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# Examining the Effectiveness of Non-Digital Game-Based Learning Among University Computer Science Students on the Topic of Improper Integrals

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**Abstract:** Using digital and non-digital card games to teach mathematics is a well-established didactic technique widely applied at different levels of education. Game-based learning strategies are also gaining ground in higher education, but the use of maths card games in university settings remains limited. Generation Z students are true digital natives, members of a hyper-cognitive generation with a learning profile different from any previous generation. In this paper, an original non-digital card game, Blue Yeti, is presented that supports determining the convergence property of improper integrals using the comparison theorems and the Cauchy-Maclaurin test, providing a motivational and effective way of acquiring knowledge for Gen Z students. This paper provides a comprehensive overview of the development process, rules, and gameplay mechanics of Blue Yeti, which was created as a key component of a multifunctional didactic framework. In addition, it presents findings from a two-year research study conducted among first-year bachelor's students in computer science on the benefits of playing Blue Yeti. Quantitative studies were carried out with 63 first-year IT students using a quasi-experimental research design to measure the effectiveness of the game. A pre- and post-test design was used with the experimental group of 31 participants to evaluate the short-term effects of card game-based learning. A t-test for paired samples was used for hypothesis testing. To assess the medium-term impact, the results from the related midterm exam problems were statistically analysed, comparing the outcomes of the experimental group with those of the control group using the Mann-Whitney U-test. Results indicated that the experimental group significantly outperformed the control group. Additionally, student attitudes towards the game were measured using a mixed-method approach, which provided not only quantitative data but also qualitative information on student attitudes towards Blue Yeti, complementing the statistics on learning outcomes. The results of the study clearly support the effectiveness of the card game.

**Keywords:** game-based learning; higher education; didactic game; non-digital game; card game; improper integral; comparison test

## 1. Introduction

Nowadays, a common problem for universities and other higher education institutions is the retention of students and the support of individual student performance to achieve success in mathematics courses. As a classical subject, calculus plays an essential role in higher education, especially in engineering and IT education. Students who intend to pursue university studies should have a strong foundation in mathematics by the end of their secondary school years [1]. However, many studies show fundamental mathematical deficiencies in first-year engineering and computer science students [2–6]. There is a growing and well-researched literature on the factors that enable a successful transition from secondary school to higher education [7–12]. Changes in students' mathematical skills upon entry into higher education have also been examined [13,14]. The relevant literature shows that no single common factor causes students to drop out. However, several factors (personal, social, cultural, and academic) influence this process with varying participation rates, as seen in the student success study. The researchers agree that the learning experiences of first-year students have a direct impact on student dropout rates and overall success in later studies. Students perform better in the university learning environment when they experience the support of their peers and teachers [15]. Integrating games into the learning process can significantly contribute to this supportive environment by fostering collaboration, communication, and peer interaction.

Teaching maths through games is not new; yet, it remains one of today's most popular teaching methods. Ersen and Ergül have analysed the research trends in game-based learning (GBL) in mathematics education between 2017 and 2021 and have provided guidance for future studies [16]. Eighty research studies were examined in their systematic review, and it was found that secondary school students were preferred as participants; the most common types of games used were digital computer games. In addition, most of the research studies yielded positive results regarding the use of games in mathematics education. There are also many examples of traditional, non-digital games in teaching mathematics. However, they are less widespread in higher education than in other areas of education [17]. Non-digital games can be played anywhere. Another significant benefit of non-digital GBL is that it enhances communication between participants and provides opportunities for increased social interaction, in addition to supporting effective learning [18]. Empirical studies on non-digital games, such as card games and board games in learning environments, show that participants achieve more significant learning gains and are more satisfied with their learning experience when learning with games [19].

Calculus is a primary subject in mathematics that lays the foundation for further mathematical knowledge. Therefore, it is crucial that students understand the concepts of calculus and develop proficiency in handling them. Several researchers have investigated the learning difficulties associated with extending the notion of a definite integral. In their articles on improper Riemann integrals, González-Martín and Camacho found that students generally have difficulty interpreting the notion of the generalised Riemann integral. They also identified the gaps that impeded the understanding of the concept and hindered its correct use [20,21]. The qualitative research presented by Mojica in [22] was carried out to characterise the different levels of understanding of the concept of the improper Riemann integral. It is generally quite complex, often impossible, to determine the value of an improper Riemann integral. In many cases, it is possible, at least, to determine whether or not the improper Riemann integral converges. The Maclaurin–Cauchy test (integral test) for convergence is a method that links an infinite sum to an improper integral [23]. If an improper integral is convergent, so is its corresponding series. Thus, there is a close relationship between certain types of improper integrals and the relevant infinite sums.

During the autumn semester of the academic year 2022/23, a three-pillar exploratory research was conducted among first-year university students enrolled in IT bachelor's programs at the University of Miskolc to assess their overall understanding of infinite sums, explicitly focusing on the comparison test [6]. The results revealed a clear need for diverse teaching aids to improve the students' comprehension of the topic, which pointed to the way to implement the YETI project. The aim of the YETI project was to develop a family of thematic didactic board games with the common theme of comparing two quantities. The YETI framework encompasses various components, including a game board and cards with original winter-themed graphics [24]. To facilitate the customisation of the card deck, a web application was also created, allowing users to incorporate scientific formulas into the cards. Within this framework, the Blue Yeti game was born, which deals specifically with the concept of improper Riemann integrals and is suitable for implementing non-digital GBL in a classroom environment.

In the 2018 Paris Declaration, the ministers responsible for higher education in the European Higher Education Area (EHEA) agreed to support institutions in developing new practical learning and teaching strategies. It was also declared that students at all levels of higher education should participate in research or activities related to research and innovation to develop the critical, creative thinking that will enable them to meet the challenges of the future [25]. In addition to the three experienced researchers, a student was actively involved in all phases of the research presented in this paper. Her participation was considered essential during the research because she provided suggestions for developing a new didactic game and framework from the perspective of Generation Z.

The following section reviews the literature on Generation Z education and available research on card game-based learning in higher mathematics education. The third chapter shows the theoretical framework, followed by a description of the Blue Yeti card game, i.e., the didactic framework. Section 5 describes the purpose and questions of the research, and Section 6 details the research methodology. Section 7 presents the data analysis, the results, and the discussion. We conclude this article with our plans and recommendations for the future.

