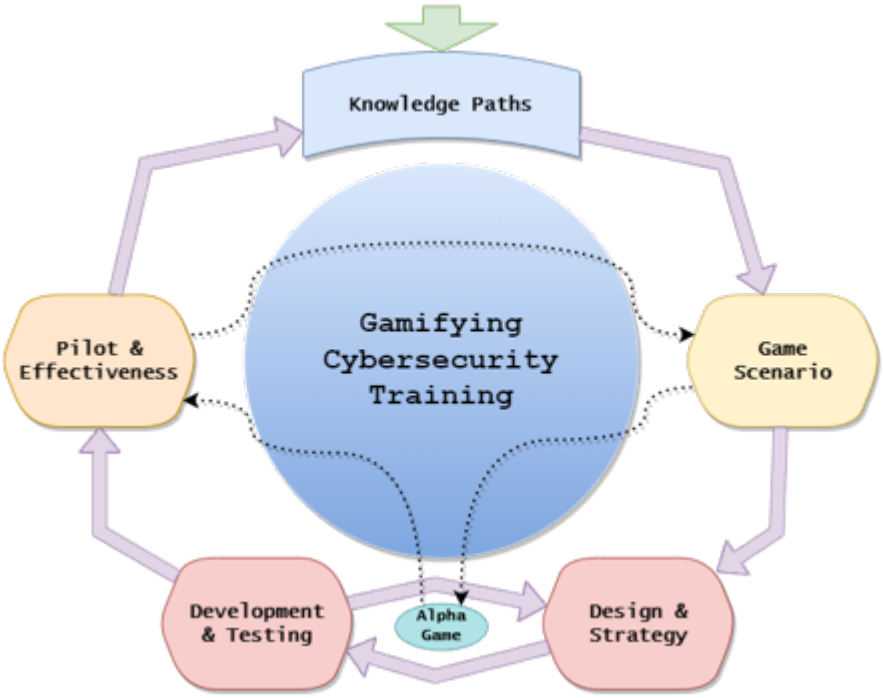

Figure 16: *Cybersecurity Gamification Model*

The model is comprised of five phases, encapsulating fundamental gamification guidelines assembled by the related work frameworks, and involves developing game elements to use in the context of cybersecurity with the purpose of streamlining educational resources into reusable gamified assets. During each phase resources are gathered, game aspects are designed and used in the next phases to identify the game's objectives, incentives, features and game mechanisms while also applying behavioral human-focus principles by design.

4.1 Knowledge Paths

The first phase of the model is the knowledge paths, which are defined by bundling the theoretical aspects and practical exercises of a cybersecurity area of interest. This includes documented resources, best practices, guidelines, scenarios, challenges, and exercises for the training process. Knowledge paths can be versatile as they could be structurally based on predefined educational frameworks such as that of university courses, learning academy classes or professional certification programs. In selecting one of these paths, the participant should receive a clear underpinning of what cybersecurity topics they will learn about, what tools they will use and what skills they will acquire.

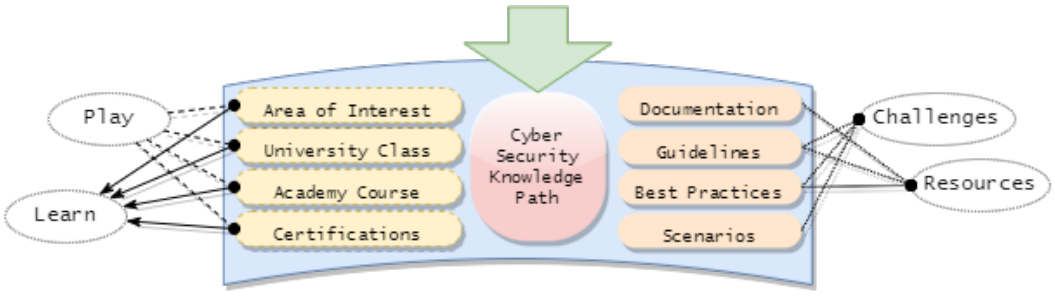

Figure 17: *Knowledge Paths Phase*

Essentially, paths defined in this stage can be cybersecurity curriculums and their corresponding study material along with several challenges and exercises on the topics covered. The challenges and exercises should provide the necessary hands-on experience and are essential for the practical education of the participant. This material will be provided to the participant beforehand or alongside the gamified process which could be comprised of lecture-based presentation, focusing on educating the fundamentals of the cybersecurity topic, or skill-based presentation, focusing on unlocking or improving a specific cybersecurity skill, or any other well-structured documentation.

