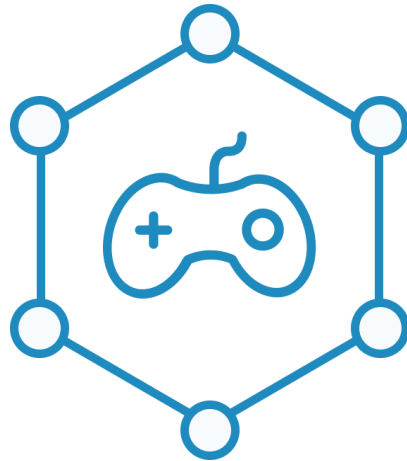# A new framework for gamifying mathematics in higher education
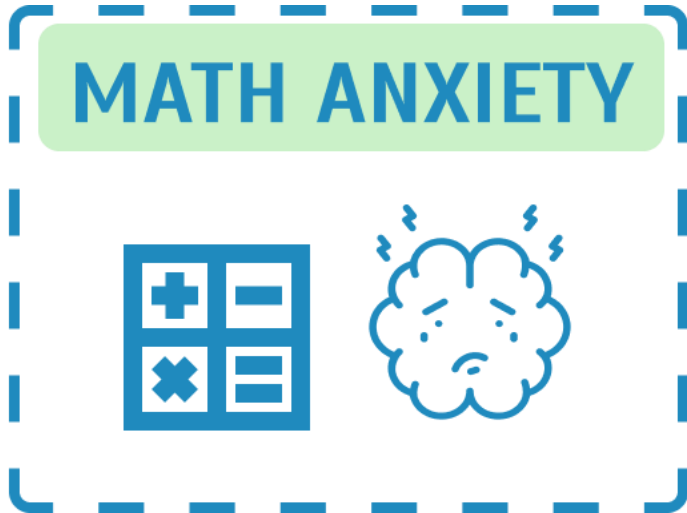
TPM3

Why do we need this?

- Mathematics in higher education:
  - Many people with math anxiety
  - Low motivation
  - Unnecessary high cognitive load not used for learning
  - High drop out and and fail rates

What is math anxiety?

«A worry or fear that occurs when people try to solve math problems, take tests, or even think about numbers.» (Weir, 2023)

Characterized by:

- intense fear
- Anxiety
- Apprehension when faced with mathematical tasks

Results in:

- Reduced mathematical performance
- Avoidance behaviour
- Can hinder an individual's ability to engage effectively with mathematical concepts and activities

Symptoms:

- Negative self-talk
- Lack of motivation to work on math
- Not studying regularly
- Putting off math homework until the last minute
- Panic when doing math homework or tests
- Difficulty remembering math facts
- Relying on memorization rather than understanding

How do you manage math anxiety?

Spot the signs

Promote mental health

Watch your language

Help people grow

Improve study skills

How do you manage math anxiety?

Spot the signs

Promote mental health

Watch your language

Help people grow

Improve study skills

Interactive learning environments can help with these two!

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Interactive learning environments (ILE)

- We use this term here to lump together the concepts of "gamification, games and simulations" to make it easier to discuss all three simultaneously in the context of learning

- We want to leverage elements from "gamification", "games" and "simulations" to create an interactive learning environment in mathematics education and a "game-based learning environment"
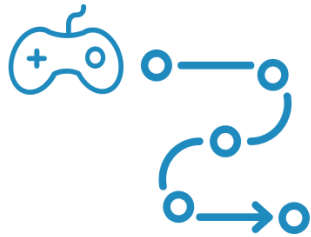
So many terms!

- **Gamification**
- Game-based learning
- Games
- Gameful design
- Gameful experience
- Simulations
- Serious games
- Playfulness and playful learning
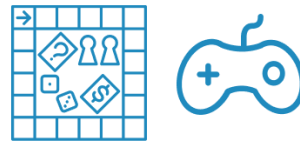- Gamified learning environment

What can we utilize to create ILEs?

GAMIFICATION

The process of applying game design principles and mechanics to non-game contexts, such as education or business, to engage users and encourage desired behaviors.

