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Board Games in Mathematics Education: Presentation of the PDCA-based Graphic Design Process of the YETI Didactic Framework

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Abstract
YETI is a didactic framework currently under development, aimed at integrating game-based learning into higher education, with a focus on the topics of infinite series and improper integrals. The visual elements hold noteworthy importance within the framework, given that beyond a well-developed set of rules, experiential aspects also play a role in sustaining students' attention, by enabling them to immerse themselves in the game. One of the standout visual elements of the YETI framework is the game mat inspired by the Koch snowflake. Through its development phases, the entire graphic design process of the framework can be observed. This paper outlines the development cycles of the game mat using the PDCA (Plan-Do-Check-Act) methodology. Furthermore, it presents the results of a survey conducted among university students on their attitudes toward the finalised graphic design of the framework.

1 Introduction

Game-based learning (GBL) has emerged as a dynamic and innovative approach to education, transforming the traditional classroom experience into an interactive and engaging journey. By incorporating elements of play and competition, GBL harnesses the innate human inclination for exploration and challenge, revolutionising the learning process across various disciplines [1]. Research has shown that in digital games, players pay attention to game attributes including connection system, popularity, graphic design, and the game genre, in search of an authentic, enjoyable experience, interactivity, an opportunity to use their imagination, and a sense of accomplishment [2]. It's worth noting that the game-based approach does not solely encompass IT innovations; traditional board games also play a substantial role. In a review led by Noda, Shirotsuki, and Nakao, focusing on eleven studies employing board games to stimulate learning outcomes, the findings demonstrated an impact ranging from small to large on educational knowledge [3].

The visual appeal of board games in a GBL context extends far beyond mere aesthetics to play a critical role in motivating students, nurturing emotional values, and ultimately elevating their overall positive experiences [4]. The graphic design of a board game can help establish a thematic context, providing students with a coherent and immersive environment, evoking emotional engagement in the players. Considering the strong link between emotions and memory consolidation [5], this can lead to

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better knowledge retention and a more profound grasp of concepts. In addition, well-crafted graphic design serves as a channel for effective communication, simplifying the transmission of complex ideas and concepts.

In this paper, we delve into the relationship between GBL and graphic design, with a focus on the development of a didactic framework named YETI. By dissecting the PDCA cycles of the YETI game mat design, we highlight the significance of thoughtful visual representation in amplifying the educational potential of board games. Additionally, we present the results of a survey conducted among university students, shedding light on the impact of the finalised graphic design on their perception of the YETI framework.

2 Methodology

The development of the various components within the YETI didactic framework followed a cyclical approach rooted in the PDCA (Plan-Do-Check-Act) methodology. The YETI game mat itself has been through four Deming cycles to reach its current form. In the spring of 2023, a survey was conducted to examine the opinions of university students in IT, the target audience of the framework, on the final design of the different game elements. Following a two-hour long play session with the game Blue Yeti, the 20 participants were asked to fill out an online questionnaire, administered using Google Forms, in which they were prompted to rate the overall visual appeal of the game - and thus, the framework - on a scale of 1 to 5.

2.1 The YETI framework

The YETI framework stands as an innovative approach to teaching and learning mathematical concepts centered around the comparison of elements, with a specific emphasis on improper integrals and infinite sums. It integrates a variety of elements that collectively contribute to the creation of an experiential learning experience. At its core lies the YETI didactic board game, designed to bring university students closer to the field of infinite series, the conceptualisation of which was based on a three-pillar survey targeting bachelor's students in IT [6]. The game components encompass a collection of 100 cards, a game mat with a unique design, and a completely original set of rules. The evaluation and the refinement of the game are continuous. The development of three separate card decks is envisioned, aiming to accommodate students with varying skills and prior knowledge, catering to novice, intermediate, and advanced proficiency levels alike. Alongside YETI, another card game called Blue Yeti serves as an extension to the framework. The Blue Yeti deck, consisting of 29 cards, was inspired by the traditional card game Old Maid, but with a unique twist to incorporate improper integrals into the gameplay.