4.2 Game Scenario

This phase of the model involves defining the target audience's core drives needs and developing the initial gamification scenario. In this phase a game scenario starts being developed, using the previously collected educational resources.

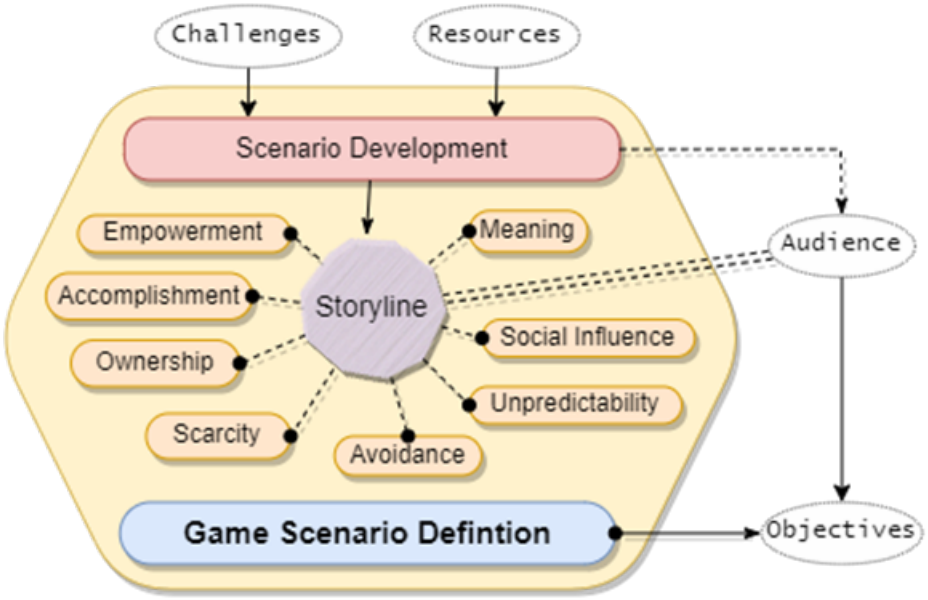

Figure 18: *Game Scenario Phase*

This is done in the form of a storyline and evaluated against the Octalysis core drives allowing for a more human-driven behavior design, where each drive comprises a behavioral aspect that can motivate the user toward performing a certain action. These core drives can also be used to evaluate the behavioral impact the storyline will have as well as the kind of audience it is going to appeal to. The evaluated storyline can then be used to outline a **game scenario** comprising of the storyline and game objectives, which involves carefully mapping the game elements to the desired learning outcomes.

4.3 Design & Strategy

This phase of the model starts by collecting the game scenario definition of the previous phase. The purpose of this phase is to evaluate and identify possible game mechanics that can be employed for the gamification process.