GAMES

Structured activities with defined rules, goals, and outcomes, typically designed for entertainment or recreation. Games often involve competition, strategy, or cooperation among players. Can be both physical and digital.
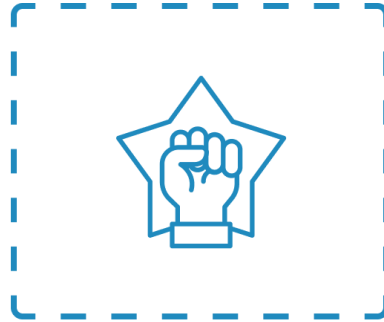
SIMULATIONS

Representations of real-world processes or systems, often interactive and computer-based, used for training, experimentation, or prediction. Simulations aim to replicate the behavior of real systems to provide insight or practice in a controlled environment.
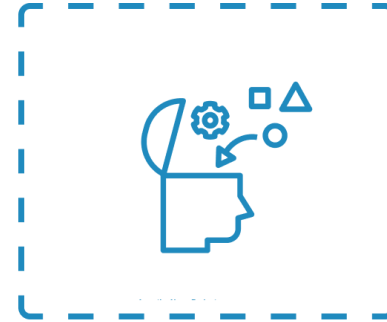
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Why gamification and ILEs?

Increases Enjoyment And Engagement

Improves Attitude And Motivation

Develops Higher-Order Cognitive Skills

Enhances Self-Efficacy And Growth Mindset

Reduces Performance Anxiety

Psychological theories

FLOW THEORY

The idea that people are happiest when they are completely absorbed in an activity, experiencing a state of "flow.". Flow happens when the challenge of the task matches your skill level, creating a harmonious and immersive experience.

SELF-DETERMINATION THEORY

Explores why people do the things they do and how their motivation is influenced. It suggests that individuals are more likely to be motivated and satisfied when their basic psychological needs for autonomy, competence, and relatedness are fulfilled. Also introduces the concept of intrinsic and extrinsic motivation.

SOCIAL COMPARISON THEORY

Suggests that people determine their own social and personal worth based on how they stack up against others. In simple terms, we tend to evaluate ourselves by comparing our abilities, opinions, and success to those of others around us. This comparison helps us understand where we stand in various aspects of life and can influence our self-esteem and motivation.

BEHAVIOR REINFORCEMENT THEORY

Is based on the idea that behaviors can be strengthened or weakened through reinforcement. In simple terms, if you reward a behavior, it's more likely to be repeated; if you punish it, it's less likely. Reinforcement can be positive (adding something desirable) or negative (removing something undesirable).
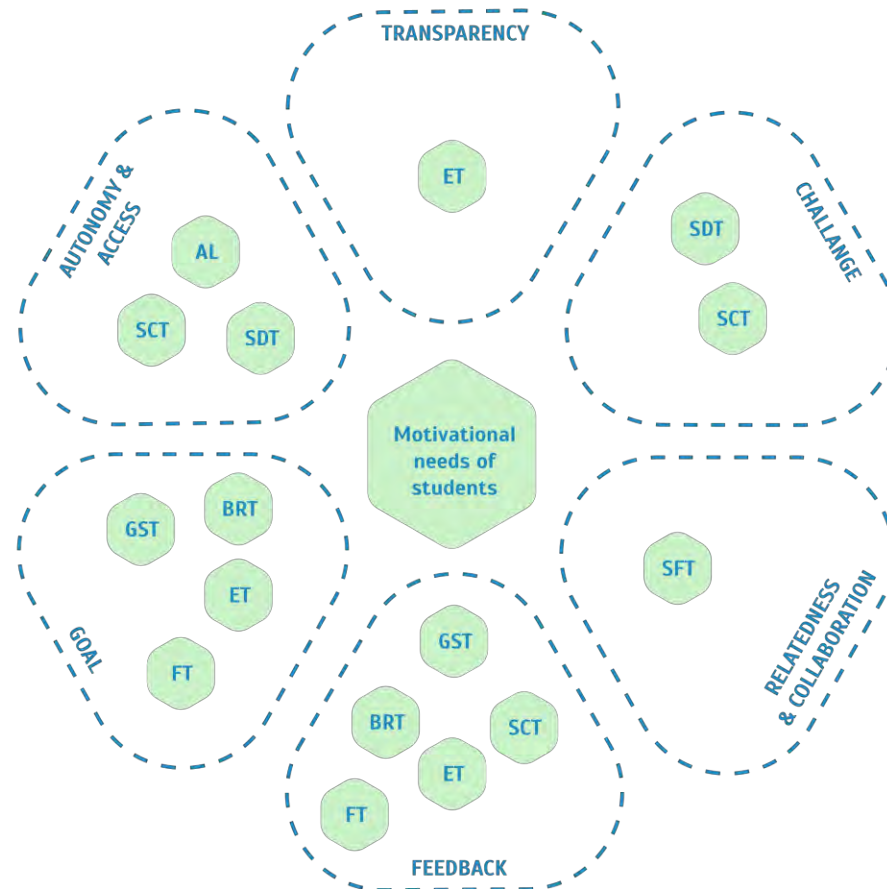
GOAL-SETTING THEORY