Both games mentioned above provide a dynamic environment for players to improve their comprehension of concepts related to convergence, divergence, and the application of comparison tests. Therefore, the YETI framework creates a flexible and tangible learning ecosystem that harnesses the power of game-based pedagogy. The different elements of the framework are brought together by a cohesive design of card embellishments and illustrations, as well as the thematic graphics of the game mat, embracing a winter theme inspired by the Koch snowflake.

2.2 The Deming cycle

The Plan-Do-Check-Act (PDCA) cycle, also known as the Shewhart cycle or the Deming cycle, is a means of process management that favours continuous improvement and enhanced efficiency. This method, primarily focused on controlling and improving the management of supply chains [7], was first discussed by Walter E. Shewhart in 1939 and later popularised by W. Edwards Deming [8]. Typically, PDCA cycles are used in the manufacturing industry to minimise waste of time when implementing changes. A cycle consists of four major stages, which are as follows [9]:

1. PLAN: The objectives of the development process or change are established.

2. DO: Measures are implemented to attain the predetermined goals.
3. CHECK: The implemented changes are assessed and evaluated against the specifications of the earlier stages.
4. ACT: Additional and/or corrective measures are taken to improve results. If the change was successful, the lessons learned are integrated into broader contexts. If not, a new cycle is initiated.

Nonetheless, the utility of Deming cycles extends beyond manufacturing and finds applicability in various problem-solving activities. PDCA offers an intuitive and convenient way of developing, testing, and improving concepts and products. Through frequent evaluation, mistakes can be identified and eliminated at earlier stages of the development. Furthermore, continuous improvement can be assured. The core rationale behind prioritising a PDCA-based development process for shaping the graphic design of the YETI framework stems from these considerations.

3 Design of the YETI game mat

Beginning in the autumn of 2022, the development of the YETI board game marked the first major milestone of the YETI framework. This process encompassed the graphic design of a thematic game mat, which serves as the centrepiece of the framework. The following sections introduce the progression through the four Deming cycles that culminated in the creation of a functional and visually appealing game mat. Subsequently, an overview is provided of other significant visual elements within the framework.

3.1 Cycle 1

Following a two-month-long planning period, the foundational ruleset of YETI was established by November 2022. YETI is a board game featuring a set of 100 cards, most of which showcase different infinite sums. Originally, the game's narrative revolved around repelling a zombie attack by laying pairs of cards upon the game board with infinite sums exhibiting less-than-greater-than relationships. This move has the potential to eliminate the zombies, depicted on their respective cards, which are present on the board. An important constraint of the game is that a valid pair must either consist of two divergent or two convergent infinite series.

As the first step of the design process of the YETI game, the layout of the board was designed on a piece of paper, featuring rectangular slots for cards to be placed onto. The card slots are grouped in units of four, forming fields. Three distinct types can be identified: there are fields for divergent sums, fields for infinite series that converge, and fields where players can place both convergent and divergent pairs. This sequence of development steps comprises the PLAN phase of the first PDCA cycle.

In the DO phase, two different versions of a test board were edited in Microsoft PowerPoint, as seen in Figure 1. The first variant was created using a vibrant colour palette, while the other one catered to potential at-home test printing, with the colours replaced by black-and-white patterns to conserve ink. The layout of the card slots was solidified, the final version of the board including 4-4 convergent and divergent fields alongside 5 mixed ones, arranged in a star-shaped configuration. After undergoing revisions within the scope of the CHECK phase of this cycle, relational operators were introduced to the second, printer-friendly version of the test board. This addition had the objective to clearly indicate the direction of inequalities between the card slots, supporting the intuitive comprehension of the game's rules. In the ACT phase of this PDCA cycle, a decision was made to advance the development of the board further by introducing a brand-new narrative, replacing the undead adversaries with yetis, drawing inspiration from the Koch snowflake to infuse a winter theme into the game.