## 2. Literature Review

### 2.1. The New Generation of Students

Generation Z, born between the mid-1990s and early 2010s, represents a distinct group of students characterised by their digital nativism and unique cognitive patterns. They have grown up in an era of rapid technological advancements, which have fundamentally shaped their way of thinking and learning. According to [26], this generation exhibits increased multitasking abilities, shorter attention spans, and a preference for interactive and visually stimulating learning experiences. The influence of the Internet and the widespread adoption of smartphones have profoundly transformed learning styles. Having grown up in an interconnected world, Generation Z has access to a wealth of information. Traditional classroom boundaries no longer confine learning, as platforms like YouTube and educational websites like Khan Academy offer alternative ways of acquiring knowledge. Generally speaking, Generation Z students prefer to learn in smaller chunks, digesting new information bit by bit [27]. They also prefer independent and self-paced learning with collaboration if necessary [28], viewing instructors as facilitators, guiding them towards developing relevant skills. They value honest and immediate feedback and less lecturing with more kinesthetic and visual representation [29]. Educators are continually seeking innovative approaches to enhance students' engagement. Traditional frontal teaching methods, which rely on a passive learning style, are less effective in capturing the attention and maximising the learning potential of Generation Z students [30], characterised by their affinity for technology, interactivity, and hands-on, experiential learning.

Consequently, exploring alternative teaching strategies that align with the preferences and learning styles of this generation becomes imperative. One such strategy is gamification, an instructional approach in which students work together in groups to tackle a complex, semester-long challenge. By actively participating in the project, students take control of their learning process through real-world problem solving, with the assistance of their instructors [31]. Another alternative to frontal learning gaining prominence is the integration of educational games into the curriculum. Games provide an interactive and immersive learning environment, encouraging active participation and fostering deeper conceptual understanding. GBL integrates game characteristics and principles within learning activities. In this context, the game Blue Yeti emerges as a promising motivational tool to improve students' performance on improper Riemann integrals.

### 2.2. Mathematical Games and Non-Digital Game-Based Learning in Higher Education

Educational games are types of games explicitly designed for education [32]. This family of games includes digital and non-digital (physical) games [33]. Educational games encompass traditional games and educational software and aids with educational and entertainment characteristics [34].

GBL has been applied in mathematics and science education to increase motivation and reduce learning anxiety for decades. Using GBL in higher education offers several advantages. Firstly, it has the ability to improve the emotional engagement of students by capturing their attention and fostering active participation [35]. Given the relationship between emotions and memory consolidation [36],

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this increased participation can result in better knowledge retention and a deeper understanding of complex concepts.

In addition, didactic games provide interactive learning opportunities that allow students to apply theoretical knowledge in practical situations through simulations, role-playing, and problem-solving scenarios. This hands-on approach enables students to develop critical thinking, decision-making, and problem-solving skills in dynamic and engaging ways [37]. Moreover, didactic games provide immediate feedback and assessment mechanisms. Students receive timely information on their progress and performance within the game, enabling them to identify their strengths and weaknesses. This feedback loop facilitates self-reflection and targeted learning, promoting a deeper understanding of the subject.

Despite the numerous advantages, there are also some potential disadvantages associated with the use of didactic games in higher education. One challenge may be the need for appropriate guidance and structure, in the absence of which students may focus more on the entertainment aspects of the games than the intended educational content. This use of games may result in superficial learning or a failure to transfer knowledge to real-world contexts. Therefore, careful instructional design and precise alignment between game mechanics and learning outcomes are essential to ensure a practical educational experience. In addition, relying solely on didactic games may not provide a comprehensive educational experience in complex disciplines. Therefore, GBL is typically utilised as a supplementary approach alongside traditional frontal learning methods rather than as a standalone educational strategy. There is evidence that lectures can effectively communicate information, model reasoning, and motivate students. Therefore, when adequately supported by other activities, lectures can be a valuable part of mathematics education [38].

The study of Fernández-Raga et al. examines the implementation of GBL in higher education [39]. It proposes a thirteen-step process for lecturers to effectively integrate GBL, addressing challenges such as cost and time constraints. The authors highlight the importance of considering security, cultural factors, and quality assurance throughout the process. A process-orientated quality assurance model is also provided to ensure effective implementation.

Naik in [18] explored the potential of using non-digital GBL in higher education during undergraduate mathematics courses. Some popular games were adopted for his research to teach basic mathematical principles. Naik used six different non-digital didactic games: an arithmetic puzzle, a crossword for numbers written in decimal form, a puzzle with logarithmic and exponential expressions, a bingo game for algebraic equations, and puzzles and magic boxes to practice conversions between number systems. The board games used by Naik in [18] have in common that they have easy-to-learn rules and can be played by several students simultaneously in the classroom. The results suggested that non-digital GBL motivates students and positively influences learning outcomes.

Educational card games (ECG) introduce students to the complex learning process at different levels of difficulty [40]. This family of games includes both digital and non-digital GBL with an ECG, which represents a novel and engaging pedagogical strategy that utilises the mechanics and dynamics of card games (CGs) to facilitate the learning process [41]. This approach is grounded in cognitive and social learning theories, promoting not only knowledge acquisition but also the development of critical thinking, problem-solving skills, and social interaction among participants. As educational paradigms evolve to emphasise active learning and student engagement, GBL with ECG emerges as a compelling method of instruction across various disciplines.

An exciting example of CGs used in mathematics education is the SET game, developed in 1974. Holdener [42] presented a first-semester Abstract Algebra project that guides students through an algebraic formulation of SET. The SET card game has interesting mathematical properties; for example, it can illustrate some theorems from group theory, linear algebra, affine and discrete geometry, coding theory and computational complexity [43,44]. SET is a vibrant source of combinatorial and probabilistic problems and a hands-on example of finite geometry [45]. SET also possesses an interesting algebraic structure because there is a natural binary operation on the cards that is commutative but possesses no identity and is not even associative [42].

