

Ingenious Game: Insights Into Evolving From a Learning Card Game to a Learning Software Application Game

Marcus Vinicius Pereira Pessoa¹, Roland Wit¹, Cristian Stan² and Colin Degens²

¹University of Twente, Enschede, The Netherlands

²Saxion University of Applied Sciences, Enschede, The Netherlands

m.v.pereirapessoa@utwente.nl

rolandoswit@gmail.com

cristianstan16@yahoo.com

cbdegens@gmail.com

Abstract: Ingenious is a collaborative and competitive learning game application in which groups of students compete against each other in a product design and development (PDD) scenario where each group is responsible for a multidisciplinary team of engineers. The game has been used since 2020 to support a mechanical engineering master course. In this period, the game evolved from a card game to a software application. During the four game rounds representing the PDD phases, the players learn when to use over 80 different engineering design techniques. By choosing varying engineers and techniques, a student group creates a design strategy with a cost to execute and might be proven more effective than the competitors' strategies. Winning the game is about effectiveness in solving the challenges posed in the PDD scenario at a minimum cost. Once the game allows scenario customisation, new PDD scenarios can be created with different complexity levels. In the gamified classroom, grading is not a result of winning the game but a reflection of the group's choices and consequences while playing the game. This article presents the different game versions, describes the Ingenious game mechanics and dynamics and reflects on the game evolution and coverage of the Octalysis dimensions.

Keywords: Learning game, Octalysis framework, Product design and development

1. Introduction

Design problems are typically the most complex and ill-structured, for which solutions are achieved through an iterative process performed by a multidisciplinary team (Jonassen, 2015; Polman, 1998). The diverse engineering disciplines in a multidisciplinary PDD team use different tools and techniques (T&T) that must be efficiently combined to solve the design problem. Therefore, an important learning goal for future engineers is identifying the adequate design T&T combinations in each PDD phase to solve the specific design problem. With this motivation, Ingenious was developed for the gamification of PDD teaching.

This article aims to present the Ingenious game and provide an example of learning game mechanics and dynamics that can be used in other game scenarios where the collaboration of multidisciplinary teams is required to resolve a challenge.

2. The Ingenious Game Background and Development

The Ingenious game was developed to support using the need-based learning (NBL) pedagogical model in the context of modelling the technical design process (MTDP) course, which is part of the University of Twente's Mechanical Engineering Master programme. NBL is a pedagogical model for teaching PDD, which innovates by integrating just-in-time (JIT) learning, flipped classroom and gamification in a project-based learning setting. NBL includes six activities: challenge, select, acquire, apply, reflect, explain and evaluate (Pereira Pessoa et al., 2021). As depicted in Figure 1, a challenge is set by the lecturer, which becomes the background for all other course works. During the game phases, the students make a JIT selection of knowledge to be acquired in the flipped classroom, applying this information in the gamified project and reflecting on their choices and results. The lecturer then gives further feedback and makes the summative evaluation.

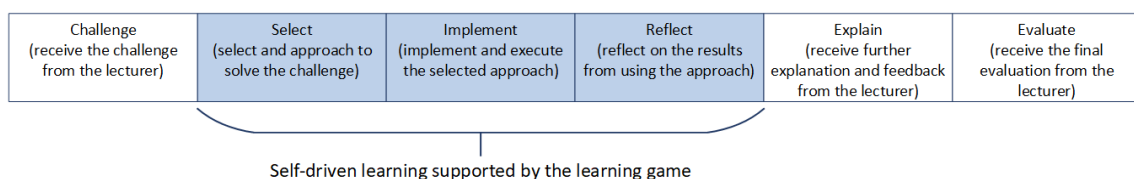


Figure 1: The Learning Game Supporting the NBL Pedagogical Model – Adapted From Pereira Pessoa, Oude Alink, et al. (2021)

The Ingenious game allowed the MTDP gamification, i.e. the use of game elements and game-design techniques in non-game contexts, thoughtfully applying typical game-like elements to real-world or productive activities (Díaz-Ramírez, 2020; Chou, 2016; Deterding et al., 2011; Werbach & Hunter, 2012). In this context, the Ingenious game aims at motivating and inducing desired actions to support an important subset of the MTDP learning goals:

- determining the appropriate PDD model (waterfall, iterative, spiral or agile), considering the product's technical requirements and uncertainty;
- defining the appropriate design and development T&T for each PDD phase, considering the disciplines needed during the process (e.g. mechanical, electronic and software);
- integrating the best practices for organisational process definition, engineering and engineering support into the PDD process according to the CMMI-Dev 1.3; and
- incorporating creative design techniques into the PDDP.