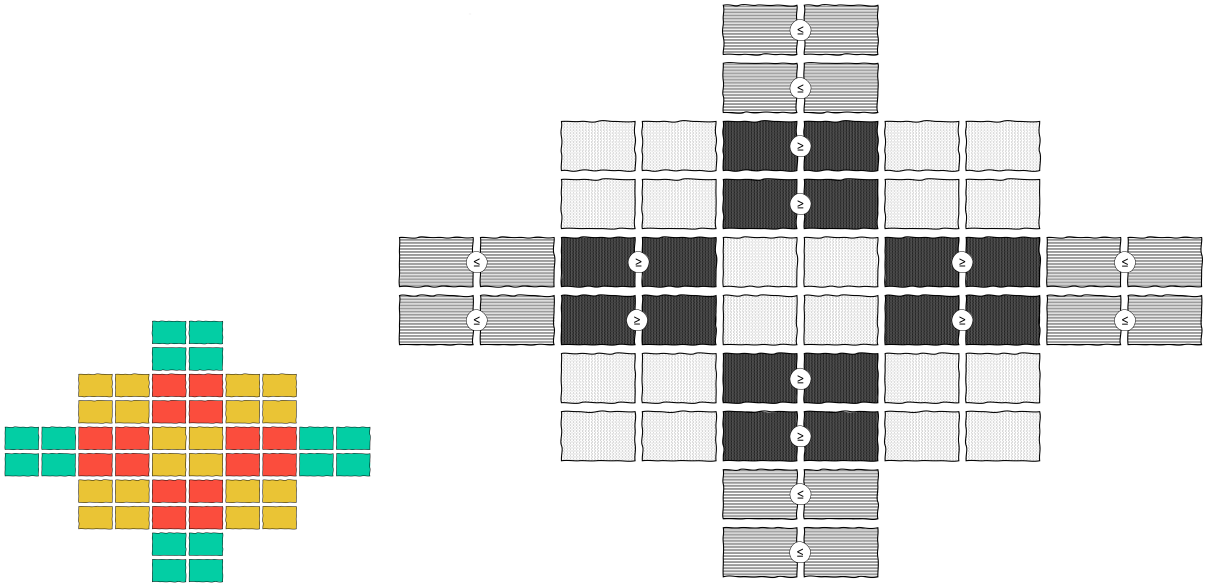

Figure 1. The two initial variants of the game board

3.2 Cycle 2

The Koch snowflake is a well-known geometric fractal, first described by Helge von Koch in 1904 [10], formed through an iterative process. It starts with an equilateral triangle, and at each stage, every line segment is divided into three equal parts. The middle segment is then replaced with two segments to create an outward-facing equilateral triangle. This recursive procedure leads to a continually expanding and infinitely intricate snowflake pattern [11]. The first four iterations of this process are depicted in Figure 2.

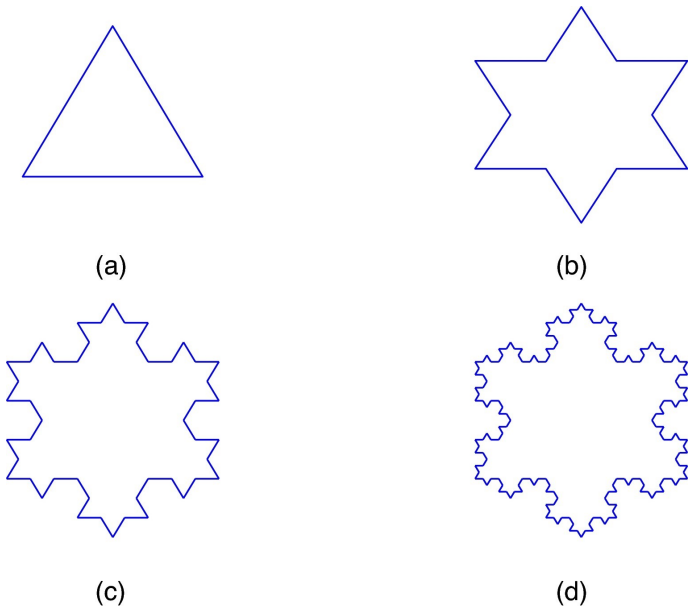

Figure 2. Generation of the Koch snowflake [12]