The development of ECGs related to calculus topics began in 2018 at the Institute of Mathematics of the University of Miskolc. The first game was completed in the spring of 2019. The Log Halli Galli game was an adaptation of Haim Shafir's famous game. With logarithmic formulas written on the card sheets, this tool is a concentration game, which has also become a didactic game. No card-generating application has been developed for this game. However, proprietary software has been developed to create the deck for Gem Hunters, which is a mathematical skill-building CG. Thanks to its editable cards, it can generate a treasure hunter-type game for virtually any mathematical topic, for example, the Trigonometric Card Game, which is an excellent tool for practising the identities of trigonometric functions and their notable angles. Gem Hunters is based on the globally popular CG Saboteur, designed by Frederic Moyersoen, but significant changes were made to the basic game deck and rules [46]. The use of Saboteur for GBL has been the subject of several studies. For example, Math-teur is a mathematical CG created and used successfully at John von Neumann University to teach remedial mathematics as part of a complex university catch-up programme in Hungary [47]. Moreover, Kelecsényi et al. in [48] have investigated levels of understanding of logarithmic expressions with this self-developed Saboteur-based mathematical CG among a small group of students. In parallel with Gem Hunters, the work on Functions in a Box, a game to practice the properties of univariate fundamental functions, was also in progress [49]. The completed games have satisfied expectations, and the development of specific ECGs for each main chapter of the Calculus courses has continued. A significant milestone in this work is the LimStorm card game, a GBL approach to calculating limits [50]. In order to bring the level of knowledge of the students closer together, different variations of the LimStorm game were developed [51].

## 3. Theoretical Framework

Different factors ensure that a didactic game effectively supports learning. These factors must be considered during the development of a new learning tool. For example, the pedagogical background, the properties of the target group, and the psychological factors that influence players' motivation, engagement, and development must be examined.

### *3.1. Psychological Background*

In the 1900s, a Russian psychologist, Lev Vygotsky, developed a sociocultural theory of learning. The basic premise of Vygotsky's theory was that children learn best through social interaction with more knowledgeable peers. The more knowledgeable other (MKO) can take many forms; the point is that this person should be someone who can provide guidance and support when needed while allowing the child to take the lead in their learning. In Vygotsky's sociocultural theory, the development of cognitive skills occurs through internalisation, where learners gradually incorporate new ideas and strategies into their thinking. This process is facilitated by interaction with an MKO, who can provide immediate help and ensure quality learning. One of the critical concepts of Vygotsky's theory is the zone of proximal development (ZPD), which represents the distance between the learner's current level of development and his or her potential level of development. The ZPD covers tasks and concepts beyond the student's current knowledge and skills but which he or she can solve or learn with help. Most learning occurs in this zone, providing optimal challenge and progress opportunities [52]. Over the years, Vygotsky's theory has been confirmed in numerous studies [53,54], in several cases regarding teaching mathematics [55–58].

Communication is vital to developing mathematical understanding. From a sociocultural perspective, students who share their reasoning about ideas with others, listen to others, and share their thinking can develop their mathematical knowledge [55]. According to Vygotsky, a game is an imaginary situation that allows the participants to think beyond their developmental limits [59]. Nicolopoulou et al. in [53] point out that harnessing the potential value of play for learning is more than just alternating periods of game-based didactic elements with traditional academic teaching.

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Teaching practice should incorporate the element of play into the educational process in a systematic and carefully structured way. Vygotsky's theory of play suggests that these purposes can best be realised by rule-structured frameworks that help to allow and support learning. However, game-based activities are only effective if they are motivating and fun for the students. Ideally, such learning activities should be structured to allow participants to enter the activity voluntarily, according to their own rhythm, inclination, and abilities, accepting and exploring the rule-governed structure of the activity.

Cooper examined Vygotsky's sociocultural theory in a university setting, and the results confirmed the benefits of peer interaction with teachers and peers [15]. Differentiation, that is, taking into account students' different learning speeds, habits, and prior knowledge, is challenging in teaching mathematics at the university level [60]. Mathematics teachers know that if the subject matter does not sufficiently challenge students, they will quickly lose interest. If the challenge is sufficient, students may continue to engage in the learning process. Using the concept of a ZPD and engaging with learners at different developmental points supports a strategic approach to designing non-digital GBL, where there are at least one or more central individuals (MKOs). Vygotsky's sociocultural theory provided the psychological basis for the creation of the Blue Yeti card game, with the concepts of MKO and ZPD proving central to its design and implementation process.

### *3.2. Mathematical Background*

Improper Riemann integrals are special cases of definite integrals. There are two types. An integral

$$\int_a^b f(x)\,dx$$

is improper if one of the following conditions holds.

Type I: The integration interval is infinite. That is, $a = -\infty$ and/or $b = +\infty$.

Type II: The integrand is unbounded on $[a, b]$.

Improper Riemann integrals of Type I are integrals of continuous functions in infinite domains [61]. In the Blue Yeti game, Type I improper integrals are featured on the cards with $a \in \mathbb{R}$ and $b = +\infty$.

In general, the notion of limits and Newton-Leibniz's rule, a fundamental calculus theorem, are used to calculate improper integrals. Because of the limits, the interest lies in the convergence or divergence of the improper integral. If the limit connected to the improper integral exists and is a finite number, then the improper Riemann integral converges. Otherwise, it diverges. Often, the precise value of improper integrals is not important; instead, the focus is solely on whether the integral is convergent or divergent. Moreover, there are some integrals that we cannot evaluate, and yet we would like to know if they converge or diverge. The comparison test allows us to deduce the convergence or divergence of an improper integral without actually evaluating the integral itself [62]. We present the comparison test exclusively for a specific sub-case of the infinite interval integral. While versions of the test are applicable to other sub-cases and to integrals with discontinuous integrands as well, Blue Yeti focuses solely on the comparison test for Type I improper integrals.

**Theorem 1** (Direct Comparison Test)**.** *Let $f$ and $g$ be continuous on $[a, +\infty)$, where $0 \le f(x) \le g(x)$ for all $x \in [a, +\infty)$. Then holds*

$$0 \le \int_a^\infty f(x)dx \le \int_a^\infty g(x)dx.$$

*The inequalities above imply the following statements:*

**(a)** *If $\int_a^\infty g(x)\,dx$ converges, then so does $\int_a^\infty f(x)\,dx$.*

**(b)** *If $\int_a^\infty f(x)\,dx$ diverges, then so does $\int_a^\infty g(x)\,dx$.*

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The first statement translates to a convergence test that involves finding a *majorant* of the improper integral. The second comparison test is similar but is used to determine divergence and involves finding a *minorant* of the improper integral. These tests allow us to determine the convergence behaviour of an improper integral by comparing it to that of another improper integral. Thus, it can answer questions about the convergence of an improper integral by considering a simpler improper integral [61,63,64]. This direct comparison test for improper integrals is very similar to the comparison test for infinite sums.