The Octalysis framework proposed by Chou (2016) was used during the Ingenious game design. Although other approaches for learning game design and gamification are available in the literature (Kapp, 2012; Zichermann & Cunningham, 2011), the main benefits of using Octalysis are its simplicity, clarity and abundant online information. Pereira Pessoa et al. (2021a) describe the rationale and choices behind the Ingenious game design. The Octalysis framework includes eight core drives that function as prerequisites for fostering motivation and triggering the planned behaviour: (1) **epic meaning & calling**, referring to when people believe they are doing something greater than themselves; (2) **development & accomplishment**, a drive to perform better, develop skills and achieve mastery; (3) **empowerment of creativity & feedback**, which is for players engaging in a creative process; (4) **ownership & possession**, motivating players by the feeling they own or control something; (5) **social influence & relatedness**, which incorporates the social elements that motivate people; (6) **scarcity & impatience**, a drive to want something simply because it is difficult to reach; (7) **unpredictability & curiosity**, which creates engagement because of the uncertainty of what comes next; and (8) **loss & avoidance**, the motivation to avoid a negative consequence. Although the Ingenious game has evolved from a card to a hybrid and finally a software-application game, all the versions incorporate the following elements, where the Octalysis' core drivers are underlined in the descriptions:

- The **game rounds** give **meaning** to the game by mimicking four phases from typical PDD (concept development; system development; detail development; and integration, verification and validation).
- The **challenge scenario** describes the development challenge that gives **meaning** to the game.
- The **risk level** contributes to the sense of **meaning**. The challenge scenario complexity indicates the risk level.
- The **die** adds an element of **unpredictability**. The die has different roles in the different versions of the game.
- The **result board** helps the team keep track of their progress. By visually representing the group's **accomplishments**, the board helps create **social pressure**.
- The **budget** is the amount of money spent. In all the game versions, there is no initial budget given to the teams, but they keep track of their accumulated costs. The budget adds **loss avoidance**, **scarcity** and **accomplishment** to the game.
- The **engineers** represent the different engineering disciplines of playing the game (mechanical, electrical, software, industrial design, production and systems engineering) that must be combined when resolving the challenge scenario. These cards provide meaning and a sense of **ownership**. Each player in the team is responsible for a different engineering discipline.
- The **T&T** represent design and development tools and techniques that can solve development issues according to their characteristics. The T&T contribute to the sense of **ownership**, as they are not the team's property but the property of each engineer, and only such engineers can play the T&T during a round.
- The **best practices** guarantee that the widely accepted best practices from PDD are also included in the game. Like the T&T, these cards help solve issues. But unlike T&T, the best practices are played by the team and not by a particular engineer.
- The **issues** represent typical issues from each PDD phase. A certain number of cards is randomly drawn in each round, contributing to the game's **unpredictability**. In the hybrid and app versions of the game, the issues became parts of the scenario, giving further **meaning** to the game.
- Finally, **empowerment** comes from the iterative rounds with design challenges, where previous play patterns would be to a team's advantage or disadvantage.

For playing the game, the class is divided into groups of students that compete against one another to create the most effective and least expensive PDD process. The groups must contain a maximum of six students so that each student is responsible for at least one of the six engineering disciplines included in the game. Although a single group can play the game, competition requires at least two groups, and there is no limit to the number of groups.

2.1 Ingenious 1.0: Card Game

The Ingenious game was initially developed as a card game, where the main inspiration was the game Munchkin® (Pereira Pessoa et al., 2021a). Using an existing game as an inspiration was an important factor to advance game development and avoid gameplay pitfalls. The idea was to create game mechanics where the warriors are the engineers, the weapons are the T&T, and the monsters are the typical challenges from the PDD phases.

During each game round representing a different PDD phase, the players execute three activities. First, they plan the round by selecting which T&T each engineer would use. After planning, they play eight challenge cards specific to the PDD phase randomly drawn from the challenge deck. A challenge is solved depending on the power of the played techniques. Finally, they have the last chance to identify and resolve unsolved challenges using the verification and validation (V&V) power from the T&T they planned for the round. Challenges that were neither solved nor reworked are carried to the next phase. Playing techniques and reworking have a cost, and the game objective is to solve all challenges at a minimum cost.