The Koch snowflake was integrated into the core of the YETI board game due to its association with infinite series. Both the area and the perimeter of the fractal can be calculated using infinite sums, even though the perimeter itself turns out to be infinite [12]. This shift in branding for the game prompted the incorporation of a winter theme into the storyline, executed during the PLAN phase of the second PDCA cycle. Guided by this new narrative, the game's primary colour palette was

reviewed, favouring a range of blues, silvers, and greys instead of the more vibrant tones envisioned initially. Furthermore, a decision was made to assign dark blue to represent convergence and light blue for divergence. Meanwhile, the mixed fields on the board were given a greyish hue. The subsequent DO phase encompassed the implementation of all necessary adjustments alongside preparations for the first print run of the game board. Soon, it was discovered that accommodating standard-sized playing cards within the card slots required a generously sized board. Consequently, the decision was made to print the board onto a tarpaulin, shifting away from the original concept of a cardboard game board and instead transforming it into a flexible and foldable game mat. This adjustment offers several advantages, notably an enhanced durability of the mat. Moreover, the flexibility of the material facilitates both the storage and transportation of the game mat.

During the CHECK phase of this PDCA cycle, the freshly printed mat underwent testing through gameplay, leading to certain refinements in the game's rules based on our observations. It also became evident that the empty corners of the mat would require further attention. In response, as part of the ACT phase, a subsequent PDCA cycle was planned to accommodate the changes deemed necessary. Additionally, minor modifications were made to the relational operators displayed on the game mat, eliminating the ambiguity in the direction of relations that could have potentially confused certain students. Figure 3 illustrates the outcomes of the second Deming cycle.