A useful strategy for solving these types of problems is as follows: first, make an educated guess about whether the given integral converges or diverges; then, based on this guess, bound the integrand above or below by a more straightforward function whose integral over the same interval converges or diverges [62]. The goal is to find a comparison function that we know will always be greater than or less than the given function. Thus, by using the comparison tests, one can determine the convergence or divergence of an improper integral in the head, without actually evaluating the integral itself.

The Cauchy-Maclaurin integral test is a useful theorem to test the convergence property of Type I improper integrals [61,65,66].

**Theorem 2** (Cauchy-Maclauren integral test)**.** *Let $\sum_{k=1}^{\infty} a_k$ be an infinite series with positive terms. If $f(x)$ is a continuous decreasing function, for which $f(k) = a_k$ for all $k$, then $\sum_{k=1}^{\infty} a_k$ and $\int_{k=1}^{\infty} f(x)dx$ either both converge or both diverge.*

The application of the Cauchy-Maclauren test is helpful when the convergence properties of infinite series are well-known, for example, for $p$-series [67] and geometric series [61]. In the Calculus I course, students gain routine in the study of series in the coupled context. This knowledge can then be applied to the use of the Cauchy-Maclauren test for improper integrals, thus strengthening the intradisciplinary coupling.

## 4. Didactic Framework

The YETI framework, an educational framework developed at the University of Miskolc, has been devised to facilitate student comprehension of diverse mathematical subject matters that encompass less than and greater than relations between elements [24,68].

### 4.1. The YETI Didactic Framework

The most prominent component within the framework is the YETI board game, which has the comparison test for infinite sums at its focus [24]. The Blue Yeti game, which this paper is centred around, is another vital addition to this framework. It is essential to highlight that the graphics incorporated in both games are entirely original, designed by the developers themselves. This effort enhances the immersive gaming experience while reinforcing the games' authenticity and originality (see Figure 1).

To facilitate the development of mathematical card decks, a web application has been designed to enable the customisation of decks that require the inclusion of scientific formulas on the cards. The application allows users to display LaTeX expressions on the cards, ensuring an accurate representation of the mathematical notation. Furthermore, the application provides convenient functionality, including two distinct types of print-ready PDF conversion, as well as the ability to import and export card decks through a text file format [69].

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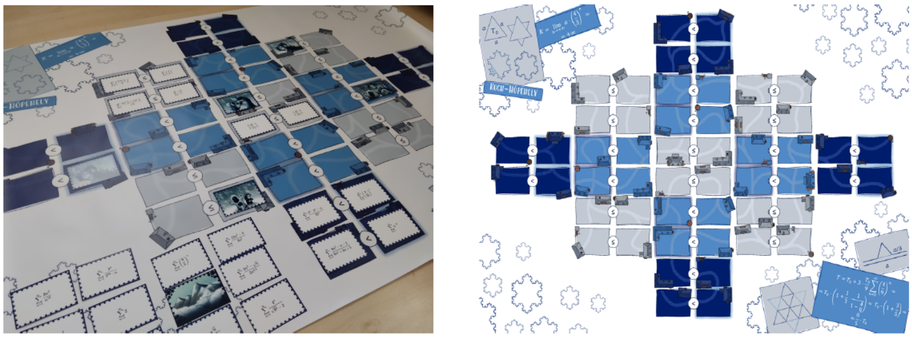

**Figure 1.** The game mat of YETI.

*4.2. Learning Improper Riemann Integrals by Cards*

Blue Yeti is a non-digital didactic card game developed to improve students' performance within their Calculus courses by merging the motivational aspect of the traditional CG Old Maid (also known as Black Peter) with the intricacies of improper integrals. The game has its didactic focus on the direct comparison test of Type I improper integrals. Apart from a distinct card known as the Blue Yeti, each card in the deck features a unique improper integral expression, with varying integrands (Figure 2 and Figure 3). The deck comprises 14 cards featuring improper integrals that converge, 14 cards with improper integrals that diverge, and the Blue Yeti card, which plays a key role in the game.

To make the game smoother, the integral cards in the beginner's deck are colour-coded according to their convergence property: cards containing improper integrals that converge are distinguishable by a dark blue colour, while those with improper integrals that diverge have a light blue edge decoration (Figure 2). This deliberate visual distinction improves the aesthetic appeal and clarity of the game, assisting players with limited experience in making their pairing decisions.

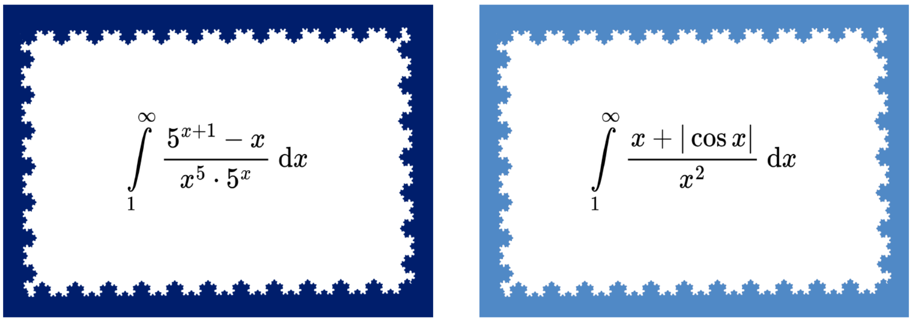


**Figure 2.** Cards from the Blue Yeti deck.

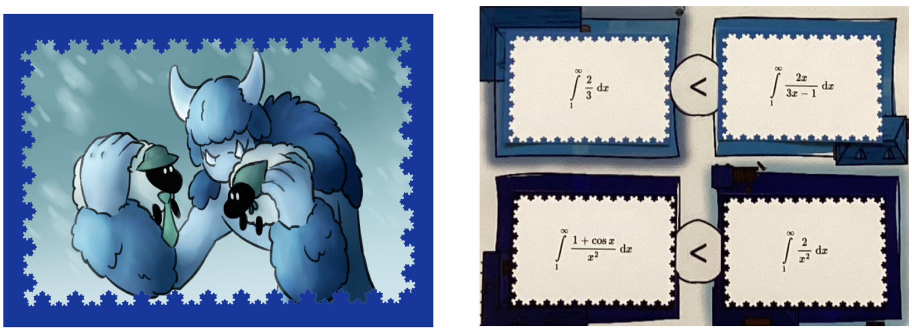

**Figure 3.** The Blue Yeti card and two pairs from the deck on the YETI game mat.

In terms of the game rules, players have the objective to strategically pair cards up, based on the comparison of the integrals they represent, to avoid being left with the unmatched Blue Yeti card at the end of the game. Pairing decisions can be made swiftly, based on experience and previous knowledge, without the need for complex calculations. If players are predominantly beginners, we

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recommend that a teacher or an MKO player conduct a theoretical overview before the game. This preliminary session aims to facilitate the identification of pairs within the deck and to improve the overall comprehension of the rules. The key to successful learning is the presence of an MKO player during the game. The MKO player will ensure mathematical correctness, check pairs, answer questions that arise, and give advice if the players need it.