Suggests that setting specific and challenging goals can significantly enhance motivation and performance. When people have clear objectives that are a bit of a stretch but still achievable, it can inspire them to work harder and smarter to reach those goals. This theory emphasizes the importance of having well-defined targets to drive motivation and improve overall performance.

EXPECTANCY THEORY

Expectancy theory posits that individuals are motivated when they believe their efforts will lead to good performance and, consequently, valuable rewards. It involves three elements: expectancy, instrumentality, and valence, emphasizing the link between effort, performance, and desired outcomes.

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How gamification can support the psychological needs connected to motivation

Pedagogical theories

ADAPTIVE LEARNING

Adaptive learning is an educational approach that uses technology to tailor instruction and resources to the individual needs and abilities of each learner, providing personalized learning experiences and adjusting content and pace in real-time based on the learner's progress and performance.

POSITIVE BEHAVIOR INTERVENTIONS AND SUPPORT

Positive Behavior Interventions and Supports (PBIS) is a proactive framework used in schools and other settings to promote positive behavior and prevent problem behavior. It involves teaching and reinforcing appropriate behaviors, establishing clear expectations, and providing support systems to help individuals succeed.
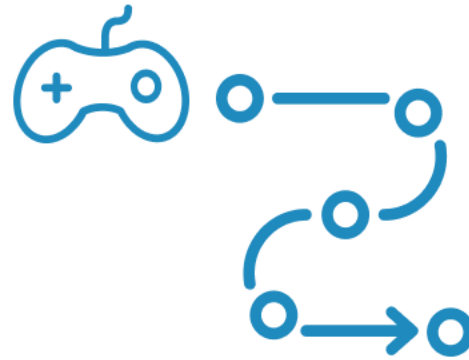
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GAMIFICATION

The process of applying game design principles and mechanics to non-game contexts, such as education or business, to engage users and encourage desired behaviors.

Two types of gamification

STRUCTURAL GAMIFICATION

Application of game elements to propel a learner through content with no alteration or changes to the content. The content does not become game-like, but the structure around the content does.

Primary focus: motivate learners to go through content and to engage them in the process of learning through rewards.

Example: a student earning points within a course for watching videos or completing assigments.

CONTENT GAMIFICATION

The application of game elements and game thinking to alter content to make it more game-like.

Primary focus: motivate learners to go through content and apply learning through immersive and fun context.

Example: adding story elements to a course with a challenge and narrative instead of a list of objectives.

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The two types of gamification can and should be combined!

What context do we want to apply this in?

ONLINE

All learning happens
exclusively online

Often supported by
learning management
systems

HYBRID

Learning happens in a
combination of online and
face-to-face learning
simultaneously

What other theories can help us gamify mathematics that result in positive ILEs?

Multimedia instructional theories

SEGMENTING

Break down content into smaller segments or units to aid comprehension and reduce cognitive overload.

PERSONALI –ZATION

Adapt learning materials to suit individual learners' needs and preferences.

REPETITION AND REINSTATEMENT

Allow learners to revisit and review content multiple times to reinforce learning and reduce anxiety.

ACCESS TO PRIOR INSTRUCTIONAL CONTENT

Provide access to previous instructional materials to support learning and reduce cognitive load.

ORGANIZATION

Structure information in a clear and coherent manner to facilitate understanding and reduce anxiety

More multimedia instructional theories

MAYER'S COGNITIVE THEORY OF MULTIMEDIA LEARNING

Principles that can reduce cognitive load and enhance learning through multimedia presentations.

Coherence: Presenting material in a logical and organized manner.

Signaling: Highlighting important information to direct learners' attention.