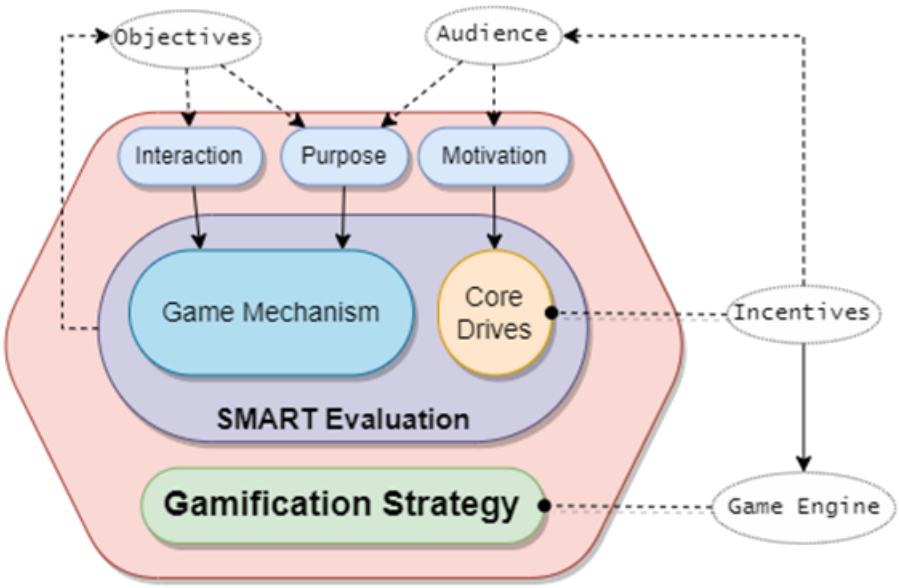

Figure 19: *Design & Strategy Phase*

The first step is analyzing interesting game mechanics by defining the *interaction* (how is the game mechanism communicated), *purpose* (what is the mechanism's goal), and *motivation* (what's driving the player to engage with the mechanism) aspects. The game mechanisms initially are analyzed to identify the aspects that make them fun, engaging, and interesting to use and then evaluated with a modified version of the SMART [23] methodology to make sure they fit to the core drives of the game storyline. The game's ability to incentivize players to do a certain action or set of actions is based on the defined objectives of each game scenario along with the interesting game mechanisms that are appropriate for that scenario.

Using the template below, the SMART methodology classifies the core drives that the game mechanism appeals to while establishing a solid framework for developing the game mechanism:

	Section	Description
S	ID	Shorthand ID of the gaming mechanism.
	Dependencies	Dependencies that the game mechanism depends on.
	Core Drive(s)	Choose from the list: - MEANING: Drive where a player believes that they are doing something greater than themselves. - DEVELOP: Drive that the player is making progress, developing skills, accomplishing tasks and overcoming challenges. - EMPOWER: Drive that the player is engaging in a creative process, figuring out and trying different combinations, expressing creativity and receiving feedback. - OWNERSHIP: Drive that the player is the owner of something and wants to accumulate in-game wealth. - SOCIAL: Drive of the social elements that relate to the player such as mentorship, acceptance, social feedback and competition. - SCARCITY: Drive that the player wants something right now that they can't have. - CURIOSITY: Drive that the player is curious to know about what is going to happen next in the game. - AVOIDANCE: Drive that the player is avoiding for something negative to happen making them lose progress.
	Short name	Meaningful and not too long.
	Description	General description of the game mechanism.
	Learning Goal	Describe the educational objectives of this game mechanism.
	Additional Information	Additional information about the game mechanism.
	Priority (MoSCoW)	This allow to identify the priority of the goal; it can be updated in the different iterations: M: Must-have. Mandatory mechanism. S: Should-have. Desirable mechanism. C: Could-have. Optional mechanism. W: Will-not-have. Possible future mechanism
M	Means of measuring the achievement of the game mechanism. Milestones, metrics, effectiveness etc.	
A	How achievable is the game mechanism? This will have to take into account the Objectives, the Priority and any possible foreseen obstacles.	
R	Objectives of the game mechanism. • Why is the game mechanism worthwhile? • What are the core drives and needs it fulfills? • How relevant is it to the project?	
T	Define development milestones, sprints and deadlines for the gaming mechanism.	

Figure 20: *SMART Evaluation*

The collected SMART evaluations can be used in defining properly a **gamification strategy** that outlines the possible game engines that can implement the game mechanism alongside with their *purpose*, *interaction*, *motivation* and *development goals*.

4.4 Development & Testing

This phase of the model involves actualizing the defined gamification strategy with the purpose of developing an Alpha Game Product.