Blue Yeti can accommodate up to 7 players. Before the game, the cards are thoroughly shuffled and then evenly distributed among the players. The gameplay proceeds in a turn-based manner, with participants taking sequential turns drawing a card from another player's hand, attempting to create pairs consisting of two improper integrals with a greater than or a less than relation between them. Upon successful construction of a valid pair, both cards involved in the pairing are immediately placed face-up on the table or game mat, and a brief explanation is given to clarify the reason for the pairing. The MKO player approves the placed pair or, in the case of faulty pairing, provides a short explanation for the error. The gameplay then proceeds clockwise, with the subsequent player commencing their turn. As the game unfolds, the players continue to form pairs and progressively eliminate cards from their respective hands. The player who runs out of cards first is declared the winner of the game. Ultimately, the one who remains with the unpaired Blue Yeti card loses the game. It should be noted that these rules are adaptable, allowing for potential customisation, including the incorporation of supplementary gameplay elements or the implementation of diverse scoring systems. A possible extension to the Blue Yeti card game is the YETI game board (Figure 1), which provides a designated space to place pairs of cards in an organised manner. By providing visual cues, the board assists players in recalling pairs of improper integrals and their convergence properties more effectively (Figure 3).

Blue Yeti incorporates mathematical concepts by introducing players to the comparison test of improper integrals through gameplay. The game encourages players to analyse integrals, compare values, and identify convergent and divergent pairs that satisfy inequality relationships, reinforcing mathematical skills in an engaging and interactive context. The full printable version of the Blue Yeti deck can be found in Supplementary Materials.

## 5. Research Aim and Research Questions

While studies in existing literature have focused on the effectiveness of digital and non-digital GBL in primary and secondary schools, few have explored student learning success and performance at the university level [70,71]. Additionally, limited research has been conducted on the use of original card decks as non-digital didactic tools [17,48,50,51]. To date, no studies have examined the effects of non-digital CGs on participants' learning responses and success on the topic of improper integrals.

This research investigated the effects of non-digital GBL on student learning performance. The main contribution of this study is to present the design and implementation of the Blue Yeti game as a non-digital GBL approach for learning improper integrals. The study aimed to examine Blue Yeti's positive effects on first-year computer science undergraduate students. The research questions guiding this investigation are outlined below.

**(RQ1)** What is the effectiveness of Blue Yeti as a tool for facilitating the learning of the comparison test for improper integrals?

- **(a)** Short-term effectiveness: Immediately after playing the game.
- **(b)** Medium-term effectiveness: Over two weeks following the gameplay.

**(RQ2)** How do students perceive Blue Yeti in terms of its design, enjoyability, difficulty, and overall gaming experience?

**(RQ3)** Are students receptive to incorporating Blue Yeti into their learning, both within and outside the classroom?

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## 6. Research Methodology

### *6.1. General Background*

This research was conducted in a Calculus II course in the spring semester of 2023 and continued one year later in the spring semester of 2024. The experiment spanned two consecutive years to ensure a large enough sample for statistical analysis. The curriculum and the instructor remained the same across both years. The study used a quasi-experimental research design and involved 63 participants from the University of Miskolc, a Hungarian university. The participants were divided into control and experimental groups. The control group learned the topic of improper integrals exclusively via the conventional learning method, while the experimental group also used non-digital GBL with Blue Yeti as a learning media.

### *6.2. Research Design*

A quasi-experimental study design is used in this quantitative research featuring pre- and post-tests, midterm examination problems, and a Likert-scale questionnaire. This study employs three approaches, incorporating different quantitative methods to gather data and draw insightful conclusions. A mixed-methods approach is adopted, combining quantitative and qualitative methods for interpreting the trends and patterns within the quantitative data to draw conclusions about student perceptions and experiences.

The survey conducted for this research encompasses a pre-test and a post-test, each consisting of 15 questions with similar but not identical content, designed to assess students' knowledge and comprehension of improper integrals before and after their exposure to the Blue Yeti game. These tests contain multiple-choice questions. With the pre- and post-tests, we measured the short-term effect of the Blue Yeti game.

Additionally, a questionnaire was administered shortly after the non-digital GBL to capture students' perceptions of the game's effectiveness, enjoyment, and relevance to their learning experience.

Furthermore, to assess the medium-term effects of the game, the research includes an analysis of exercises embedded within a midterm exam.

### *6.3. Participants*

The experiment was carried out at the University of Miskolc in Northern Hungary. The research involved students enrolled in informatics bachelor's programmes, primarily first-year students. All participants were between 18 and 22 years old. To examine the effectiveness of the Blue Yeti game as a teaching aid, the participants were divided into two groups: an experimental group and a control group.

In the spring semester of 2023, 80 computer science students enrolled in the Calculus II course, many of whom volunteered to participate in the non-digital GBL experiment. A year later, 114 computer science students enrolled in Calculus II, of whom we also invited volunteers to participate in the non-digital GBL experiment. A total of 31 students formed the experimental group, with 18 students eligible to participate in the GBL with Blue Yeti in 2023 and 13 students in 2024. For both semesters, the process of selecting participants for the experimental and control groups was based on comparing initial performance, as measured by the results of the first mid-semester exam. This consideration helped to ensure that any differences observed between the two groups were attributable to the use of the Blue Yeti game and not to pre-existing differences in academic ability. In each group, students who scored 34-41% on the first midterm exam were included. Note that in selecting students for the experimental group, priority was given to students with lower average grades, as the primary goal of Blue Yeti is to help those who have difficulty catching up with the curriculum. Students who already understand the subject well rely less on supplementary learning tools.

The experimental group consisted of 31 students (87.10% male, 12.90% female). The control group consisted of 32 students (84.37% male, 15.63% female). The total sample comprised 63 students,

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consisting of 54 men (85.71%) and 9 women (14.29%), as seen in Table 1. Although females are under-represented in the sample, this proportion is typical in STEM fields [72–75].