Redundancy: Avoiding unnecessary repetition of information.

Spatial and Temporal Contiguity: Presenting related elements close together in time and space to facilitate comprehension.

Modality: Presenting information using multiple sensory channels (e.g., visual and auditory).

Segmenting: Breaking down information into smaller, manageable chunks.

Pretraining: Introducing key concepts before presenting complex material.

Personalization: Tailoring content to individual learners' preferences and needs.

Voice and Image: Using human voice and relevant visuals to enhance understanding.

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Gamification/game theories

LUDIC PLAY

The act of engaging in playful activities or experiences that involve elements of fun, enjoyment, and creativity. It emphasizes the idea that playfulness is inherent in human behavior and can be applied to various contexts, not only for entertainment but also to enhance learning.

THE MAGIC CIRCLE

The metaphorical boundary that separates the fictional world of a game from the real world. Within this boundary, players willingly suspend disbelief and accept the rules and norms established by the game. The magic circle serves as a temporary escape from reality, allowing players to immerse themselves fully in the game's narrative and challenges. Can be used by instructor to tackle students skepsis towards games and play.

PLAYER TYPES

Framework by Marczewski used to categorize individuals based on their motivations and preferences in gamified systems. The framework identifies several player types, such as Achievers, Explorers, Socializers, and Killers, each representing different motivations and behaviors in gaming contexts. Understanding these player types can help designers tailor gamification strategies to better engage and motivate users based on their individual preferences.

GAME ELEMENTS AND MECHANICS MODELS

Frameworks used to analyze and understand the components and interactions within games. For example, the MDA model focuses on Mechanics (rules and systems), Dynamics (player actions and behaviors), and Aesthetics (emotional responses and experiences). Other models are the DMC model and the MAT model.

GAME TYPES

There are many different game types and game genres that can inspire the gamification of courses. Some genres/types are: action, RPG, platformer, simulation, sandbox, adventure, survival, sports, puzzle and fighting.

GAME DYNAMICS

Ecompasses what the learners are actually doing in the game. Are they moving a character around the screen? Are they collecting coins for correcly answering questions? Some dynamics include: allocating resources, building, chasing/being chased, collecting, dodging, exploring, matching, problem solving, racing, role playing, stealing, strategizing.

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Theories from other disciplines

INCREMENTAL DEVELOPMENT
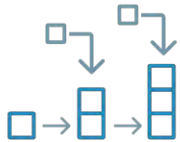
Incremental development is an iterative approach to software development where the product is built and delivered in small, manageable increments or stages, each adding new functionality or features. This method allows for continuous feedback and adaptation, leading to more flexible and responsive development processes.

MINIMUM VIABLE PRODUCT (MVP)

A Minimum Viable Product (MVP) is the most basic version of a product that includes only core features, just enough to satisfy early users and gather feedback for future development.

SCRUM

Scrum is a type of project management framework within "agile development" used for developing, delivering, and sustaining complex products. It emphasizes iterative development, collaboration, and flexibility, with key practices including time-boxed iterations (sprints), daily stand-up meetings, and continuous feedback loops to adapt to changing requirements.

DESIGN THINKING

Design thinking is a problem-solving methodology focused on understanding user needs, generating creative ideas, and prototyping solutions iteratively to create innovative and effective products, services, or processes.

SYSTEMIC THINKING

Systemic thinking is an approach to problem-solving and decision-making that considers the interconnectedness and interdependence of various elements within a system. It involves analyzing how different parts of the system influence each other and understanding the system as a whole rather than focusing solely on individual components.

Incremental and MVP

- Don't start with gamifying your whole mathematics course!

- To start with, can you gamify just one topic or learning objective of the course? Could you start making just one module?