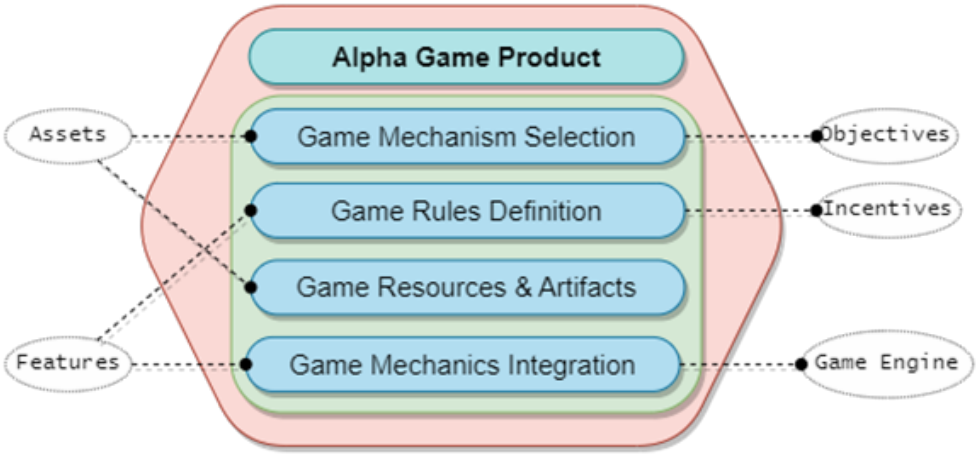

Figure 21: *Development & Testing Phase*

The gamification strategy is implemented top-down as shown in the figure:

1. Selecting the game mechanisms appropriate to the objectives of the game scenario. The implemented game mechanisms can contribute to the gamification assets available for future iterations of the process.

2. Defining the rules for incentivizing and enabling game scenario core drives, these are unique features of the Alpha Game Product.

3. Creating the game resources, artifacts, and assets for the game scenario, usable also for future iterations of the gamification process.

4. Integrating the implemented game mechanics to the appropriate game engine using the development goals set by the strategy. These also comprise unique features of the Alpha Game Product.

The steps of the gamification strategy aim at creating an **Alpha Game Product**,which is *a platform employing the required game mechanics for the objectives of the game scenarios defined by the knowledge paths.*

4.5 Pilot & Effectiveness

This phase of the model involves evaluating the effectiveness of the Alpha Game Product. The previous two phases are interconnected with the common goal of designing and developing a gamified platform with proper game mechanics that can make the learning experience more practical, engaging, and fun. Once the Alpha Game Product is implemented, a game pilot run will test the game mechanisms by end-users, who will provide feedback for playing and for any specific measurements defined in the game mechanism SMART analysis. Evaluating the effectiveness of the game can be done by understanding which behavioral core drives were enabled on the target audience while playing the game. Learning path examinations both practical and theoretical, will determine how well the participants understood the educational purpose of the game and the knowledge they acquired.

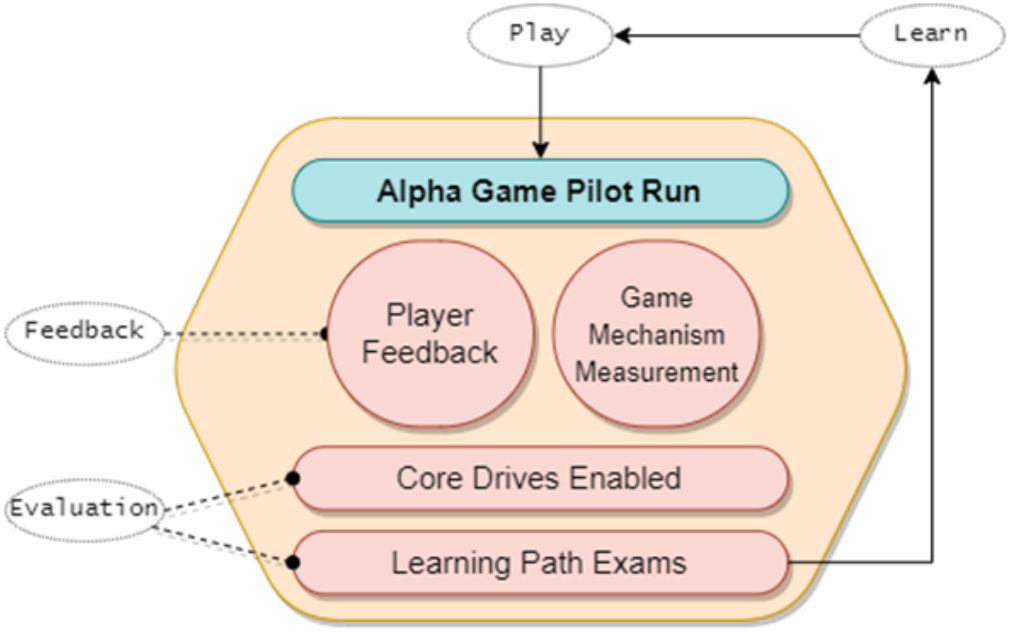

Figure 22: *Pilot & Effectiveness Phase*

4.6 Alpha Game Product

The purpose of creating a gamified educational platform is to be able to have a streamline for gamifying cybersecurity educational resources. As shown in the figure below the model aims at automating the gamification process so that any future educational resources could easily be gamified by feeding their game scenarios into the Alpha Game Product developed:

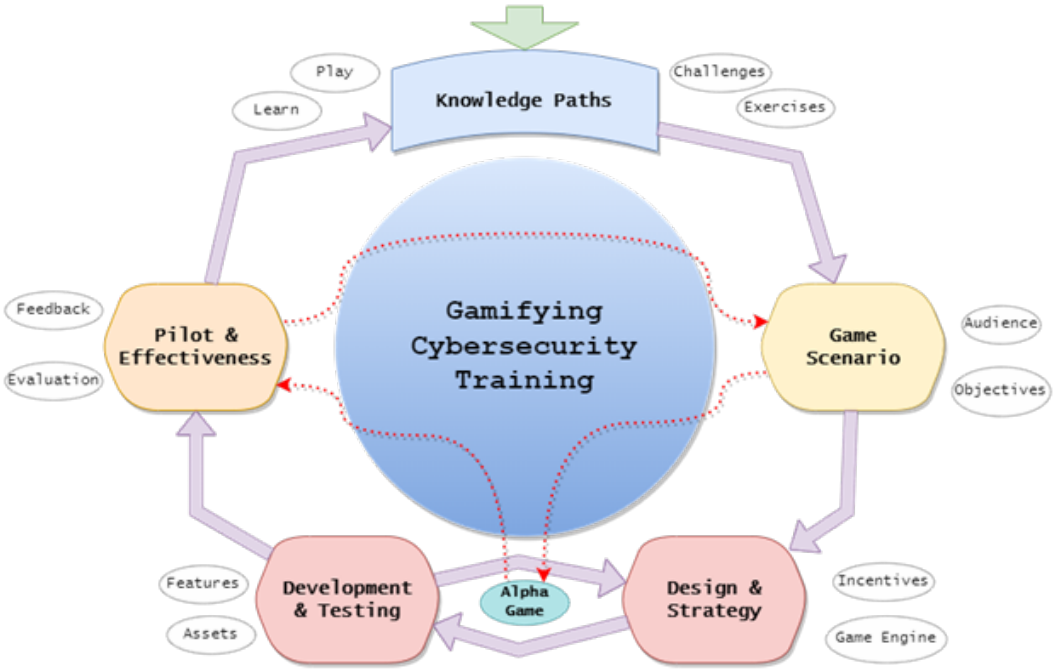

Figure 23: *Alpha Game Streamline*

After the pilot and effectiveness of the Alpha Game Product are evaluated, participants can play and learn through the game. Properly documenting the creation of game scenarios and game mechanisms can allow participants to contribute to the gamification process. This can expand the possible knowledge paths and gamified assets of the Alpha Game Product, upscaling it to a collaborative learning and development environment for enhancing skills and sharing knowledge on cybersecurity.

5 Conclusion

When used in educational and training programs, the term "gamification" describes the incorporation of game-based learning strategies and components. Traditional training methods often struggle to captivate learners, leading to passive learning and limited knowledge retention. Training and educational courses should employ ways and mechanisms to properly encourage and motivate their participants into learning the material at hand. The experience can be enhanced by embedding game elements where the participants learn through the practical problem-solving nature of gaming. These methods can be especially useful in the subject of cybersecurity, since typical training methods can be seen as uninteresting, if not even downright ambiguous by some students. The proposed gamification model offers a promising approach to cybersecurity training by addressing the limitations of traditional methods to foster an engaging and interesting learning experience. By designing and implementing game mechanics for tracking a learner's progress or altering the material and difficulty level based on their needs and abilities, the presented gamification model could be used to create personalized, adaptive learning experiences. This work's focus on gamifying cybersecurity resources is not exclusive to that area as any other type of educational resource that could be packaged into a suitable knowledge path can be a gamification model candidate. Together with the model's independence from specific game engines, it allows for a wide range of options in terms of how educational and training materials will be gamified. The incorporation of virtual reality (VR) and augmented reality (AR) into cybersecurity training programs is a cutting-edge application in gamification. The proposed gamification model could even be used to develop VR game scenario simulations where students can practice recognizing and responding to cyber threats and incidents in an immersive virtual world.

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