Figure 2 illustrates how Ingenious 1.0 is played. Both the T&T cards (1) and the challenge cards (2) have general traits (3) and specific traits related to V&V (4). Although solving a challenge might be possible using only one technique, a group of techniques often need to be combined to include all the traits required by the challenge. If two techniques in the set have the same trait, the one with higher power solves the challenge.

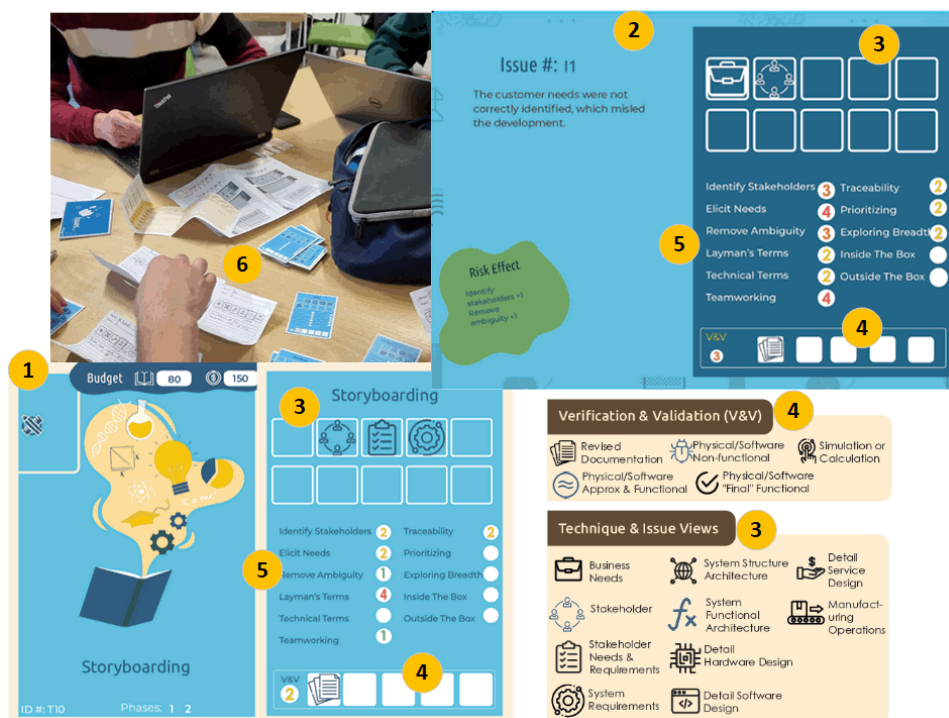


Figure 2: Ingenious 1.0

In this game version, the die adds unpredictability by giving a chance to trigger risks in each challenge card, increasing the power of some of its characteristics to be solved. If the challenge is not initially solved, it can still be reworked using the V&V. Finally, all the results from each round are annotated in specific sheets (6) to track the progress and compare the different teams' results.

This game version was played during the 2021 MDP course. The 25 students in this cohort answered a survey, and qualitative feedback was also gathered during the gameplay. After playing this version of the game, the students' feedback was mostly positive; they particularly liked the dynamics the game brought to the class and reported being more motivated to come to class than for regular lectures. Some drawbacks of this version were mainly the generic nature of the challenge cards and the need for manual annotation. The defined challenges

gameplay, which is essential because the course grade is based on this reflection's quality rather than on winning the game. The locking and validating of cells in the spreadsheet almost eliminated the errors, and the winning team was easily identified, which gave a nice closure to this part of the course.

When playing this version, some groups worked on optimising their round choices by combining the T&T with higher trait values. It sometimes led to a strong combination of T&T that would not be used in a real-case scenario. During the feedback, the students highlighted that this issue negatively impacted the full achievement of the course's learning goals. Besides this critical point, they suggested that the engineers should already know some basic T&T.

2.3 Ingenious 2.0: App Game

After the experience from playing version 1.5, it was considered that the game format was mature enough to reflect the last feedback and become a software application. This version was developed in a project partnering with Stichting GameLab Oost (gamelaboost.nl/) and had the main objective of turning the Ingenious game into a learning game application, which included further good practices of game development and comprised creative solutions to approach the opportunities of improvement identified when playing version 1.5. The main changes included creating a software application with a coherent look and feel, covering all the relevant information for playing the game and calculating the team's results. While the app embeds most of the game mechanics, it was decided that the unpredictability risk and use of physical objects (dice) would be left outside the software application. The objective was to create interaction among the players outside of the computer screen.