- In the 'module' you are gamifying, what is the minimum you can gamify for it to be considered «a game» (or ILE)?
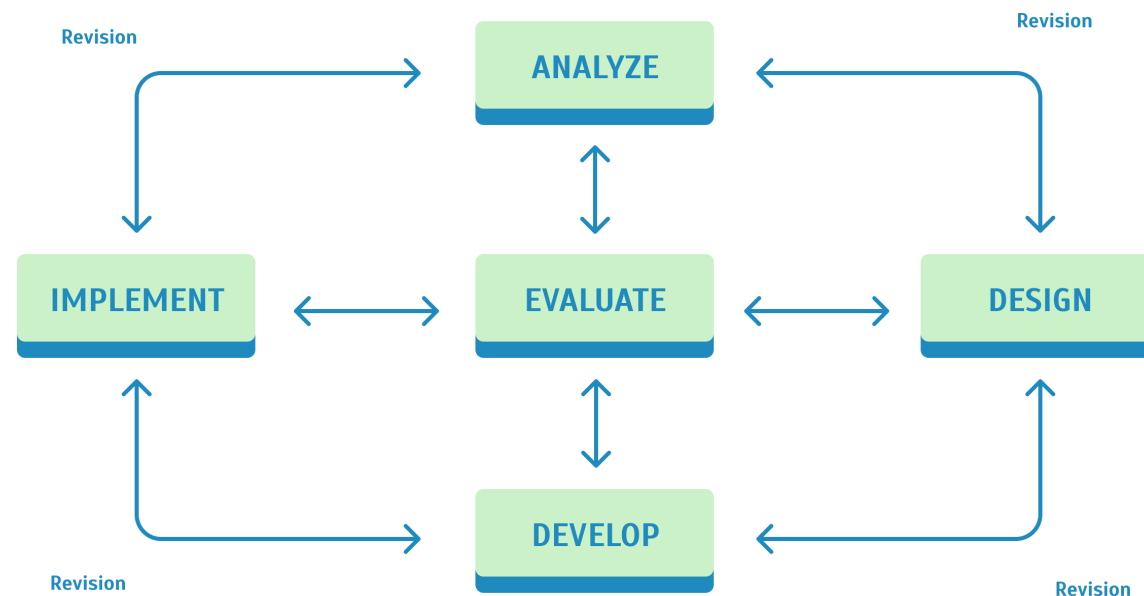

Not like this....

Like this!

Henrik Kniberg
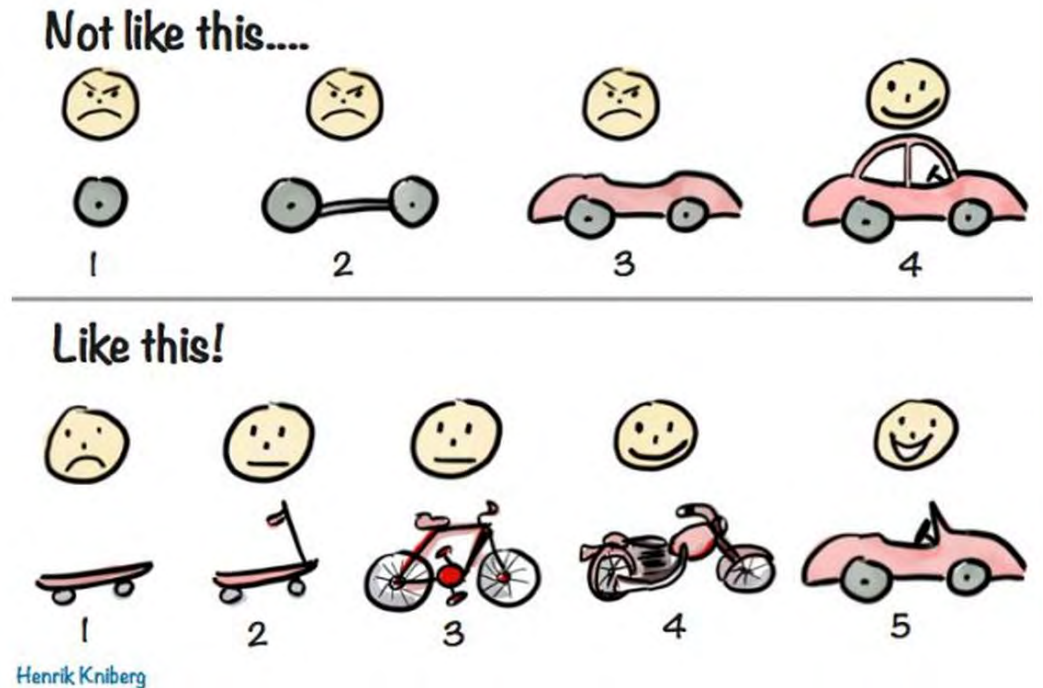
How can we gamify to create ILEs?

