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Enhancing Student Engagement: A Gamified ADDIE Framework for Mathematics Courses in Online & Blended Higher Education Learning Environments

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Abstract

This paper addresses challenges in mathematics education, including declining motivation and knowledge retention, proposing gamification as a solution, and reviewing current trends and efforts within gamification. We suggest a new Gamified ADDIE Framework to gamify mathematics courses, rooted in psychological and pedagogical theories, tailored for online and blended learning environments. The framework offers a systematic approach to instructional design, incorporating elements of gamification to enhance engagement and learning outcomes. Guidelines for implementation are provided, alongside a theoretical example where we apply the framework to an image processing course in a blended learning environment. By integrating theories from psychology, pedagogy, and multimedia instructional design, the framework aims to address the growing issue of math anxiety and improve student motivation and performance in mathematics education.

Keywords: Gamification, Mathematics, Higher Education, ADDIE Model of Instructional Design, Online & Hybrid Learning, Game-Based Learning

1. Introduction

Mathematics is a cornerstone discipline across various academic fields. However, higher education mathematics courses often face challenges with student motivation and attitudes towards the subject resulting in increased dropout rates and decreased knowledge retention (Triantafyllou et al., 2016). Math anxiety is one of the reasons for this and can begin as early as elementary school and persists into adulthood for many individuals (Daker et al., 2021; Harari et al., 2013; Khasawneh et al., 2021). Math anxiety stems from factors like confidence in mathematical abilities and impacts problem-solving skills. Khasawneh et. al. found evidence that suggests that math anxiety plays a crucial role in shaping students' engagement and success in STEM fields, also beyond the influence of their mathematical skills (Khasawneh et al., 2021). Previous studies have shown that highly math-anxious individuals tend to avoid math-related courses and perform poorly in such courses when they are younger, but there is now growing research demonstrating that these effects persist over the years at university (Harari et al., 2013; Khasawneh et al., 2021). Gamification, the application of game-like elements in non-game contexts, has emerged as a promising approach to enhance student engagement and attitudes in mathematic educational settings to help combat some of these challenges (Deterding et al., 2011; Rincon-Flores et al., 2023).

2. Methodology

This paper explores the potential of gamification to support mathematics education in online and hybrid learning environments in higher education, an area where initiatives remain scarce (Ortiz Rojas et al., 2016). We will start by defining gamification and presenting central theories and existing frameworks associated with gamification. Then, we will elaborate on how theories from other disciplines support the use of gamification beyond a superficial level. Following this, we will present some of the most common challenges associated with gamification in higher education. Lastly, we will propose the new Gamified ADDIE Framework for higher education and present a learning scenario where we exemplify how the framework could be applied to an image processing course in a blended learning environment.

3. Gamification

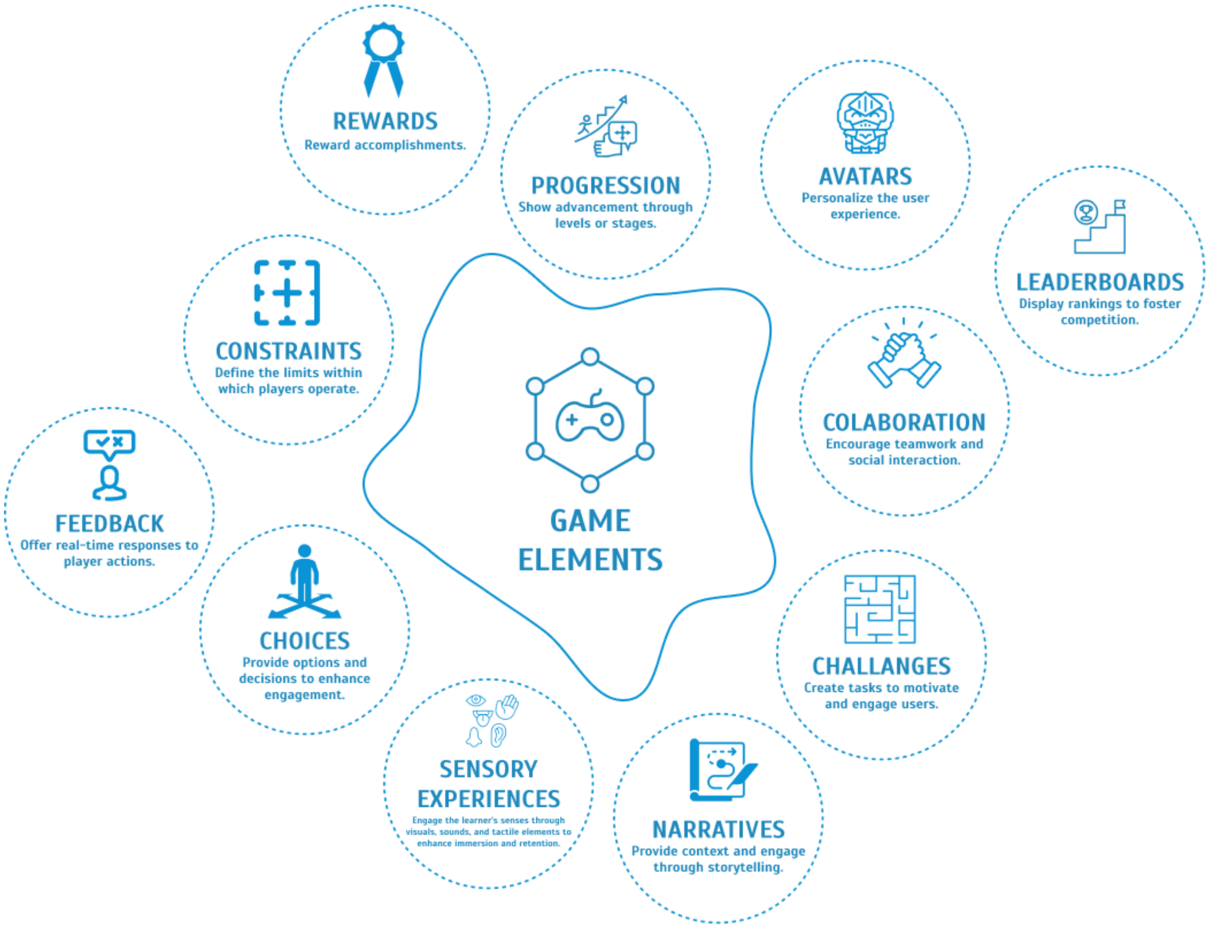
3.1 Definition

Gamification has emerged as a powerful tool in education, leveraging game design elements to enhance engagement, motivation, and learning outcomes. Most commonly defined as "the use of game design elements in non-game contexts" (Deterding et al., 2011), gamification draws on theories and insight from diverse disciplines such as game design, instructional design, psychology, playful design, serious games, and simulations to create interactive learning environments (Kapp, 2012; M. Kapp et al., 2014). In mathematics education, gamification has garnered significant attention due to its potential to improve students' engagement, practice, feedback, and enjoyment, thus fostering a conducive environment for knowledge-building (Partovi & Razavi, 2019).

3.2 The Game Design Elements

Central to gamification are the game design elements (sometimes referred to as game mechanics), which can include points, badges, leaderboards, avatars, narratives, challenges, and cooperation (see examples in figure 1) (Alzahrani & Alhalafawy, 2022; Bernardes et al., 2022b; Khaldi et al., 2023; Manzano-León et al., 2021).

Figure 1: examples of different game elements that could be incorporated when gamifying.