Based on the previous feedback, the following aspects were considered:

- To further guarantee the learning goals' achievement, the T&T's trait values were hidden from the players. Consequently, the players must select the T&T based on their theoretical capabilities instead of selecting them based on their trait values.
- To increase the game fidelity, the learning activity was removed, and the engineers gained three seniority levels (junior, medium or senior). In each round, the group can play with up to one engineer from each discipline, who can be junior, medium or senior. The higher the seniority becomes, the more advanced T&T the engineer can play, but the higher the T&T playing cost gets (senior engineers cost more). There is no limit to the techniques an engineer can play per round, and some techniques have a bonus if played by a multidisciplinary group.

Other important requirements for the game app were the flexibility for changing the scenario and the related challenges, updating the traits and characteristics' values from the T&T and the possibility of adding new T&T.

3. Playing the Ingenious 2.0 Game

Ingenious is played over four rounds, relating to different PDD phases. These phases are concept development, system design, detail design and integration and validation. In each phase, the gameplay includes a planning stage and a playing stage. During the planning stage, the group defines which T&T will be played during the phase. The playing stage can start when the group is satisfied with the T&T selection. At the start of the playing stage, the T&T selection is locked, and the development challenges are presented in sequence. The last step of the playing stage relates to V&V activities when the group can uncover and correct (rework) issues from unsolved or partially solved challenges. Any remaining issues are carried as **hidden problems** to the next phase. The remaining issues from the integration and validation phase end up in the hands of the customer.

Planning Stage

Figure 4 shows the planning stage screen. To reduce the amount of information on the screen, the T&T were divided into categories. The figure shows the Refine & Improve category T&T playable by different engineering disciplines according to the chosen engineering seniority. Some T&T have a teamwork bonus, which means they become more powerful if two or more engineers play this same T&T during the same round. By keeping track of the current budget expenditures, the group can view the financial consequences of different choices of T&T and engineers.