By using ADDIE as a base

- A framework designed to guide instructional design and e-learning professionals through the process of creating learning solutions

ADDIE

A

ANALYZE

1. Identify Learning Goals
Define Clear Learning Objectives And Outcomes That Align With The Organization's Goals And Learners' Needs.

2. Assess Audience
Understand The Demographics, Preferences, And Existing Knowledge Of The Target Audience.

3. Analyze Content
Breakdown The Subject Matter Into Manageable Chunks And Identify Key Concepts Or Topics For Gamification.

4. Identify Resources
Find Out What Resources You Might Need Access To, Such As Specific Domain Knowledge Or People That Have Domain Knowledge (Art, Gamification, Programming, Etc.), Physical Facilities,Technology And Tools, Etc.

You Should Come Out With

An analysis of training/ learning needs and a learning plan (learning objectives).

D

DESIGN

1. Decide On Structural VS. Content Gamification

Decide Whether To Focus On Structural Gamification Or Content Gamification Based On The Nature Of The Content And Learner Preferences. These Can Also Be Combined.

2. Choose Game Elements And Mechanics

Select Appropriate Game Mechanics And Elements Based On Motivational Needs To Drive Engagement And Motivation.

3. Employ Psychological Theories

Select Appropriate Psychological Theories To Apply Based On Your Audience And Find Out What Elements And Mechanics You Can Match To Apply These Theories.

4. Employ Pedagogical And Instructional Theories

Select Appropriate Pedagogical And Instructional Theories To Apply Based On Your Audience And Find Out What Elements And Mechanics You Can Match To Apply These Theories.

5. Visual Representation

Create A Visual Representation Of The Gamified Learning Experience's Narrative, Interactions, Progression And Other Important Elements. This Does Not Have To Be Good Looking.

You Should Come Out With
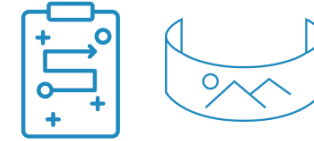
An overview of the course design and content sketches.

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D
DEVELOP

1. Assemble A Team

Depending On The Type Of Gamification You Choose And The Scope Of It, You Need To Assemble An Appropriate Multidisciplinary Team To Develop It. This Might Include Instructional Designers, Game Designers, Subject Matter Experts, Graphic Designers, Software Developers, And User Experience Specialists.

2. Make A Development Plan

Breakdown The Gamified Learning Experience Into Manageable Tasks For Development. This Can Be Done Using Agile/Scrum Development With Short Iterations Iterations (Sprints).
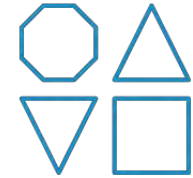
3. Prototype

Create Interactive Mock-Ups Or Prototypes Of The Gamified Learning Experience To Test Its Functionality, Usability, And Engagement. Prototypes Can Range From Simple Sketches To Full Fledged Simulations, Depending On The Stage Of Development And Available Resources.

4. Create Content And Develop

Execute The Plan. Develop The Individual Pieces Of The Learning Materials, Game Assets, And Interactive Elements To Support The Gamified Activities. Start Putting The Pieces Together, This Can Be Done By Using Incremental Development Or MVP.

You Should Come Out With

A development plan, prototypes, and the first version of the gamified course/module.

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IMPLEMENT

1. Train The Instructor

Ensure Instructors Are Trained Effectively By Providing Them With The Necessary Skills And Knowledge To Deliver The Instructional Materials.

2. Prepare The Learners

Prepare Learners By Providing Them With The Necessary Resources, Guidance, And Support To Engage Effectively With The Instructional Materials. This Involves Ensuring Learners Understand The Objectives, Expectations, And Available Support Mechanisms, Empowering Them To Actively Participate And Succeed In The Learning Process. The Magic Circle Can Be Used Hear To Put Students In The Right Mindset.

3. Arrange The Learning Space

Arrange The Learning Space Physically To Optimize The Environment For Effective Instruction And Learning. This Includes Organizing The Physical Layout, Seating Arrangements, And Resources To Facilitate Engagement, Interaction, And Comfort Among Learners.

You Should Come Out With

A live course that is working and ready to run.

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EVALUATE

These Steps Should Be Repeated Multiple Times Throughout The Process.