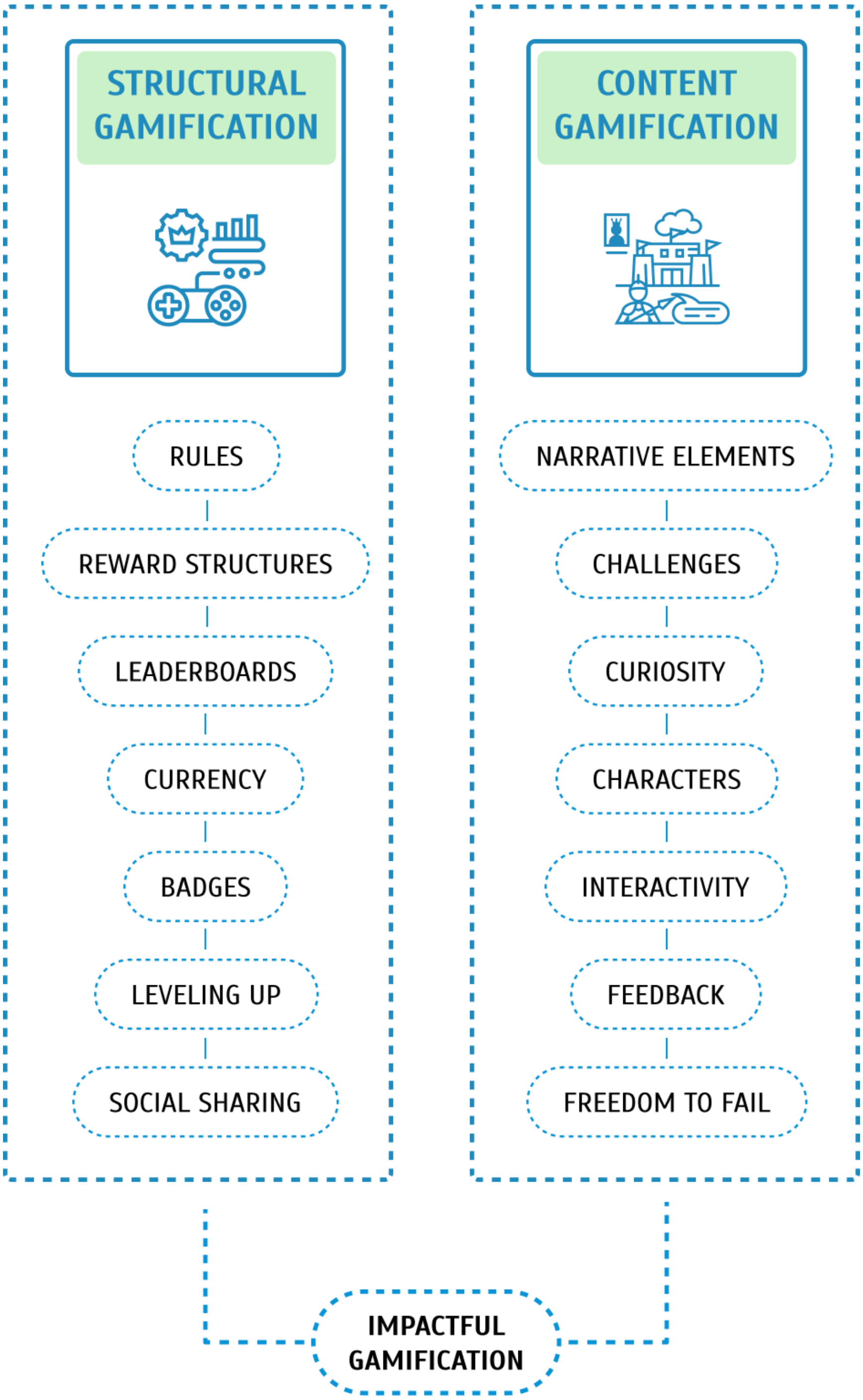
Various models, such as the MDA (Mechanics, Dynamics, Aesthetics) model proposed by Hunicke et al., the DMC (Dynamics, Mechanics, Componens) model by Werbach & Hunter, and the MAT (Mechanics, Aesthetics, Game Thinking) model by Kapp, provide frameworks for understanding how these elements contribute to the overall gamified experience (Hunicke et al., 2004; Kapp, 2012; Werbach & Hunter, 2012). The frameworks share more similarities than differences and are all helpful to better understand what needs to be included and taken into consideration when gamifying something.

3.3 Structural Gamification vs. Content Gamification

However, gamification is not simply about superficially adding extrinsic motivators like badges and points to activities that could be intrinsically motivating (Bernardes et al., 2022b; Werbach & Hunter, 2012). It transcends these elements to encompass engagement, storytelling, visualization of characters, and problem-solving, aiming to accelerate learning, immersing users, and foster systems thinking (Bernardes et al., 2022b; Werbach & Hunter, 2012). Additionally, gamification is not a trivialization of learning; rather, it is a serious approach with historical roots in military war games and simulations, incorporating techniques such as embedding stories and creating challenges to enhance educational experiences (Kapp, 2012). To better understand the nuances of gamification, Kapp et. al introduced the concepts of *structural gamification* and *content gamification* (see figure 2) (Kapp, 2012; M. Kapp et al., 2014).

Structural gamification involves the application of game elements to the framework surrounding the educational content, without altering the content itself (M. Kapp et al., 2014). The primary focus is to motivate learners to progress through the content and engage them in the learning process through rewards and incentives. Examples of structural gamification include earning points for completing assignments or watching videos within a course. Structural gamification comprises several key components, including rules, reward structures, leaderboards, currency, badges, levelling up, and social sharing. These elements are designed to define the parameters within which participants operate, establish a reward system for achievements, and foster healthy competition among learners.

Figure 2: the difference between structural and content gamification, and their main components.



Content gamification, on the other hand, involves the application of game elements and game thinking to alter the educational content itself, making it more game-like (M. Kapp et al., 2014). The primary focus is to motivate learners by immersing them in an engaging and enjoyable learning experience. Examples of content gamification include adding story elements, challenges, and interactivity to educational content. Content gamification encompasses narrative elements, challenges, curiosity, characters, interactivity, feedback, and freedom to fail. These elements are incorporated into the educational content to create a more immersive and memorable learning experience, sparking learners' curiosity and facilitating active engagement.

While structural and content gamification can be effective on their own, combining these approaches often yields the most impactful results (M. Kapp et al., 2014). By integrating game elements into both the framework surrounding the content and the content itself, educators can create a comprehensive gamified learning environment that motivates learners and enhances their engagement and retention of course material.

These different types of gamification can be leveraged in online and blended mathematics education by incorporating digital tools from the game industry, or other information communication technology (ICT) tools (Dhakal, 2018; Weir, 2023; *Why Integrate |ICT in Primary Maths|*, n.d.).

3.4 Gamification in online and blended learning environments

Online education, or e-learning, delivers educational content and instruction through digital platforms and the internet, allowing students to access courses and materials remotely, offering flexibility in time and location (Sun & Chen, 2016). It includes fully online courses, degree programs, or individual modules that supplement traditional instruction. Hybrid education, or blended learning, combines traditional face-to-face instruction with online learning (Kazu & Yalçin, 2022). Students participate in both in-person and virtual activities, benefiting from classroom interactions and the flexibility of online resources. This approach may involve scheduled in-person classes supplemented with online content and assessments.

ICT tools play a crucial role in enhancing the gamification of online and blended learning environments. These tools can be categorized into four types based on their interactive features: educational networking, web-based learning, mobile learning, and classroom equipment (Luo & Lei, 2012). Educational networking platforms facilitate learner connections using social networking technologies, similar to Facebook or MySpace. Web-based learning tools, including wikis, blogs, podcasts, and social bookmarking, expand learners' abilities to interact and collaborate in generating educational content.