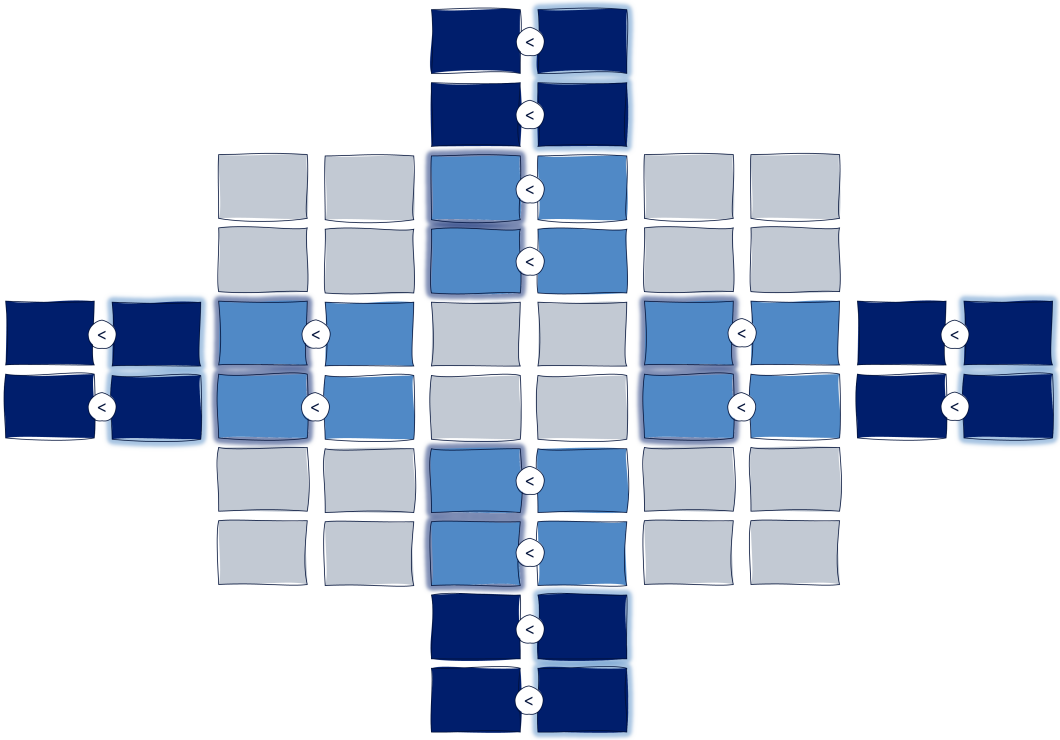

Figure 3. The game mat following the second PDCA cycle

3.3 Cycles 3 and 4

The third cycle of the game mat development entailed further refinements to the relational operators displayed on the mat, necessitated by the decision to permit equality between the pairs of infinite sums situated within the grey fields. Simultaneously, this cycle also involved the conception of graphic design elements for the mat's corners, focusing on the Koch snowflake motif, incorporating formulas for the calculation of its area and perimeter. However, it became apparent by this point that the graphic design in its existing form lacked an immersive quality, as it did not include any elements tied to the game's narrative. Consequently, during the fourth PDCA cycle of the development process, the addition of houses and roads to the game mat - a symbolic representation of a village -

introduced a heightened degree of narrative coherence, aligning the visual design more closely with the overarching storyline. The final rendition of the game mat, of which four copies were printed, is displayed in Figure 4. This specific version of the game mat was the one evaluated by the 20 participating students in the survey, the findings of which will be elaborated upon in this paper.