**Table 1.** Number of participants per year and group.

| | Participants | | | |
|---|---|---|---|---|
| | **Experimental Group** | | **Control Group** | |
| Year | 2023 | 2024 | 2023 | 2024 |
| Female | 2 | 2 | 1 | 4 |
| Male | 16 | 11 | 17 | 10 |
| Total | 18 | 13 | 18 | 14 |

*6.4. Ethics*

The students were informed of the research objectives at the beginning of the experiment, and all agreed to participate. The researchers explained the entire experimental process to the participants. Data collection was voluntary throughout the study. Codes were used instead of the participants' names to record and evaluate data. The participants actively participated in all the planned events of the experiment. The study followed the ethical standards established in the Code of Ethics of the University of Miskolc.

*6.5. Procedures and Materials*

The control and experimental groups were subjected to the same conventional academic environment and educational experiences. Both groups attended an equal number of lectures during the semester, with three 45-minute sessions per week, providing them with the same foundational knowledge. Additionally, they participated in practical courses consisting of two 45-minute sessions per week dedicated to problem-solving. All students participated in classroom lectures and exercises. In addition, online 15-question tests were administered biweekly throughout the semester to help students review each unit, including the topic of improper integrals (see Figure 4). The only difference in the learning process was that the experimental group participated in non-digital GBL with the Blue Yeti card game. The pre-test was administered immediately before the GBL session. The Blue Yeti game was introduced in 20 minutes, followed by playful learning. After a short break, the participants completed the post-test on the same day. Including the pre- and post-test taking, the entire event lasted 4 hours (see Figure 4). Pre -and post-tests can be found in Supplementary Materials.

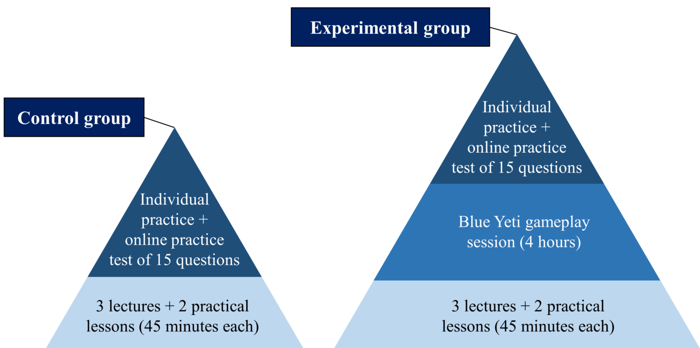


**Figure 4.** The learning pyramids of the control group and the experimental group.

Following the gameplay session, experimental group participants were invited to complete an online questionnaire through Google Forms. The questionnaire contained 19 closed-ended and one open-ended question. In the first section of the questionnaire, students were asked to respond on a 5-point Likert scale from strongly agree (5) to strongly disagree (1). The subsequent section focused

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on rating various aspects of the Blue Yeti game, including design, difficulty, and others, using a scale ranging from 1 to 5. The questionnaire covered various aspects of the research topic, such as participants' general approach to board games and GBL, their perception of Calculus and improper integrals, and their opinion on the design, enjoyability, difficulty, and overall gaming experience of the Blue Yeti game. The questionnaire consisted of 20 items. 19 were closed-ended and the last question was open-ended. The responses provide valuable insights that complement the quantitative data collected from the pre- and post-tests.

The data collection timeline aligns with the participants' academic progression, beginning with introducing improper integrals in lectures, followed by the first midterm test, the gameplay session, and finally, the second midterm test. This timeline allows for assessing the short-term and medium-term impacts of the Blue Yeti game on students' performance. To ensure the integrity of the testing process, all assessments were supervised. Figure 5 shows the timeline for the 2023 semester. The same layout was applied in 2024, with a few calendar days difference.

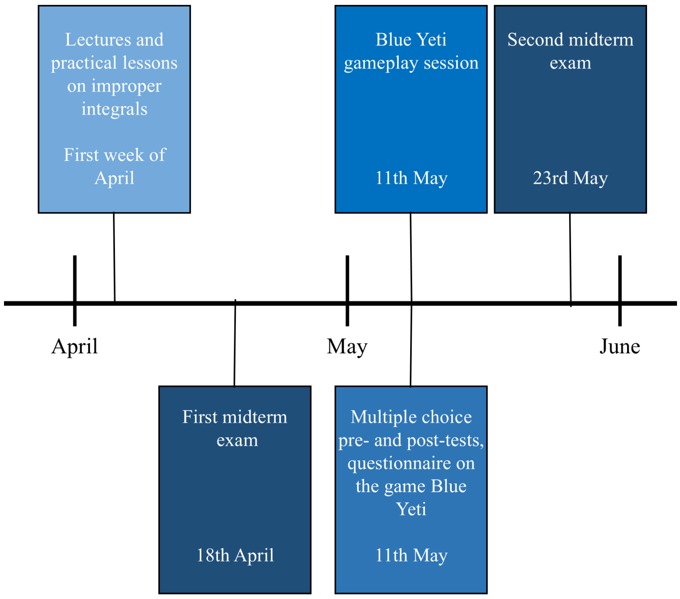


**Figure 5.** Timeline of the assessment in 2023.

Throughout the semester, both groups underwent the same examination processes, ensuring equitable assessment of their mastery of the subject matter. By maintaining uniformity in the educational setting, the study aims to isolate the impact of the Blue Yeti game as an independent variable. The second midterm exam included problems for improper integrals, which can be found in the Appendix A.

In summary, pre- and post-tests consisting of 15 multiple-choice questions were administered in a classroom environment directly before and after the gameplay session. These tests assess students' understanding of improper integrals and measure their knowledge acquisition through playing the game. Additionally, the results of the improper integral-related exercises from participants' midterm exams were analysed, which provide a medium-term perspective on participants' learning progress. The motivation for students to perform well on the tests was reinforced by the fact that the midterm exams contribute to their final grades. Participants were assigned unique identifier numbers to ensure confidentiality.

## 7. Data Analysis, Research Results and Discussion

This section answers the research questions following a statistical analysis of the data. The DATA*tab* statistical calculator was used for data analysis. Box plots were chosen for data visualisation, as they provide a clear representation of the descriptive statistics, as well as the outliers, indicated by individual points that fall outside the box and whiskers. Correlation analysis was performed using Jupyter Notebook.

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### *7.1. The Short-term Effects of the Blue Yeti GBL and Answer for Research Question RQ1 (a)*

The participants in the experimental group were required to complete two multiple-choice tests consisting of 15 questions each, administered immediately before and after the gameplay session. These tests aimed to assess the immediate impact of the game by evaluating the number of correct answers. The tests were marked by two experienced teachers.