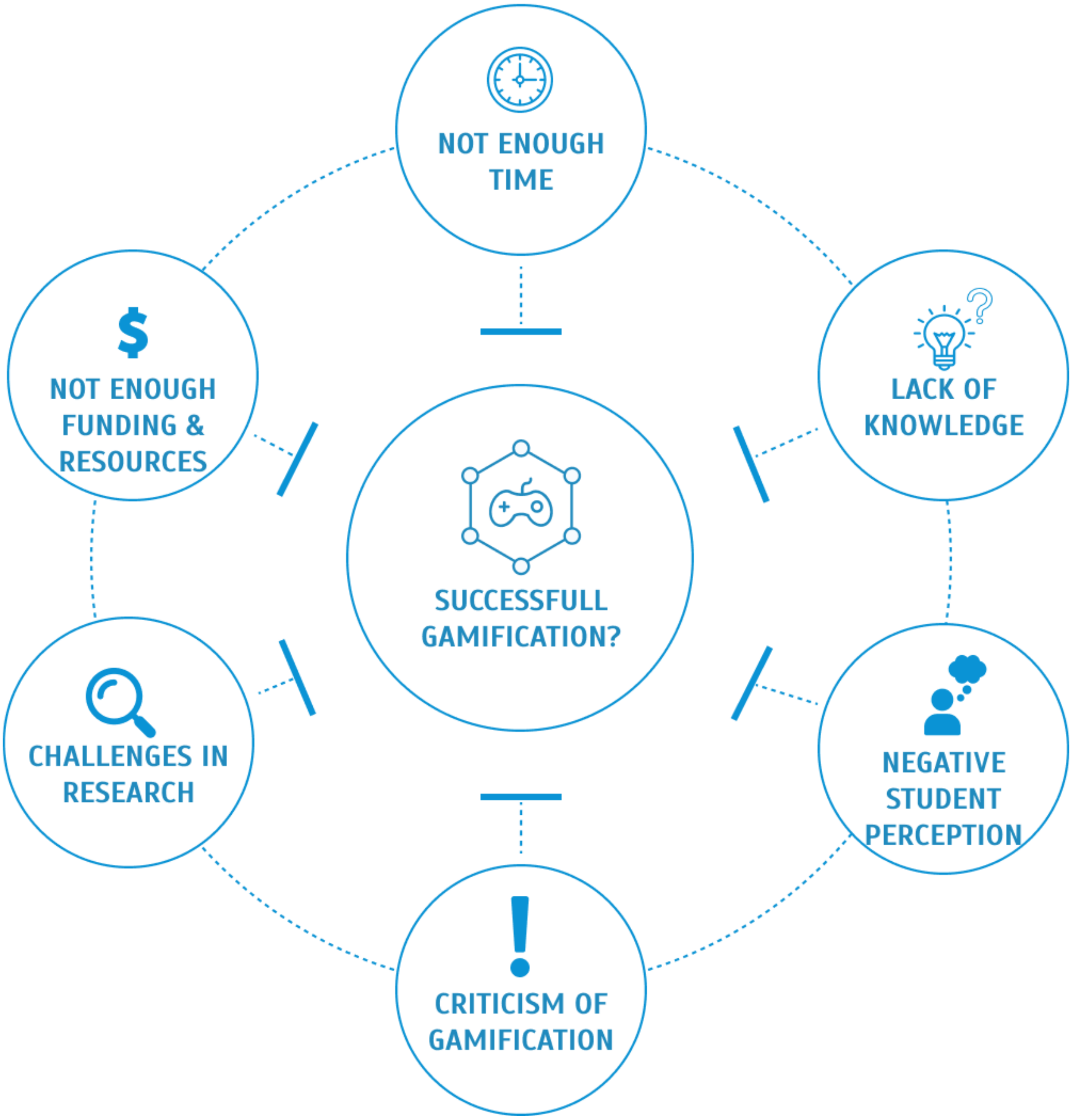
Mobile learning technologies, such as smartphones and GPS for augmented reality games, support various instructional aspects and introduce new educational activities. Lastly, classroom equipment like interactive whiteboards and touchscreen computers enhance teacher-student interactions during class activities. Integrating these ICT tools into gamified learning environments can create more engaging, interactive, and effective educational experiences in online or hybrid mathematics (Dhakal, 2018; Luo & Lei, 2012).

3.5 Challenges with Gamification in Higher Education

The integration of gamification in higher education (HE), especially within disciplines like mathematics, encounters numerous challenges that hinder its widespread adoption (see figure 3). These challenges arise from factors such as limited funding, time constraints for implementation, insufficient knowledge about gamification, and concerns regarding its alignment with course content (An et al., 2021; Bernardes et al., 2022a; Watson-Huggins & Trotman, 2019). One major obstacle is the lack of financial resources, which restricts institutions from investing in gamification initiatives and providing training programs for educators (An et al., 2021). Similarly, the scarcity of time and resources for implementing gamification in courses poses a significant challenge, as educators often face competing priorities and limited support (Watson-Huggins & Trotman, 2019).

Figure 3: challenges to gamification.

CHALLENGES TO GAMIFICATION



Moreover, there exists a knowledge gap among educators regarding gamification strategies and their effective integration into the curriculum (An et al., 2021). This lack of understanding can lead to scepticism or reluctance to adopt gamified approaches in teaching. Student perceptions of gamification may also pose challenges, as some students may view it negatively or question its relevance to their learning objectives (Bernardes et al., 2022a). Overcoming this stigma requires educators to effectively communicate the benefits of gamification and address any misconceptions.

Critics of gamification argue that game elements may serve as distractions rather than enhancers of learning, diverting students' attention away from relevant content (Fisch, 2005). Moreover, there are some conflicting evidence regarding the positive impact of games on learning outcomes that raises concerns about the sustainability of gamified approaches in education (Akl et al., 2013; Breuer & Bente, 2010; Harris, 2008).

Furthermore, challenges related to research in the field of game-based learning and educational gamification include blurred distinctions between games and other training media, between gamification and similar approaches like game-based learning, difficulties in measuring learning outcomes, and the need for standardized research protocols (Bernardes et al., 2022a). Addressing these challenges requires efforts to establish clear definitions, understand the learning process of games, and draw accurate implications from research findings.

To address these challenges and capitalize on opportunities in gamification, educators and instructional designers must allocate adequate resources, involve stakeholders in the instructional design process, and collaborate effectively to create engaging and effective gamified learning experiences (Bernardes et al., 2022a).

3.6 Gamification of Mathematics in Higher Education

Research on gamification in education is primarily conducted at the higher educational level (Torres-Toukoumidis et al., 2021). However, Yiğ & SezgiN found that most research on gamification in mathematics more specifically is still focused on primary school level (Yiğ & SezgiN, 2021). Literature reviews indicate a general lack of studies on gamification within STEM areas in higher education (Khaldi et al., 2023; Ortiz Rojas et al., 2016). Rojas et al. specifically highlight the need for studies that identify particular game elements associated with positive impacts on student performance, validated psychometric measurements, and consideration of student variables as mediating/moderating factors in gamification's impact on STEM learning and teaching in higher education (Ortiz Rojas et al., 2016). Despite the modernization and digitalization of education, examples of gamification in higher education mathematics are scarce. However, some empirical studies and case studies provide successful applications of gamification in this context.

One such study, conducted at Grace International Academy, examined the impact of gamification tools in a Business Mathematics course for undergraduate students (Lawrance et al., 2021). Tools like Kahoot!, Socrative, Quizlet, Quizizz, and Showbie were employed to boost motivation, engagement, critical thinking, and problem-solving skills. Data from questionnaires, observations, interviews, and online feedback indicated these tools significantly enhanced student motivation and engagement, with a high percentage of students reporting positive effects on their learning experience.

At Cummins College of Engineering for Women in Pune, India, a 'Jeopardy-style classroom quiz' was used as a gamification tool in a 'Big Data and Analytics' course (Mandke & Jahirabadkar, 2021). Inspired by the popular game show 'Jeopardy,' the quiz format aimed to assess students' knowledge while promoting active participation, teamwork, and engagement. The study reported improvements in team building, leadership skills, technical knowledge, and overall classroom engagement, demonstrating the tool's effectiveness in enhancing the learning experience.

Another approach was explored by Cezar et al. through the introduction of an RPG-style educational digital game, "The Fellowship of the Calculus," in a Calculus course (Cezar et al., 2022). This game, grounded in gamification principles, aimed to boost student motivation, interaction, and learning outcomes. Featuring mechanics, aesthetics, and narrative elements, the game engaged students and facilitated a deeper understanding of Calculus concepts. The study found increased student motivation, improved comprehension, and a shift in study habits, underscoring the potential of gamification in making complex subjects more accessible and engaging.

A pilot project at CEU University integrated robots and interdisciplinary collaboration to gamify a mathematics course as part of the EXPLORIA project (Hilario et al., 2022). Students participated in a transportation challenge using LEGO EV3 robots to apply mathematical and physics concepts. The use of educational robotics and the GeoGebra applet for Bézier curve design led to increased student motivation, enhanced understanding of mathematical concepts, and more positive attitudes toward mathematics. This project highlighted the effectiveness of gamification in promoting interdisciplinary learning and practical application of theoretical concepts.

In summary, while there is a significant need for more research and examples of gamification in higher education mathematics, these studies provide valuable insights into how gamification can effectively enhance learning experiences in higher education online and blended learning environments of mathematics with the help of ICT tools.