1. Formative Evaluation

Collect Ongoing Feedback From Learners And Instructors To Identify Strengths, Weaknesses, And Areas For Improvement.

2. Summative Evaluation

Assess The Effectiveness Of The Gamified Learning Experience In Achieving Its Objectives Through Measures Such As Knowledge Retention, Skill Acquisition, And Behaviour Change.

3. Accessibility And Inclusivity Evaluation

Assess The Accessibility And Inclusivity Of The Gamified Course By Doing Different Evaluations Designed For This.
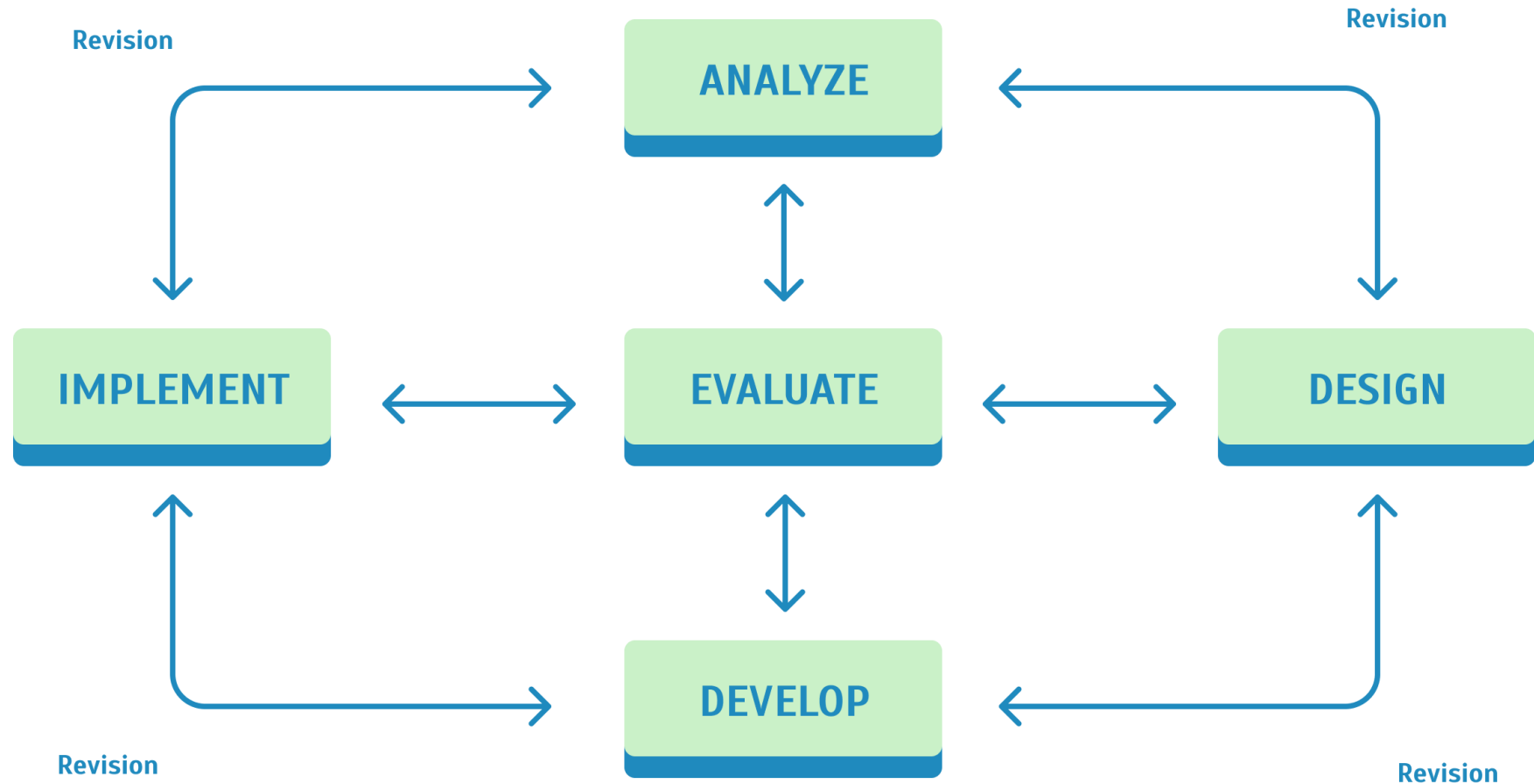
4. Iterative Improvement

Use Evaluation Data To Refine The Gamified Learning Experience And Enhance Its Effectiveness For Future Iterations Or Implementations.