All 31 participants completed both tests; the descriptive statistics of these are presented in Table 2.

**Table 2.** Descriptive statistics for pre- and post tests.

| | **Pre-Test** | **Post-Test** |
|---|---|---|
| *N* | 31 | 31 |
| Mean | 5.23 | 7.32 |
| Median | 5 | 7 |
| Mode | 5 | 5 |
| Std. Deviation | 2.32 | 2.95 |
| Variance | 5.38 | 8.69 |
| Minimum | 1 | 3 |
| Maximum | 10 | 15 |

The mean score increased from the pre-test to the post-test, suggesting a performance improvement. The median also increased, which indicates that the central tendency of the scores moved upwards, reinforcing the results of the mean. The mode remained the same in both tests (5), indicating that this score was the most frequently occurring in the dataset for the pre-test. The post-test has a mode of 5 as well, but it does not fully represent the post-test distribution, especially with the higher mean. The standard deviation increased in the post-test, suggesting that the variability of the scores was greater after the intervention than before. Like standard deviation, variance has increased, indicating a wider spread of scores in the post-test results. The range of scores in the post-test (3 to 15) shows that participants achieved higher scores compared to the pre-test, where scores ranged from 1 to 10. This further supports the trend of improvement.

The mean $\pm$ standard deviation represents the range within which approximately 68% of the data points lie, provided that the data follows a normal distribution. In the pre-test, the typical score range was from 2.91 to 7.55, indicating that while some participants had lower scores, most scores were somewhat clustered around the mean of 5.23. After the intervention, the typical score range in the post-test spanned from 4.37 to 10.27. This range shows that scores improved significantly, with many participants achieving higher scores after the intervention. Figure 6 illustrates the essential features of the sample for both tests. In the box plot, the box contains three vertical lines that represent the lower, middle, and upper quartiles. The line in the centre of the box represents the median, which is the midpoint of the values and divides the data into two halves. The whiskers extending from the box denote the extreme values, also known as outliers, which fall outside the upper and lower quartiles. The position of the whiskers and the length of the box offer insights into the variability of the variable; the further the whiskers are from the box, the greater the spread of the data.

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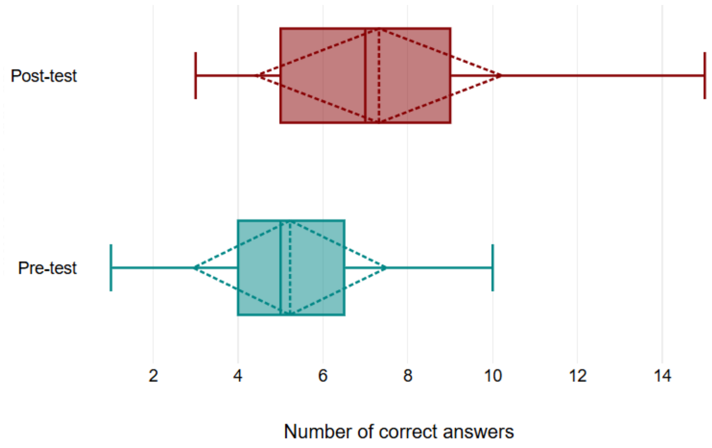


**Figure 6.** Box plot for the distribution of the scores. (The figure was created using DATA*tab*.)

The analysis indicates a significant improvement in mean, median, and overall score distribution from the pre-test to the post-test, suggesting that the intervention between these two tests was effective. However, while scores improved, the increased variability in the post-test also indicates that some participants performed much better while others did not improve as much. Hypothesis testing was utilised to evaluate the hypothesis formulated from descriptive statistics to determine if there is a statistically significant difference between the variables being examined. To answer the research question RQ1 (a), the following hypotheses were formulated:

- *Null hypothesis:* The post-test results are equal to or lower than the pre-test results.
- *Alternative hypothesis:* The post-test results are greater than the pre-test results.

A paired t-test was used for hypothesis testing. The primary condition for applying the paired t-test is that the sample is normally distributed. This condition is particularly important when the sample size is small (usually n < 30), as the statistical methods of the t-test rely on a normal distribution. Therefore, the normality of the samples was first tested (see Table 3). High p-values, that is, greater than 0.05, indicate that the data do not significantly differ from a normal distribution.

**Table 3.** Different statistical tests to check the normality.

| | Pre-test | | Post-test | |
|---|---|---|---|---|
| | Statistics | $p$ | Statistics | $p$ |
| Kolmogorov-Smirnov | 0.14 | 0.544 | 0.16 | 0.389 |
| Shapiro-Wilk | 0.96 | 0.381 | 0.94 | 0.065 |
| Anderson-Darling | 0.43 | 0.3 | 0.69 | 0.072 |

We used the t-test for paired samples to test our hypothesis. This test is beneficial when the same subjects are measured under two different conditions, such as before and after an intervention. Table 4 presents the results of a paired samples t-test.

In this case, the calculated t-statistic ($t$) is 4.36. The t-statistic measures the difference between the two tests relative to the variation in the data. A higher absolute t-statistic value indicates a more significant difference between pre-and post-tests. The sign of the t-statistic shows the direction of the difference, indicating that the mean score for the pre-test is lower than that of the post-test. The value of degrees of freedom ($df$) for this test is 30. A $p$-value of less than 0.001 indicates a 0.1% chance of obtaining these test results if the null hypothesis is true. Typically, a $p$-value of less than 0.05 is regarded as statistically significant, suggesting that there is a statistically significant difference between the means of the pre-test and post-test. Additionally, Cohen's $d$ of 0.78 suggests a large effect size, meaning that the difference between the two means is not only statistically significant but also practically significant.

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**Table 4.** Data from the t-test for paired samples.

| | t | $df$ | $p$ | Cohen's $d$ |
|---|---|---|---|---|
| Pre-test - Post-test | 4.36 | 30 | $<0.001$ | 0.78 |

We reject the null hypothesis based on the provided data and the $p$-value. Consequently, the answer to research question RQ1 (a) is that Blue Yeti demonstrates moderately high effectiveness as a tool in the short term, specifically immediately after playing the game.

### *7.2. Questionnaire Results*

All 31 participants in the experimental group completed the online questionnaire, answering all the questions. In the first part, students were asked to indicate their agreement with ten statements on a 5-point Likert scale. The statements are presented in Table 5.