3.7 The GAFCC model for gamification

To further explain the mechanisms behind the benefits of gamification and how one can apply it successfully, Huang and Hew propose the GAFCC (Goal-Access-Feedback-Challenge-Collaboration) model that integrates motivational theories into a gamification design framework for educational settings, particularly in the context of flipped learning (B. Huang & Hew, 2018). By aligning gamification strategies with the principles of motivational theories, the intention is that educators can effectively enhance student engagement and participation, ultimately improving learning outcomes in diverse educational contexts. The GAFCC model encompasses five key stages: examine, decide, match, launch, and evaluate, each of which plays a crucial role in the practical implementation of gamification strategies.

The initial stage – Examine - involves a comprehensive examination of instructional objectives, learner context, and the gamification landscape. Educators analyze the specific learning goals they aim to achieve through gamification, consider the characteristics and preferences of their student population, and assess the suitability of gamification elements for their educational context.

In the decision-making stage – Decide – educators determine the motivating elements and game design features that align with their instructional objectives and learner needs. This process involves selecting appropriate gamification strategies, such as badges, leaderboards, or quest-based activities, based on their potential to enhance student engagement and motivation.

The matching stage focuses on aligning motivating elements with game design elements to create a cohesive and engaging gamified learning environment. Educators identify how each selected gamification strategy contributes to fostering student motivation, autonomy, and competence, ensuring a successful integration of game elements with educational content.

Once the gamification design is finalized, educators proceed to the launch stage, where they implement the gamified learning activities within their instructional framework. This phase involves introducing students to the gamified elements, providing clear instructions on how to participate, and integrating gamification seamlessly into existing teaching practices.

The final stage of the GAFCC model involves evaluating the effectiveness of the gamification implementation through ongoing assessment and feedback mechanisms. Educators monitor student engagement, motivation, and learning outcomes, gathering data to measure the impact of gamification on student performance and satisfaction. This evaluation process informs iterative improvements to the gamification design and ensures its alignment with educational goals.

This model is one of few that try to give a practical approach on how apply gamification in educational environments at the same time as providing a deeper psychological explanation of what each element of gamification is contributing with. The new framework we propose in this paper, will try to build on this intention by adding more theories, but also by making a clearer connection to online and blended learning environments and mathematics more specifically.

4. Theoretical Foundations for Gamification in Higher Education

Further expanding our understanding of gamification requires delving into the diverse theories that explain its effectiveness in educational settings. This paper builds on existing frameworks, introducing a variety of theories from different disciplines to enhance student motivation and learning. Gamification is supported by numerous theories, reflecting its complex nature. The following theories we present are not exhaustive but provide a solid foundation for understanding the intricate mechanisms behind successful gamification.

4.1 Playfulness and Playful Learning

Playfulness is a central part of gamification, encompassing elements of fun, enjoyment, and low-risk experimentation (Högberg et al., 2019; Patricio et al., 2018). Playful learning approaches, including games, game-based learning, and serious games, adopt a lusory attitude towards teaching and learning, encouraging reflection, immersion, and exploration in the learning process (Bernardes et al., 2022a). By embracing playfulness, educators can create safe spaces for learning, promoting active participation and reducing anxiety associated with challenging subjects like mathematics (Fisher et al., 2012).

The concept of the "magic circle," introduced by Huizinga (1955) is an example of how playfulness can be applied in higher education (Huizinga, 1955). It refers to a symbolic boundary where the rules and dynamics of a game apply, encouraging a playful mindset. In higher education mathematics, introducing this concept can create a mental space where students feel free to explore mathematical concepts with curiosity and enjoyment. This approach can foster a positive attitude towards learning, reduce anxiety associated with challenging subjects like mathematics, and promotes a more immersive and engaging educational experience (Fisher et al., 2012).

4.2 Psychological theories of motivation

Like introduced in the GAFCC Model, motivational theories serve as the foundation for understanding how gamification can effectively enhance student engagement and performance in educational settings. Huang, Hew, and Kapp have identified several key motivational theories that support the implementation of gamification: self-determination theory, flow theory, goal-setting theory, social comparison theory, behavior reinforcement theory, and expectancy theory (B. Huang & Hew, 2018; Kapp, 2012; M. Kapp et al., 2014). See table 1 for further explanation of the different theories and their possible usage in gamification and figure 4 for visualization.

Figure 4: Key psychological theories of motivation contributing to successful gamification.

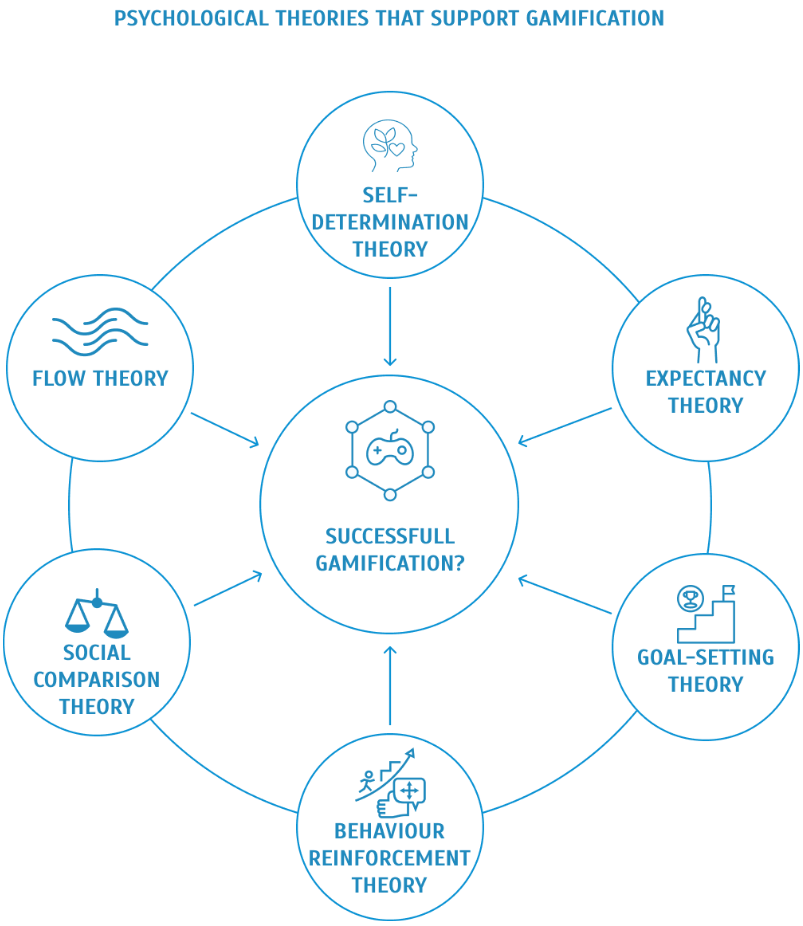


Table 1: Key psychological theories of motivation contributing to successful gamification.

Theory	Description	Example of usage in a gamified mathematics course
Flow Theory	Describes a state of total immersion and engagement in an activity, resulting from a balance between challenge and skill (Beard & Csikszentmihalyi, 2015; Csikszcntmihalyi, 1990).	Designing tasks in a mathematics course that progressively increase in difficulty, ensuring that students are continually challenged yet capable of succeeding, thus maintaining their engagement and focus.
Self-Determination Theory (SDT)	Focuses on the intrinsic and extrinsic motivations behind human behavior, emphasizing the fulfillment of psychological needs for autonomy, competence, and relatedness (Ryan & Deci, 2000).	Implementing a system where students choose their own math-related projects, receive competence-based badges, and engage in collaborative problem-solving activities to fulfill their psychological needs.
Goal-Setting Theory	Empathizes the importance of setting specific and challenging goals to enhance motivation and performance (E. A. Locke & Latham, 2002; E. Locke & Latham, 2006).	Setting clear, challenging goals for students such as completing a series of math problems within a time limit, and providing immediate feedback on their progress to help them stay focused and motivated.
Social Comparison Theory	Suggests that individuals evaluate their abilities and opinions by comparing them to those of others in their social environment (Festinger, 1954).	Creating leaderboards that rank students based on their performance in math quizzes and assignments, encouraging them to improve their standing through friendly competition.