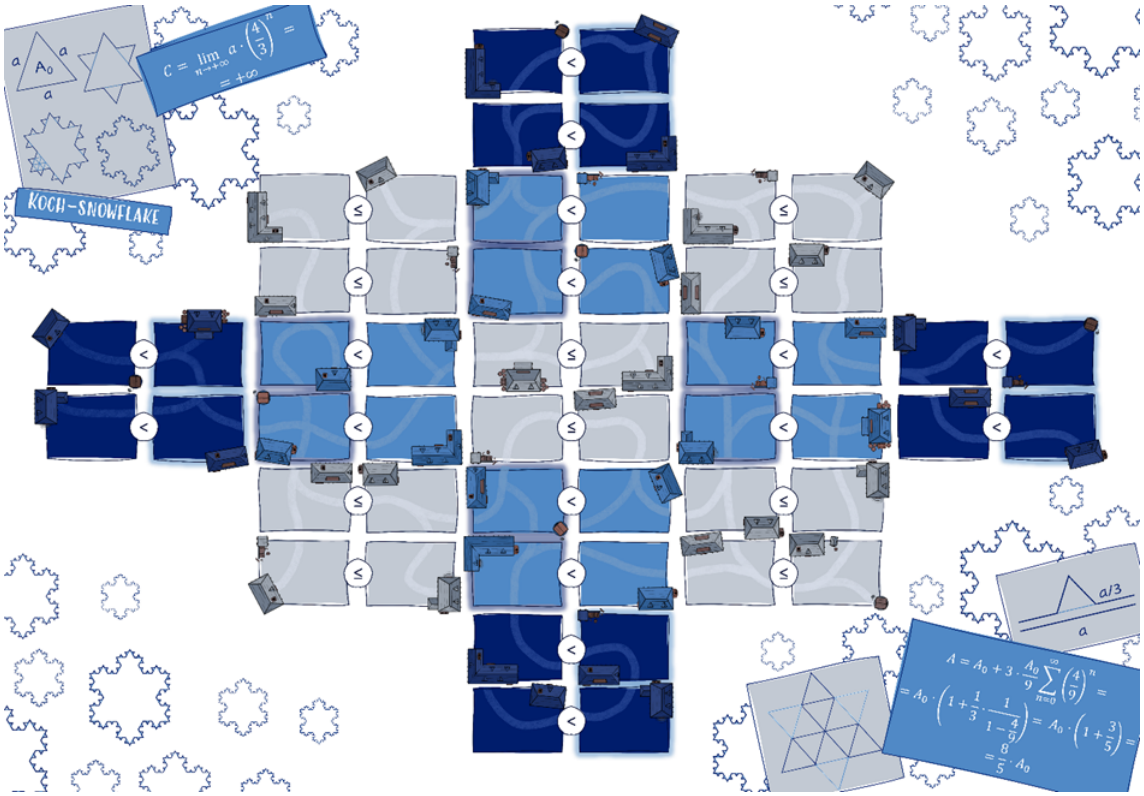

Figure 4. The final version of the game mat

3.4 Other elements of the framework

Parallel to the design process of the game mat, the development of other important YETI game components, notably the card decks, was underway. First, edge decorations for the front sides of the cards were designed. These embellishments, just like the game mat, were strongly influenced by the Koch snowflake. They are available in the prevailing colors of the game mat, contributing to the cohesiveness of the different game components. In the intermediate and advanced card decks, a distinct shade of blue is employed for the edge decorations. On the other hand, the novice deck employs edge colours that correspond to the convergence properties of the infinite sums they represent. In this case, the same shades of blue are used to denote convergence and divergence as on the card slots of the game mat. This measure assists beginners in becoming accustomed to identifying relationships between infinite sums and building an intuition for recognising convergent and divergent infinite series on sight.

Subsequently, the cardback images for the three different levels of difficulty were designed, also featuring the Koch snowflake in a winter-like, cold-toned colour scheme. The intricacy of the cardback design varies based on the difficulty level of the specific deck. As the decks' complexity escalates, the fractal patterns become more and more detailed, resulting in busier cardback images, depicted in Figure 5.

Figure 5. Cardback images for the three difficulty levels, from novice to advanced (left to right)

Aside from the cards featuring infinite sums, the YETI deck also contains avalanche and yeti cards. The avalanche cards function as action cards, having the power to clear an entire field, represented by a 2×2 arrangement of card slots of the same colour, on the game mat. In contrast, the yeti cards embody the main adversaries within the game. Over the course of a gameplay session, an increasing number of yeti cards appear on the game mat, requiring players to eliminate them in order to fend off the yeti attack and secure victory. During the game's design process, the graphics for these special cards were also developed, as showcased in Figure 6.

Figure 6. Some special YETI cards with edge decorations

4 Results of the questionnaire

In May 2023, a gameplay session was organised, involving the active participation of 20 university freshmen enrolled in IT courses. This select group was granted the opportunity to immerse themselves in the card game Blue Yeti, which constitutes another part of the broader YETI framework, sharing the very same design as the YETI board game. Drawing from prior assessments and experience, a significant majority of the chosen participants were situated at the novice level in applying the comparison test to improper integrals, the central aspect of the game Blue Yeti. Following the interactive session, the participants were asked to complete a questionnaire via Google Forms asking about their firsthand encounter with the gameplay of Blue Yeti, including their opinions on the design of the game elements. Although the focal point of the survey was the game Blue Yeti,

it also served as a channel for collecting valuable insights into the participants' perceptions of the overarching framework's design.

First, students were prompted to evaluate the graphic design of the game using a 5-point scale. Likewise, they rated their overall experience of the Blue Yeti game using the same scale. Subsequently, our inquiry turned towards gauging whether the participants thought that the implemented colour coding for distinguishing divergence and convergence largely impacted the level of difficulty of the gameplay. The students also had the opportunity to give detailed feedback on the game at the end of the questionnaire, in their response to the following question: In your opinion, how could the game Blue Yeti be further improved?