You Should Come Out With

An evaluation report and actionable changes for the current or future courses.

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ADDIE

Player types

- **Socialisers** are motivated by ***Relatedness***. They want to interact with others and create social connections.

- **Free Spirits** are motivated by ***Autonomy and self-expression***. They want to create and explore.

- **Achievers** are motivated by **Mastery**. They are looking to learn new things and improve themselves. They want challenges to overcome.

- **Philanthropists** are motivated by ***Purpose and Meaning***. This group are altruistic, wanting to give to other people and enrich the lives of others in some way with no expectation of reward.

- **Players** are motivated by ***Rewards***. They will do what is needed of them to collect rewards from a system. They are in it for themselves.

- **Disruptors** are motivated by ***Change***. In general, they want to disrupt your system, either directly or through other users to force positive or negative change.

Player types and their willingness to play

Example 1:

Digital Twin for Math Education: A Study on the Utilization of Games and Gamification for University Mathematics Education

- Mission
  - Four games were used in this course. Each game was composed of three modules: playing a game, mathematics lectures related to the game, and evaluation of the form of the quiz. As one game had one mission, there were a total of six missions over the course. It took two weeks to accomplish one mission. Therefore, the course was 15 weeks, including orientation, midterm, and final term for one week each.

- Leaderboards
  - In each mission, the best student, who achieved the highest game score or the highest quiz results, was selected and displayed on the leaderboards on the bulletin of the online class.

- Progress Charts
  - The results of the mission of each student were transferred through the learning management system (LMS) system on campus. Thus, each student could check their learning progress using SMS messages.

- Badges
  - There were various badges for presenters: high-ranking students in quizzes, leadership in a team, outstanding teams in assignments, and students of full attendance. This led learners to collect more badges, which could be reflected in their grades. Badges were produced as a sticker using Formtec and distributed in every class and recorded and presented in the math education digital twin.
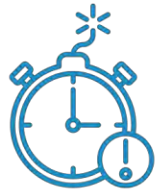
Example 2:

A Preliminary Examination of a Gamified Course to Address Affective Domain Issues in Learning Statistics

- A **story** was added using a narrative that led students through **Quests** (Modules),

- **Missions** (Assignments)

- **Power Ups** (calculation tools)

- and culminating in **Boss Fights** (demonstrating learning via exams).

- Additionally, **Multiple Attempts** at viewing and practicing the content, and **Goals** and **Progress Markers** in the form of a map which fills as the student progresses

- The choice was made to not use the game element of **Winning** or using a **Leaderboard** to ensure students focused on playing and learning rather than on competing with one another.
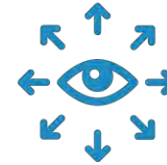
Challenges and barriers to gamification in HE
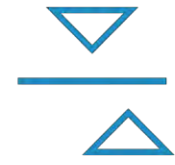
Lack Of Funding

Time Constrains

Limited Knowledge And Expertise

Stigma And Perception
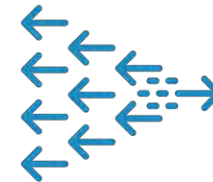
Misalignment With Course Content

Lack Of Guidance And Training

Lack Of Good Examples To Follow

Inflexible Platforms

Resistance To Change

How can we solve this?

- Invest in professional development
- Offer support and resources
- Collaborate with gamification, game or development experts
- Address funding challenges
- Promote awareness and change perceptions
- Tailor gamification to course content
- Provide technical support and platforms
- Encourage collaboration and knowledge sharing
- Conduct research and evaluation
- Embrace a growth mindset

NB!

- Not everyone loves games and gamification

- Inclusivity and universal design is crucial

- It is not easy and quick to gamify

- Gamification is not just a quick fix to better learning, because learning is a complex phenomenon that happens in a bigger system

This workshop and its content is curated and developed by Tone Eide Hilmen in collaboration with Georgios Triantafyllidis. She is a student research assistance in the Pythagoras project at AAU, and masters student in Service Systems Design. (LinkedIn link)

Professor at the Institute of Architecture and Mediology at AAU and research associate in the Pythagoras project. (University Profile Link)

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