Behavioural Reinforcement Theory	Posits that behaviors can be strengthened or weakened through positive or negative reinforcement (Skinner, 1965, 1989).	Using a reward system where students earn points for completing math problems correctly, which can then be exchanged for privileges or small prizes, thus reinforcing their efforts to practice and learn math skills.
Expectancy Theory	Expectancy theory, developed by Vroom, emphasizes the link between effort, performance, and desired outcomes, suggesting that individuals are motivated when they believe their efforts will lead to valuable rewards (Vroom, 1964).	Providing a clear connection between effort (e.g., completing extra practice problems) and rewards (e.g., extra credit or recognition), helping students understand how their efforts can lead to tangible benefits. Then stay consistent with these structures.

These theories are instrumental in designing gamified learning experiences that effectively engage students. By incorporating these psychological theories, gamification can create dynamic and engaging learning environments that motivate students to actively participate and excel in their educational pursuits.

4.3 Pedagogical theories

Understanding gamification in education requires exploring various pedagogical theories. Bíró asserts that gamification integrates elements from multiple learning theories, particularly behaviorist, constructivist, and connectivist approaches, and even argues that it is possible to view it as an entirely new learning theory (Bíró, 2014). The integration of diverse pedagogical theories when gamifying can help tailor learning experiences to meet diverse learner needs. See table 2 for further explanation of the different theories and their possible usage in gamification and figure 5 for visualization.

Figure 5: Key pedagogical theories contributing to successful gamification.

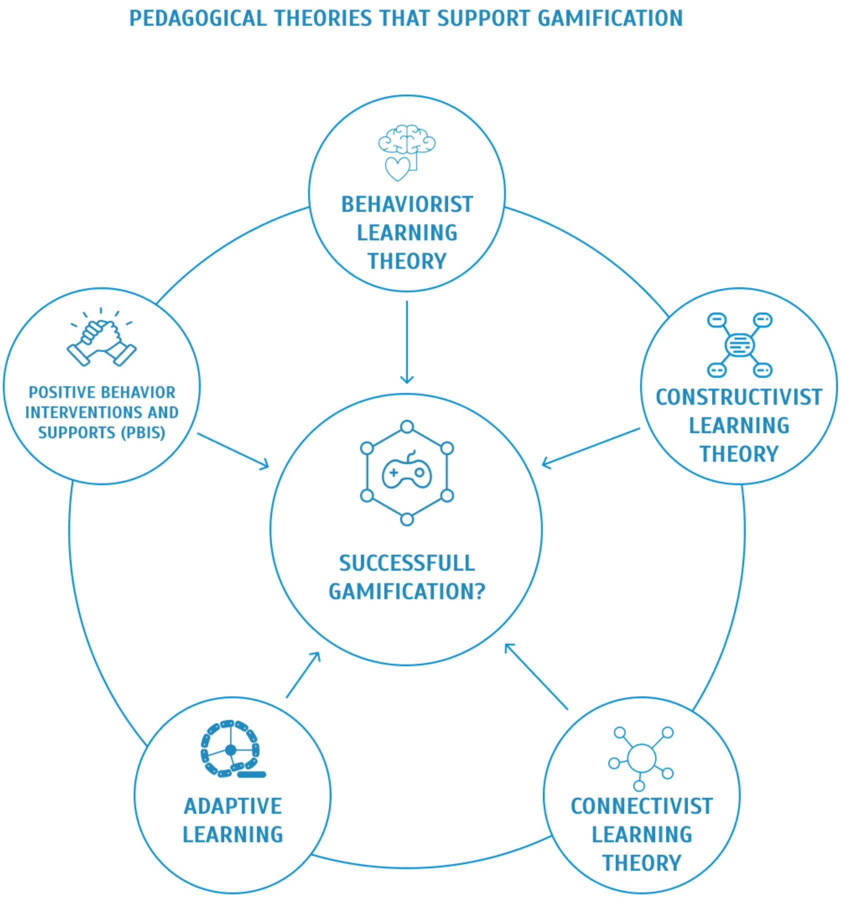


Table 2: Key pedagogical heories contributing to successful gamification.

Theory	**Description**	**Example of usage in gamified mathematics course**
Behaviorist Learning Theory	Focuses on positive reinforcements and immediate feedback (Bíró, 2014).	Using a system of rewards and punishments to reinforce desired behaviors, such as providing immediate feedback and rewards for correct answers in math quizzes.

Constructivist Learning Theory	Knowledge is constructed by learners through interactions (Bíró, 2014).	Designing math projects where students explore and discover mathematical concepts themselves, and then discuss and reflect on their findings with peers.
Connectivist Learning Theory	Learning is connecting information across networks (Siemens, 2008)	Creating an online community where students share and discuss math problems and solutions, leveraging social networks to enhance their understanding and learning.
Adaptive Learning	Tailors instruction to individual learner's needs (Yarandi et al., 2013).	Utilizing adaptive learning software that adjusts the difficulty of math problems based on each student's performance, ensuring personalized learning paths.
Positive Behavior Interventions and Supports (PBIS)	A framework for implementing interventions to improve academic and behavioral outcomes based on individual needs of students and student groups. Emphasizes a multi-tiered system of support (Sugai & Simonsen, 2012).	Implementing a points system that rewards students for demonstrating positive behaviors, such as supporting other students with understanding difficult concepts.

By incorporating these pedagogical theories, gamified learning environments can be designed to support effective teaching and enhance student engagement and motivation.

4.4 Multimedia Instructional Theories

Lameras emphasizes the importance of combining pedagogical approaches with ICT tools to create successful digital learning experiences, which is highly relevant when gamifying online and hybrid settings (Lameras, 2015). By engaging in the creation of digital artifacts like games, narratives, simulations, or rich media presentations, students can achieve deep learning and encounter critical concepts and methods (Lameras, 2015). Integrating diverse ICT tools successfully in online and blended learning environments in mathematics requires following specific heuristics to ensure content delivery and immersive experiences are optimized. Multimedia instructional design theories are crucial for understanding how this can be done as they provide guidelines for designing and using ICT tools effectively. See table 3 for further explanation of the different theories and their possible usage in gamification and figure 6 for visualization.

Figure 6: Key multimedia instructional theories contributing to successful gamification.

Table 3: Key multimedia instructional theories contributing to successful gamification.

Theory	Description	Example of usage in Gamification
Segmenting	Breaking content into smaller, manageable units (Mayer, 2009).	Dividing complex mathematical concepts into smaller, easily digestible modules or units that students can complete sequentially.
Personalization	Tailoring content to individual learner preferences (Clark & Mayer, 2016).	Allowing students to choose topics or types of math problems they find most interesting, providing personalized feedback and resources based on their choices.
Repetition and Reinstatement	Allowing learners to revisit content to reinforce learning (Mayer, 2009).	Providing opportunities for students to retake quizzes and revisit practice problems to reinforce their understanding of key mathematical concepts.
Access to Prior Instructional Content	Providing access to previously covered material (Clark & Mayer, 2016).	Creating an online repository of past lessons, problem sets, and solutions that students can access anytime to review and reinforce previous learning.
Coherence	Presenting material in a logical, organized manner (Mayer, 2009).	Ensuring that math problems and instructional videos are presented in a clear, logical sequence that builds on previously learned concepts.
Signaling	Highlighting important information to direct attention (Mayer, 2009).	Using visual cues, such as arrows or highlighted text, to draw students' attention to critical steps in solving a math problem.
Redundancy	Avoiding unnecessary repetition of information (Mayer, 2009).	Streamlining instructional materials by removing repetitive explanations, ensuring that each piece of content adds new value to the learning experience.
Spatial and Temporal Contiguity	Presenting related elements together in time and space (Mayer, 2009).	Placing equations and their graphical representations close to each other in both time (e.g., in the same lesson) and space (e.g., on the same page or screen).
Modality	Using multiple sensory channels (e.g., visual, auditory) (Mayer, 2009).	Combining video explanations with written instructions and interactive simulations to cater to different learning styles and reinforce understanding through multiple channels.