Among the surveyed students, a substantial 70% (14 participants) bestowed the highest attainable rating of 5 points to the game's graphic design. Remarkably, a mere 10% (2 participants) rated it 3 points, with an interesting observation that no participant rated it below 3 points (Figure 7). Reflecting on the overall game experience, a significant 95% (19 students) responded with a score of 4 or higher when asked to rate their encounter with the Blue Yeti game. The aesthetics and immersive components within the framework contributed to this affirmation as well. Most participants (95%) agreed that Blue Yeti would be considerably harder without the colour coding associated to divergence and convergence, which helps beginners navigate the intricacies of applying the comparison test to improper integrals.

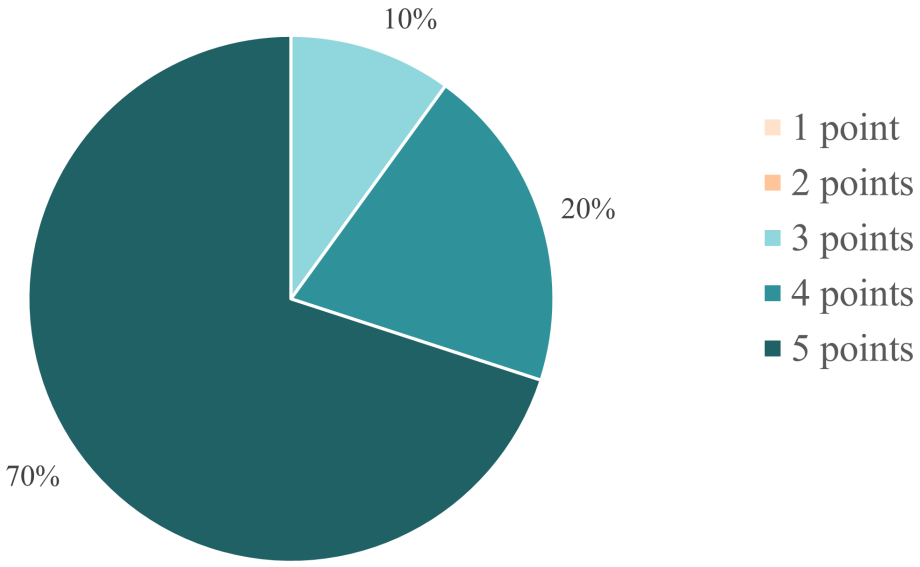

Figure 7. The distribution of the answers given by the 20 students to the question "On a scale of 1 (worst) to 5 (best), how would you rate the graphic design of the game Blue Yeti?"

Concerning the detailed feedback solicited for potential game improvements, most respondents (90%) found no noteworthy issues with the various facets of Blue Yeti. One of them even voiced a sense of particular satisfaction with the graphic design of the game, while another praised the application of colour coding to differentiate divergent and convergent cards. However, two students offered a constructive suggestion, proposing that the cards could be rendered more vibrant in colour. Their reasoning was rooted in their perception of the cool-toned shades as excessively sombre and serious for a gaming context. Yet, a valid concern arises that the incorporation of additional graphic elements and vibrant hues might divert attention from the formulas on the cards. This could potentially pose challenges for students with shorter attention spans, compromising their capacity to effectively engage with the game's substantial components. Taking into account our main audience - university bachelor's students - we are mindful of crafting a framework that resonates with their maturity and academic focus. We must refrain from creating a framework that they might deem too childish or frivolous. Consequently, after careful consideration, the idea of introducing a more vibrant colour palette to the framework was ultimately set aside. This decision aligns with our intention of preserving

the winter-oriented atmosphere and the overarching narrative woven into the framework.