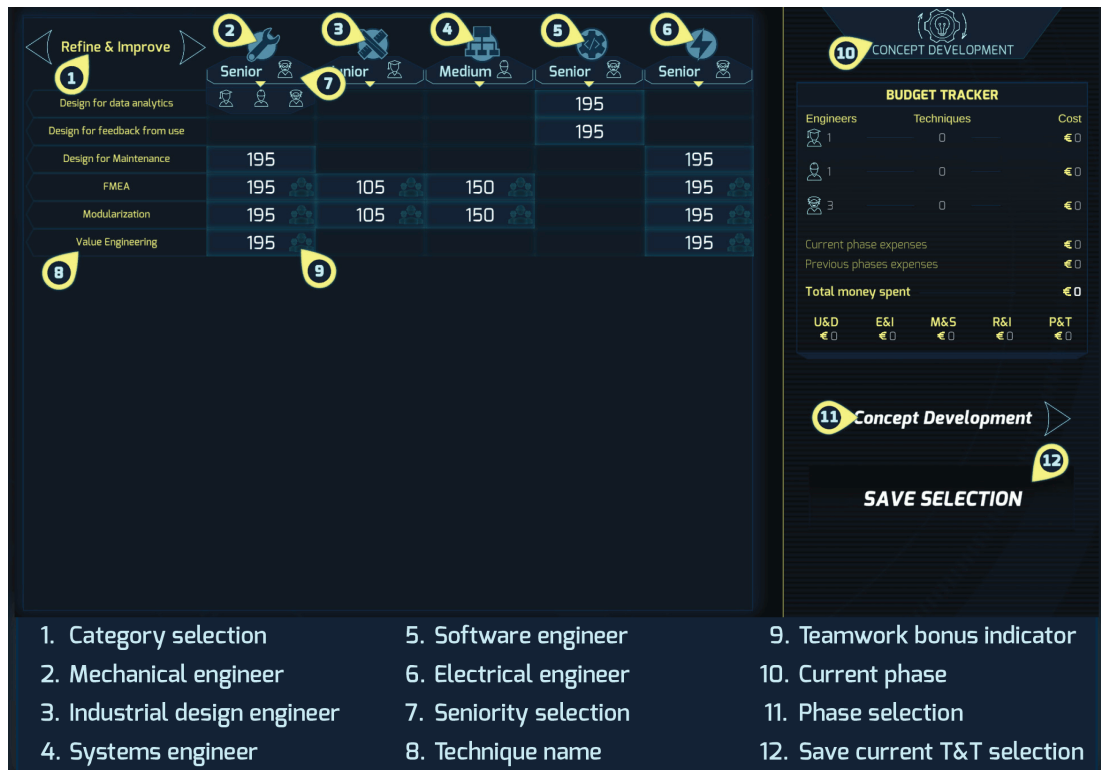


Figure 4: Ingenious 2.0 – Planning Stage Screen

Playing Stage – Steps for Preventing Issues From Challenge Failure

After selecting all the techniques to be played during all rounds, the plan is locked, and the scenario is loaded to play. The challenges from the scenario are presented in sequence, and the group checks if their T&T choices are good enough to solve the challenge, preventing the consequences of failing it. Figure 5 shows a sample screen where a challenge is described. On the left side, the team can see the chosen T&T score in the traits required to solve a challenge and if they also selected the PDD best practices that influence the challenge. Based on the points they accumulated by the chosen T&T and best practices, the number of green tokens is calculated, and based on the challenge's difficulty, the number of red tokens is measured. The group put the physical green and red tokens in a bag, shuffle the bag and pick one token. If the token is green, they have solved the challenge; if it is red, they have failed.

Playing Stage – Steps for Reworking Open Issues From Failed Challenges

At the end of each round, the group can solve issues from failed challenges and avoid carrying them to another round. This part of the playing stage represents the V&V activities that normally happen at the end of any PDD phase. This way, issues not prevented by a good design can still be detected and corrected during the tests. Figure 6 shows the screen where open issues from unsolved challenges are presented. Depending on the quality of the T&T planned for V&V, the player can discover and perform rework that solves open issues. The number of times the players can throw the die is based on their strategy quality. A special die is used here, with values 0, 1 or 2 only.

After throwing the special die and getting the number of issues that can be solved, the group can resolve open issues from the actual or previous rounds. The rework cost for solving an issue from the round in play is €500, but this cost increases in the case of previous rounds. For instance, reworking an issue from CD will cost €1000 during the SD phase, €2000 during the DD phase and €4000 during the IV phase.