Pretraining	Introducing key concepts before presenting complex material (Mayer, 2009).	Providing introductory videos that explain basic concepts before students tackle more complex math problems that build on these foundational ideas.
Voice and Image	Using human voice and relevant visuals to enhance understanding (Mayer, 2009).	Incorporating narrated video tutorials with visual aids, such as diagrams and animations, to help explain challenging mathematical concepts.

These theories help ensure that educational content is engaging and accessible, reducing cognitive load and enhancing learning, especially in online and hybrid contexts.

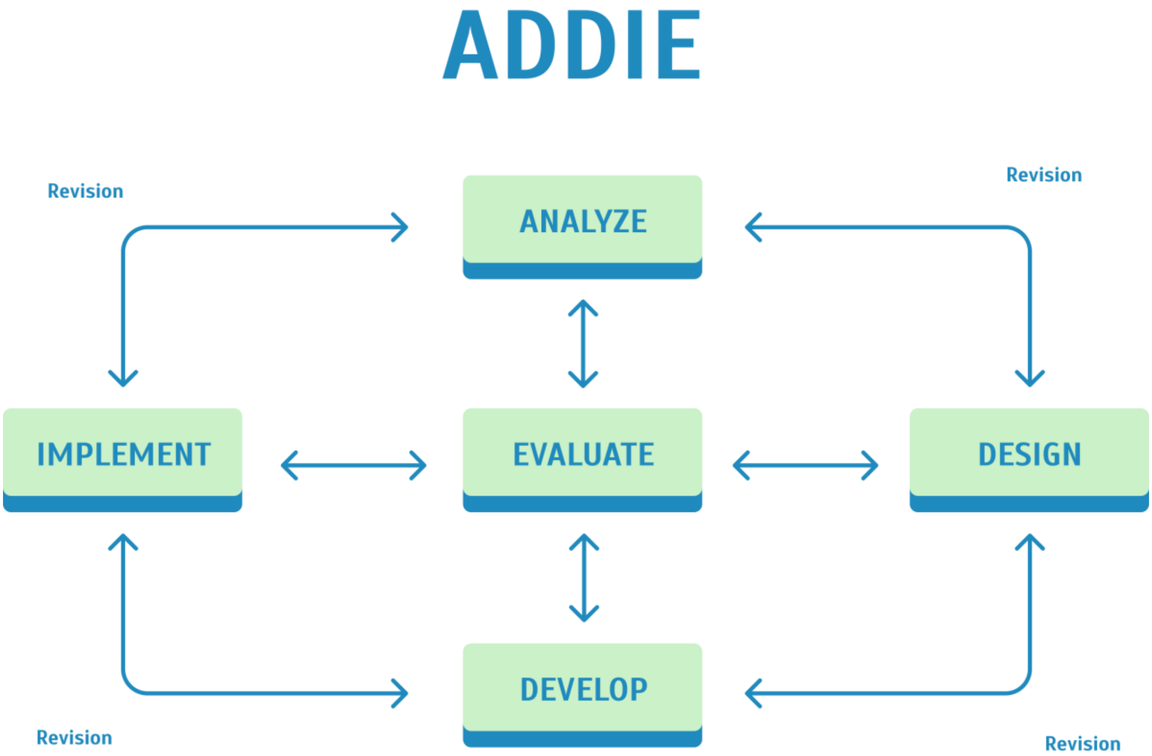
5. A Gamified ADDIE Framework

The goal of this paper is to aid educators and instructional designers in higher education to gamify their mathematics courses effectively. To do this, we propose a novel gamified ADDIE framework designed to incorporate various theories and methods while still maintaining flexibility and applicability. The framework serves as a general template where different theories can be utilized or substituted without losing its core purpose. This adaptability ensures that educators can tailor the framework to their specific needs and contexts.

Think of this framework as a menu template: the structure is set, and the process is clear, but the content can be customized to suit the specific requirements of a mathematics course in a gamified context. Our intention is to provide a concrete and clear framework that can be applied practically, unlike many abstract models that lack practical examples and directions. We encourage educators to use this framework as a "cookbook," where they can modify specifics, remove parts, and adjust ingredients based on their unique circumstances. To illustrate this, we will hypothetically apply the framework to a blended learning scenario of an image processing course.

To address the challenges in gamifying mathematics courses in higher education, we propose this gamified ADDIE framework, which extends the original ADDIE model by integrating the GAFCC model for gamification along with relevant theories at each stage. We first introduce the original ADDIE framework before elaborating on the new gamified model.

5.1 The ADDIE Framework



The original ADDIE model consists of five phases that can be followed both sequentially and iteratively: Analyze, Design, Develop, Implement, and Evaluate (Branch, 2010; Molenda, 2003). During the analysis phase, instructors identify student needs, learning objectives, and course content, considering factors such as existing knowledge and preferred learning styles. In the design phase, the focus shifts to structuring the learning experience, outlining instructional strategies and content delivery methods. The development phase involves creating instructional materials based on the design specifications, including the production of content and resources. Implementation entails the delivery of the instructional materials to learners, ensuring proper instruction and support are provided. Finally, the evaluation phase assesses the effectiveness of the instructional materials and delivery methods, gathering feedback to inform revisions and improvements for future iterations.

5.2 The Gamified ADDIE Framework

In this section, we will introduce the Gamified ADDIE Framework (see figure 6) and provide concrete examples of how this framework can be applied to a hypothetical mathematics course in image processing. The goal is to tailor the original ADDIE model to better fit the needs of gamification in online and blended learning environments, ensuring it is practical and applicable in real educational settings.

The Gamified ADDIE Framework integrates the well-established ADDIE model with elements from the GAFCC model and the possibility to incorporate other relevant theories (as introduced earlier) to create a comprehensive approach for designing and implementing gamified learning experiences of mathematics in HE. Below are the detailed phases of the Gamified ADDIE Framework, tailored specifically for gamified learning in a mathematics context in online and blended learning environments.

Figure 6: the Gamified ADDIE Framework

THE GAMIFIED ADDIE FRAMEWORK

1. ANALYZE

1. Identify mathematics course learning goals
2. Assess audience of the mathematics course
3. Analyze mathematics course content
4. Analyze Gamification context
5. Identify gamification resources

2. DESIGN

1. Decide on structural & content gamification
2. Identify and Employ Theories from Gamification Relevant Disciplines
3. Choose Game Design elements & mechanics to support the theories
4. Create sketches & notes

3. DEVELOP

1. Assemble a gamification team
2. Make a gamification development plan
3. Prototype the gamified learning environment elements
4. Create content, gamify & develop the elements
5. Assemble all the elements

4. IMPLEMENT

1. Train the instructor(s) in gamification and course content
2. Prepare the Learners for a gamified mathematics learning environment
3. Arrange the learning space to support a gamified mathematics learning environment
4. Launch the Gamified Course

5. EVALUATE

1. Conduct formative evaluation
2. Conduct summative evaluation
3. Conduct accessibility & inclusivity evaluation
4. Analyze Data and Identify Trends
5. Report Findings and Make Recommendations
6. Plan for Iterative Improvement

Analyze

In this phase, the foundation for the gamified learning experience is established. This involves understanding the learning goals, audience, content, gamification context, and available resources.

1. **Identify mathematics course learning goals:**

   Define clear and specific learning objectives for the mathematics course. These should align with both educational standards and the needs of the learners. This involves breaking down the course into measurable learning outcomes that students need to achieve.

   Example: For an Image Processing course, a learning goal could be "Students will be able to apply convolution operations to process digital images," "Understand and implement various filtering techniques," and "Analyze the effects of different image processing methods."

2. **Assess audience of the mathematics course:**

   Gather information about the learners, including their demographics, prior knowledge, learning preferences, and motivational factors. This can be done through surveys, interviews, and diagnostic assessments to tailor the course to their needs.

   Example: Conduct surveys or interviews to understand that students have a range of experiences with programming and mathematics, from novice to advanced levels. In the image processing course and insight might be that some students may have experience with Python, while others are new to coding. This means there might be a need for a pre-course or learning module before the start of the actual course.

3. **Analyze mathematics course content:**

   Break down the course content into key topics and concepts that are essential for understanding mathematics. Identify prerequisite knowledge and how new content builds on this.