5 Conclusion

This paper has delved into the the significance of graphic design within the YETI framework. The distinct visual elements of the framework were presented, alongside the Deming cycles governing the development of the game mat. Through analysis and practical implementation, we have demonstrated how the integration of these visual elements, inspired by the Koch snowflake, contributes to an enriched educational environment and engages students in a dynamic manner. According to the results of our survey targeting bachelor's students in IT, the YETI framework's strategic design choices, including thematic coherence and purposeful colour coding (Figure 8), have been shown to have a positive impact on players' perception of the framework.

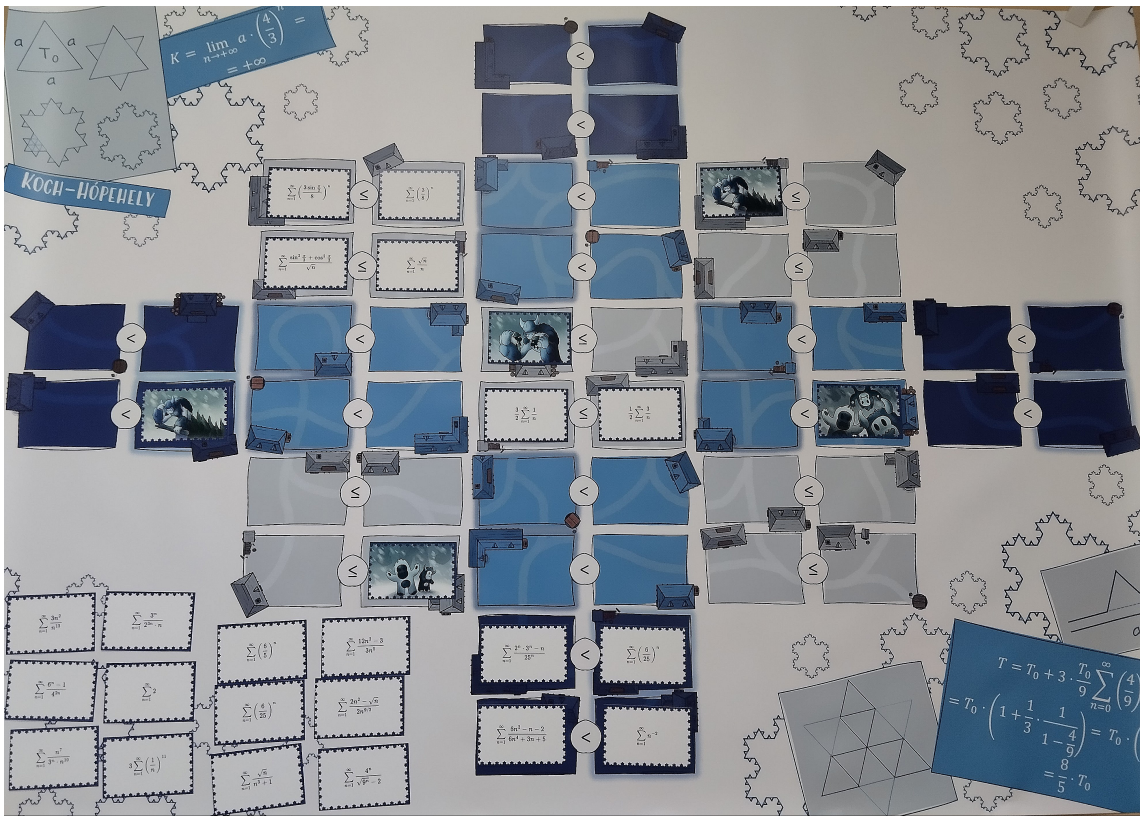

Figure 8. A possible game state of the YETI board game

In summary, the development process of the YETI framework has emphasised the critical role of graphic design in optimising the game-based learning experience, elevating engagement and comprehension in serious game contexts. By harmonising visual allure with didactic principles, educators and curriculum developers can harness the power of design to create immersive and effective learning experiences for young adults. As we continue to refine the YETI framework or create similar didactic games, it remains essential to consistently factor in graphic design as a key element, ensuring its alignment with the educational objectives of these games.

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