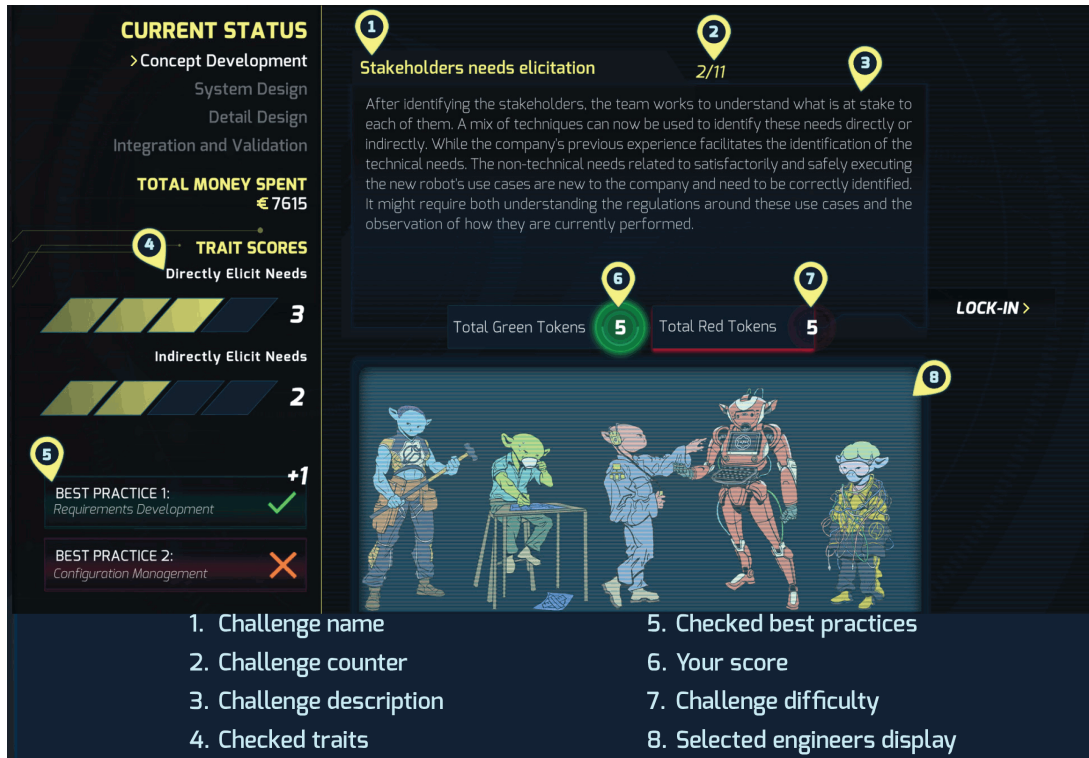


Figure 5: Ingenious 2.0 – Challenge Solving Screen



Figure 6: Ingenious 2.0 – V&V and Reworking Screen

Checking Results

Figure 7 shows the overview screen, where the results from each round can be revised. Here the group can check which techniques they played per round, how many challenges issues were solved, how many issues were resolved or remain open, the round expenditures and the total expenditures. The group can work on their reflection report using this information and after reviewing the challenges.

All this information is also exported to an Excel file the lecturer can use to compare the groups and define the winner.

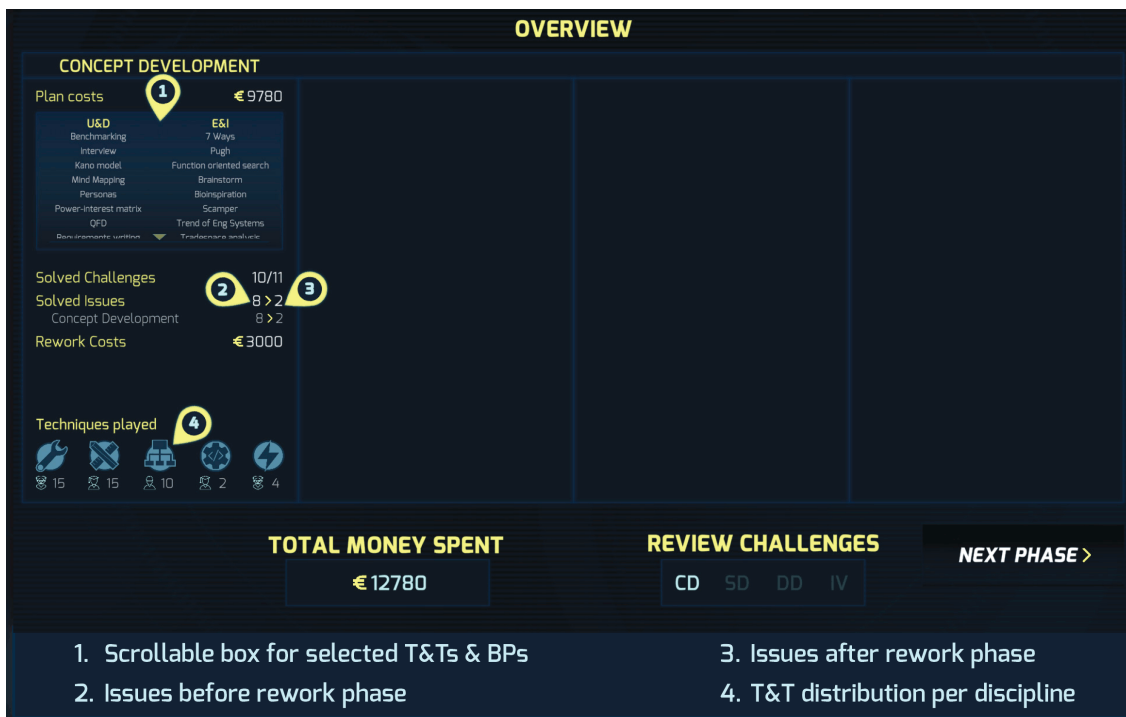


Figure 7: Ingenious 2.0 – Overview Screen

4. A Reflection on the Ingenious Game Evolution

During the Ingenious game evolution, the game elements were adjusted to support the learning goals’ achievement better and deliver a better gameplay experience for the students. Table 1 summarises the drivers and results of these changes. The gameplay improvement was analysed using a Pugh chart, where the criteria are the dimensions from the Octalysis. The improvement in supporting to achieve the course’s learning objectives was based on the students’ feedback. Note that the Ingenious Game 2.0 was tested in pilot groups but has not yet been used during the MDTP course.