   Example: Identify critical topics such as image representation (pixels, color spaces), filtering techniques (Gaussian blur, edge detection), and transformations (Fourier Transform). Determine that students need to understand linear algebra concepts like matrix operations.

4. **Analyze Gamification context:**

   Determine the context in which gamification will be applied, including technological capabilities, institutional support, and cultural factors. Identify potential challenges and opportunities for integrating gamification in your specific context.

   Example: Ensure that the university's main learning management system (LMS) supports gamification features like leaderboards and badges. Verify that students have access to necessary technology (computers, internet access) and are comfortable using online learning platforms. Identify the need to explore more resources outside of the LMS to support the gamification process.

5. **Identify gamification resources:**

   Identify the resources required for implementing gamification, including software, tools, and expertise. This might involve securing licenses for gamification platforms or tools and ensuring technical support is available.

   Example:

   Resources might include access to gamification platforms such as Kahoot!, graphic designers for creating content, developers to make specific game modules, and different subject matter experts.

Outcome:

An analysis report that includes learning goals, audience characteristics, mathematics course content breakdown, and identifications of needs, challenges and resources to the gamification process and the gamified learning experience.

Design

This phase involves designing the structure and content of the gamified learning experience, incorporating relevant theories and game design elements.

1. **Decide on structural & content gamification:**

Determine whether to use structural gamification (e.g., points, badges) or content gamification (e.g., storytelling, challenges) or a combination of both. This decision should be based on the analysis phase findings.

Example: For the Image Processing course, use structural gamification to award points for completing modules and content gamification to create a storyline where students "unlock" parts of an image by solving problems. Each module could represent a different "mission" where students help restore a damaged image by applying appropriate processing techniques. There could be a storyline where students are wizards in a magical realm tasked with restoring ancient, enchanted images. Each module represents a different "quest" where students use their "magic" (image processing techniques) to reveal hidden details and restore the images. For instance, a quest could involve using convolution operations to reveal a hidden map in a damaged scroll. As students progress, they earn magical artifacts (badges) and increase their wizard ranking (leveling up).

2. **Identify and Employ Theories from Gamification Relevant Disciplines:**
Apply relevant and supportive theories to support the gamified learning environment. Examples of these could be psychological, pedagogical, and multimedia theories as presented earlier, but others might also be relevant.

Example:

- *Flow Theory (Csikszentmihalyi):* Design challenges that are neither too easy nor too hard to keep students engaged. For instance, starting with basic tasks like adjusting brightness and contrast before moving on to more complex operations like Fourier Transforms.
- *Self-Determination Theory (Deci and Ryan):* Ensure students feel autonomy by allowing them to choose the order in which they tackle certain quests or modules. In the context of the Image Processing course, students could be presented with a "Quest Map" at the beginning of the course. This map displays various quests (modules) that they need to complete. Each quest covers a specific topic or skill in image processing.
- *Constructivist Learning Theory (Piaget, Vygotsky):* Encourage students to build their own understanding through hands-on activities and problem-solving tasks. For example,

students could be asked to experiment with different filters and observe their effects on images, promoting active learning and discovery.

- *Playfulness Theory (Barnett):* Foster a playful learning environment by incorporating game-like elements such as role-playing and exploration. Students might take on the role of an image processing detective, solving visual puzzles to uncover hidden details.
- *Multimedia Learning Theory (Mayer):* Apply principles of multimedia learning by combining text, images, and interactive elements to enhance understanding. For example, using animations to explain complex processes like edge detection.
- *Magic Circle (Huizinga):* Create a distinct boundary where the course content is the "magical world," encouraging immersion and focus. For example, students enter the "magic circle" when they log into the course platform, fully engaging in their wizard roles.
- *Goal-Setting Theory (Locke and Latham):* Set clear, challenging, yet achievable goals for each quest. For instance, "Use the Sobel filter to detect edges in the enchanted map image."
- *Social Comparison Theory (Festinger):* Use leaderboards to motivate students by comparing their progress with peers. For instance, display a leaderboard showing the top wizards who have completed the most quests or earned the most points.
- *Behavioral Reinforcement Theory (Skinner):* Provide immediate rewards (e.g., points, badges) for completed tasks to reinforce desired behaviors. For instance, awarding a badge for successfully restoring an image using multiple filters.
- *Expectancy Theory (Vroom):* Ensure students believe that their efforts will lead to success and that the rewards are valuable. For instance, clearly explain how mastering image processing techniques will help them in future courses or careers.
- *Adaptive Learning*: In the context of the Image Processing course, adaptive learning technologies can be used to create a dynamic learning environment where tasks and challenges are tailored to each student's current level of understanding and progress. This can be implemented through e.g. an intelligent learning system that continuously assesses student performance and adjusts the content accordingly.

3. **Choose Game Design elements & mechanics to support the theories:**

   This step goes hand in hand with the previous step and should be used interchangeably. Select game elements that align with the identified theories and learning objectives.

Example:

- *Points and Badges:* Award points for completing tasks correctly and badges for mastering specific skills, like successfully implementing a Sobel filter for edge detection.
- *Leaderboards:* Display leaderboards to foster friendly competition and motivate students to improve their skills.
- *Narrative:* Create a storyline where students are part of a team of image processing experts tasked with restoring historical photographs, each module representing a different photograph with unique challenges.
- *Challenges:* Design progressively difficult challenges that require students to apply their knowledge and skills. For example, students might start with basic image enhancement tasks and progress to more complex projects like building a facial recognition system.
- *Feedback:* Provide immediate, targeted feedback to guide students and reinforce learning. Use interactive quizzes with instant feedback and suggestions for improvement.

4. **Create sketches & notes:**

Develop preliminary sketches and notes that outline the gamified learning experience, including the narrative, interactions, and progression. This visual planning helps in understanding how the course will flow and where gamification elements will be integrated.

Example:

Sketch a storyboard for the course where students progress through levels, starting with basic image representation and moving to complex filtering techniques. Include visual aids like flowcharts for decision-making processes in the narrative and mock-ups of the user interface showing where points, badges, and progress bars will appear.

Outcome:

A detailed document that includes the course structure, selected game elements, theoretical underpinnings, and visual sketches.

Develop

The third phase of the Gamified ADDIE Model focuses on the development of the gamified learning experience.

1. **Assemble a gamification team:**

   Depending on your resources, form a multidisciplinary team that includes instructional designers, game designers, subject matter experts, and technical developers. Each member brings unique skills to ensure the course is educationally sound and engaging.

   Example: Include a software developer to implement the gamified elements in the LMS, a graphic designer to create visual assets like badges, avatars, and maps, and a subject matter expert in Image Processing to ensure the content is accurate and relevant.

2. **Make a gamification development plan:**

   Outline a detailed plan for developing the gamified course, including timelines, tasks, and responsibilities. This ensures the project stays on track and that all team members know their roles.

   Example: Develop a Gantt chart that schedules the creation of content, development of gamification features, and testing phases. Assign tasks such as scriptwriting for video tutorials, coding for interactive exercises, and graphic design for visual elements. Consider working with an agile approach while developing the course for faster iterations and continuous evaluation.

3. **Prototype the gamified learning environment elements:**

   Create prototypes or mock-ups of key elements to test their functionality and engagement potential. Prototyping allows for early feedback and adjustments before full-scale development.

   Example: Develop a prototype of a gamified quiz where students earn points for correct answers and receive immediate feedback. Include features like a progress bar that shows how close they are to earning a badge for the module. You could also create a prototype of a map that represents the fantasy world where the Image Processing course takes place. This could should include different regions or areas, each corresponding to a specific module or set of challenges in the course like

4. **Create content, gamify & develop the elements:**
   Develop the actual course content and integrate gamification elements, ensuring they are aligned with the learning objectives. This involves writing instructional materials, creating multimedia resources, and embedding gamified elements.

   Example: Create interactive simulations where students apply convolution operations to images and receive real-time feedback. Develop video tutorials that guide students through complex tasks, such as applying a Fourier Transform to filter noise from an image.

5. **Assemble all the elements:**
   Combine all the developed elements into a cohesive course, ready for implementation. This step involves ensuring all parts work seamlessly together and are accessible to students.

   Example:
   Integrate quizzes, interactive activities, and narrative components into the LMS, ensuring a seamless user experience.

Outcome:
A gamification development plan, prototypes, and the first version of the gamified mathematics course/module.

Implement

This phase involves delivering the gamified learning experience to students and ensuring that instructors are prepared.

1. **Train the instructor(s) in gamification and course content:**

Provide comprehensive training for instructors on the gamified elements and how to facilitate the course. This includes technical training on using the tools chosen and pedagogical strategies for engaging students.

Example: Conduct workshops to familiarize instructors with the gamification platform and best practices for engaging students. Provide them with a manual or guide that explains the gamified elements and how to support students in using them effectively. For instance, show instructors how to navigate the fantasy world map, track student progress, and utilize the interactive features.

2. **Prepare the Learners for a gamified mathematics learning environment:**
   Orient students to the gamified elements and explain how they contribute to their learning. Provide clear instructions and support resources to help them navigate the gamified course.

   Example: Create an introductory video or guide that explains the point system, badges, and how to progress through the course. Offer a demo session where students can ask questions and get hands-on experience with the gamified elements before starting the course. For example, the video could introduce the storyline, showing how they will help restore ancient, enchanted images using image processing techniques.

3. **Arrange the learning space to support a gamified mathematics learning environment:**
   Ensure that the physical or virtual learning environment supports the gamified elements. This includes setting up necessary technologies and creating a supportive atmosphere.

   Example: In the online part of the image processing course, set up a dedicated section in the LMS where students can access the fantasy world map and track their progress. Create online forums or discussion boards where students can share achievements, discuss challenges, and collaborate on quests. Ensure that technical support is available to resolve any issues students might face with the gamified features.

4. **Launch the Gamified Course:**

Officially start the course, monitor the initial engagement, and be ready to provide immediate support as needed. This step includes ensuring that all elements are functioning correctly and that students are engaging with the content as intended.

Example: Host a kick-of launch day, with a live online session where students can explore the course together, guided by the instructor. Use this session to address any initial confusion and to build excitement around the gamified elements. Monitor student engagement through the LMS and be prepared to offer additional guidance or technical support.

Outcome:

A live gamified mathematics course that is working and ready to run.

Evaluate

The evaluation phase involves assessing the effectiveness of the gamified learning experience. This includes gathering and analyzing data to determine how well the course met its objectives and identifying areas for improvement. Evaluation should be both formative (ongoing during the course) and summative (at the end of the course), but it is also important to evaluate in-between the other phases of the gamified ADDIE to get feedback on and iterate on the smaller elements of the course being developed before launch.

1. **Conduct formative evaluation:**

   Conduct ongoing assessments to monitor student progress and engagement throughout the course. This helps to identify and address issues in real-time, ensuring that the learning experience remains effective and engaging.

   Example: Use analytics tools within the LMS to track student activity, such as login frequency, time spent on tasks, and completion rates of modules. Conduct regular check-ins with students through surveys or quick polls to gather feedback on their experience. For instance, ask students how they are finding the quests and if the challenges are appropriately difficult.

2. **Conduct summative evaluation:**

Conduct a comprehensive assessment at the end of the course to evaluate overall effectiveness. This involves analyzing student performance data, collecting detailed feedback, and reviewing the achievement of learning objectives.

Example: At the end of the Image Processing course, analyze the final exam results, project submissions, and overall grades to assess student learning outcomes. Distribute a detailed course evaluation survey to gather student feedback on the gamified elements, storyline, and instructional design. Questions could include: "Which part of the course did you find most engaging?" and "How did the gamified elements help you understand image processing concepts?"

3. **Conduct accessibility & inclusivity evaluation:**

   Ensure that the gamified course is accessible and inclusive for all students.

   Example: Review course materials for accessibility, conduct usability testing with diverse learners, and ensure representation in game narratives.

4. **Analyze Data and Identify Trends:**

   Review the data collected from both formative and summative evaluations to identify trends, strengths, and areas for improvement. This analysis should be thorough and consider various perspectives, including student performance, engagement levels, and feedback.

   Example: Use statistical analysis to determine if there were significant improvements in student performance compared to previous cohorts who did not use gamification. Look for patterns in the feedback, such as common suggestions for improvement or recurring praise for certain elements. For example, if many students reported enjoying the narrative but found some quests too challenging, this could indicate a need to adjust the difficulty levels.

5. **Report Findings and Make Recommendations:**

   Compile the evaluation findings into a comprehensive report that includes both quantitative data (e.g., test scores, completion rates) and qualitative data (e.g., student comments, instructor observations). Provide actionable recommendations for future iterations of the course.

Example: Prepare a report summarizing the impact of the gamified elements on student engagement and learning outcomes. Highlight key successes, such as increased participation rates or improved understanding of complex concepts. Provide recommendations, such as refining certain quests to balance difficulty, enhancing certain narrative elements, or incorporating additional interactive features based on student feedback.

6. **Plan for Iterative Improvement:**

   Use the insights gained from the evaluation to plan for iterative improvements. This involves updating the course design, content, and gamification elements to enhance future iterations.

   Example: Based on the evaluation report, set goals for the next course iteration. For example, you might plan to add more diverse challenges, improve the clarity of instructions, or integrate new technologies to further enhance interactivity. Schedule a timeline for implementing these changes and consider piloting the revised course with a small group of students before a full rollout.

Outcome: A detailed understanding of the course's effectiveness, challenges and opportunities, and a clear plan for iterative improvements, ensuring that future iterations of the gamified mathematics course is even more engaging and effective.

6. Conclusion

This paper presents a comprehensive framework where gamification is integrated into the ADDIE model, specifically to enhance the learning experience in mathematics courses within online and blended learning environments. By infusing the traditional ADDIE model with gamified elements, we aim to foster greater engagement, motivation, and ultimately, deeper learning among students.

Our exploration began with an in-depth review of the foundational theories underpinning gamification, including game design elements, structural and content gamification, typical challenges, the GAFCC model, playfulness, psychological, pedagogical, and multimedia instructional design theories. These theories provide the bedrock upon which the gamified ADDIE model is built, ensuring that each phase of the instructional design process is informed by robust, evidence-based practices.

The ***Analysis*** phase of ADDIE was enhanced by leveraging specific gamification theories to identify learning needs and preferences, establishing a clear understanding of how game mechanics can address these needs. In the ***Design*** phase, we illustrated how to create a cohesive and engaging learning journey using the different underpinning theories through mechanisms such as narrative elements, adaptive learning technologies, and a well-structured progression system. During the ***Development*** phase, we emphasized the creation of prototypes to test and refine the gamified elements, ensuring they meet educational goals and maintain high levels of student engagement. This iterative approach allows for continuous feedback and improvement, vital for the success of any gamified course. The ***Implementation*** phase focused on the seamless integration of gamified components into the actual teaching process, highlighting strategies for maintaining student engagement and ensuring the gamified elements function as intended. This phase also underscored the importance of instructor training and technical support to address any issues that may arise. Finally, the ***Evaluation*** phase stressed the need for both formative and summative assessments to gauge the effectiveness of the gamified course. By analyzing performance data and student feedback, we can identify strengths and areas for improvement, ensuring that the course evolves and improves with each iteration.

Overall, the gamified ADDIE model provides a structured yet flexible approach to incorporating gamification into educational contexts and should be used accordingly. The specific examples and practical applications outlined in this paper serve as a roadmap for educators looking to enhance their courses through gamification, but the application of the framework should always be adjusted to the given context and relevant theories related to that context. To integrate different relevant theories effectively into the gamification process, the instructional designer can for example align each section of content and structural gamification with the relevant psychological, pedagogical, instructional, or other theories to see which ones fit in the specific context. The repetition and similarities in how different theories are applied within the sections underscore the integrated nature of gamification, where psychological, pedagogical, instructional, and game design principles work together to enhance the overall learning journey.

We encourage further research into the adaptation of instructional design models to incorporate gamification, and there is still a need to conduct a practical evaluation of the proposed framework to validate its efficiency and effect. Still, we believe that by thoughtfully integrating gamification elements by using the Gamified ADDIE Model, we can create engaging, motivating, and effective learning experiences that resonate with students and support their academic success. This approach could not only enhance the learning of mathematics concepts but also foster critical thinking, creativity, and a love for learning that extends beyond the classroom.

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