In Table 1, Ingenious 1.0 is used as a reference, and the other versions are compared to it. Therefore, ++, +, 0 and – relate to being better, equal or worse than 1.0. Consequently, these are not absolute values, which means that ++ does not imply the version has a great implementation of that specific dimension but solely that it is much better than 1.0. Giving absolute values to the dimensions would require comparing the Ingenious game versions to other games, which is outside this work’s scope.

Table 1: A Reflection on the Ingenious Game Evolution

Criteria	V1.0	V1.5	V2.0	Comments
Epic meaning & calling	0	+	+	While the challenges in v1.0 were generic cards, which did not necessarily reflect the scenario, the challenges in v1.5 and v2.0 became specific to the scenario (the game fidelity was increased).
Development & accomplishment	0	+	++	As the game fidelity increased, the sense of accomplishment became clearer.
Empowerment of creativity & feedback	0	0	0	Feedback was based on whether a challenge was solved. In all the versions, each game round was played only once, and the empowerment was limited to the experience gained from playing the previous round.
Ownership & possession	0	0	–	Ownership and possession were related to the engineers and the techniques they could play. This dimension was more potent when using the cards and when the engineers learnt techniques (possessed knowledge).

Social influence & relatedness	0	0	0	In all versions, social influence was based on the players competing as a group against other groups. In this sense, there was social influence among group members.
Scarcity & impatience	0	0	0	Although there was no predefined budget, the scarcity sense was given through the objective of minimising the total money spent during the rounds.
Unpredictability & curiosity	0	+	++	Unpredictability was presented by not knowing which challenges might arise in one game scenario and the possibility of the risks increasing the challenge difficulty. Unpredictability improved in the different versions of the game to bring challenges and risky conditions closer to the real case scenario.
Loss & avoidance	0	+	++	Loss and avoidance were illustrated by avoiding rework penalties, which were always more severe than the cost of solving the challenge directly. This required the players to prioritise balancing the conflict between minimising expenditures on T&T to be played and lowering the chances of rework. By using an app, the rework penalisation was greatly improved and became more transparent.
Learning goals achievement support	0	+	++	Both automation and fidelity increased through the versions. The former reduced the chances of errors, and the latter brought the game closer to reality. These changes combined led to game mechanics and dynamics that better fulfilled the course's learning objectives.

5. Final Remarks

This article presented the Ingenious learning game, developed to facilitate the teaching of how to choose a good set of design T&T to be used by different engineering disciplines and where these T&T must be efficiently combined to solve the design problem. The Ingenious game is in version 2.0, based on a software application and some physical elements to promote interaction among the teams playing the games. Its first version (1.0) was a card game inspired by the commercial leisure game Munchkin®, and its second version (1.5) used MS Excel® and MS PowerPoint® to simplify the gameplay and facilitate the game score calculation. The insights from this game development journey included the following:

- There is a benefit to having a previous and tested game as inspiration to accelerate the initial game development and reduce the risk of poor gameplay.
- Using a widely accepted game-creation framework to reduce the chances of designing an imbalanced game with poor fun and engaging factors is advantageous. The Octalysis considered and helped balance the eight core drives that function as prerequisites for fostering motivation and triggering the expected learning behaviour.
- Creating a physical version of the game instead of directly developing a computer version is beneficial. A physical game is more flexible to try small variations from the game mechanics and dynamics (e.g. adding elements or modifying the rules). Software development takes time, and constant changes in requirements delay the development and increase the risk of inconsistencies.
- Getting feedback from the students is essential. Regardless of the game framework used, the players (the students in this case) are the ones that can best rate the game quality. In this journey, the student feedback was critical towards understanding how the game could support the learning objectives.

Although the Ingenious game was developed in the context of design problems and PDD scenarios, its game mechanics and dynamics can be generalised to other situations that benefit from the collaborative work of diverse specialists, which use specific T&T to solve a common problem. In this sense, the work presented here can be used as inspiration to other game developers. Future work, therefore, includes possible expansions towards other scenarios where professionals' collaborative work with different disciplines is required to solve a challenge successfully.

Acknowledgements

The Ingenious Game v1.0 and v1.5 development was funded by the Comenius programme from the Netherlands Initiative for Education Research (NRO) as part of the Comenius Teaching Fellow Project 405.20865.016.

The Ingenious Game v2.0 development was funded by the project 4TU.CEE – Ingenious 2.0, project number 20003325.

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