**Table 5.** Statements in the first part of the questionnaire.

| No. | Statements |
|---|---|
| S1 | I prefer solving practical problems to learning mathematics solely through definitions. |
| S2 | I often don't have the patience or the willpower to practice Calculus at home. |
| S3 | I am more anxious about midterms and exams in Calculus than in other subjects. |
| S4 | I like playing board games in my free time. |
| S5 | Occasionally, I would like to play relevant skill-building games in practical lessons instead of the usual problem-solving. |
| S6 | Occasionally, I would like to engage in mathematics skill-building games even beyond the confines of the classroom. |
| S7 | I find game-based learning effective. |
| S8 | Based on the definitions explained in the lectures, I was able to understand the topic of improper integrals and their comparison test. |
| S9 | Based on the definitions explained in the lectures and the problems solved in practical lessons, I understood the topic of improper integrals and their comparison test. |
| S10 | I find improper integrals to be one of the most difficult topics covered this semester. |

For the evaluation of the results, answers 4 and 5 (agree and strongly agree) are considered agreement, answers 1 and 2 (strongly disagree and disagree) are categorised as disagreement, while response 3 (neither agree, nor disagree) is considered an indicator of uncertainty. Table 6 contains descriptive statistical data for the sample and Figure 7 displays the box plots.

Most students in the experimental group unanimously agreed with statement S1, expressing a clear preference for problem-solving over learning mathematics through definitions, highlighting the inclination of Generation Z students towards a practical approach in their educational experience. The descriptive statistical data analysis of statement S2 suggests that while the average sentiment about practising Calculus at home is moderately low (mean of 3.35), a significant portion of respondents (median and mode both at 4) feels more positive about their capacity to practice. The relatively high standard deviation indicates diverse opinions, suggesting that, while many feel capable, there are also students who may struggle more with practising at home. Moreover, in response to statement S3, 20 students (64.5%) reported experiencing higher levels of anxiety specifically related to midterms and exams in Calculus compared to their other subjects. This finding may indicate the presence of mathematical anxiety within the experimental group. Research has shown that students with elevated

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levels of anxiety in mathematics are more susceptible to underperforming in their maths-related studies [76–79]. Consequently, it becomes crucial to explore strategies to alleviate these anxieties and promote a positive learning environment.

**Table 6.** Descriptive statistics for the first part of the questionnaire.

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 4.65 | 3.35 | 3.58 | 3.81 | 4.1 | 4.06 | 4.48 | 2.55 | 3.1 | 3.35 |
| Median | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 3 | 3 | 3 |
| Mode | 5 | 4 | 4 | 5 | 5 | 4 | 5 | 3 | 3 | 3 |
| Std. Deviation | 0.55 | 0.91 | 1.06 | 1.14 | 0.98 | 0.96 | 0.81 | 0.72 | 1.04 | 1.11 |
| Variance | 0.3 | 0.84 | 1.12 | 1.29 | 0.96 | 0.93 | 0.66 | 0.52 | 1.09 | 1.24 |
| Minimum | 3 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| Maximum | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 |

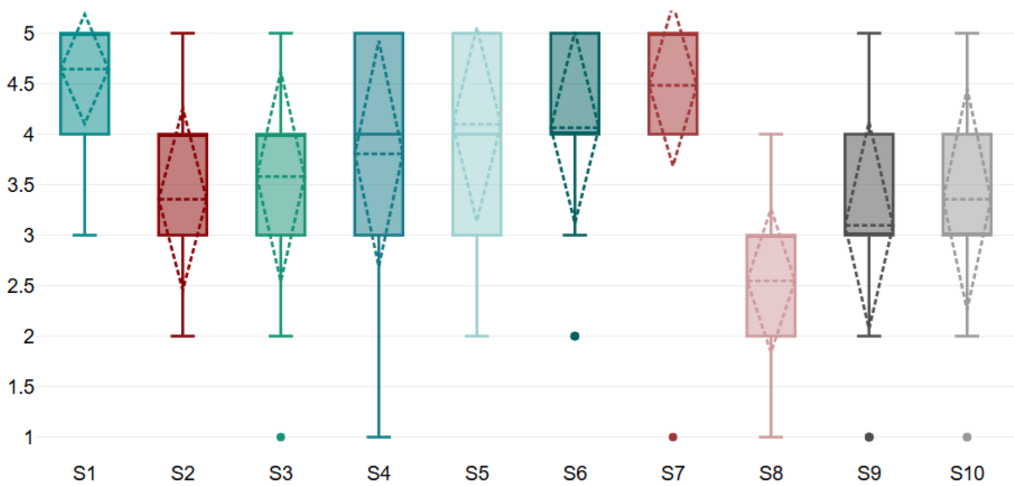


**Figure 7.** Box plots for the first part of the questionnaire. (The figure was created using DATA*tab*.)

The mean score for the statement about playing board games (S4) is 3.81, indicating that overall, participants hold a neutral to moderately positive attitude towards playing board games. This score is closer to the middle of the scale, suggesting a positive but not overwhelmingly strong impact. The median value is 4, which supports a central tendency towards a slightly positive outlook. The mode, however, is the highest score (5), reflecting a strong preference for board games among the experimental group. The mean score of 4.1 for statement S5 indicates a strong interest in incorporating skill-building games into practical lessons. This implies that participants find this concept valuable and enjoyable. A median score of 4 and a mode of 5 reinforce the preference for skill-building games, with most responses leaning positively and a significant number of students strongly favouring this learning method. The standard deviation of 0.98 indicates that the responses are relatively consistent, with less variation from the mean. This suggests that most of the student ratings are closely grouped around the mean, pointing to a strong consensus about the value of skill-building games. Responses for statement S6 indicate a strong preference for engaging in mathematics skill-building games outside the classroom. The consistent ratings suggest this interest is robust, with most responses clustering positively around the mean. The data reflects a clear enjoyment and value placed on these activities.

Statement S7 measured the general attitude toward GBL. The mean score of 4.48 indicates a very high level of agreement with the effectiveness of GBL. Most participants agreed on the effectiveness of GBL, showcasing a positive overall attitude towards integrating games into the educational experience. The standard deviation of 0.81 indicates that the responses are relatively consistent, with low variability from the mean. This suggests that there is a general agreement in perceptions regarding the effectiveness of GBL.

The last three statements addressed the experience of learning about improper integrals in a traditional classroom environment. The average score of 2.55 for statement S8 indicates a slightly below-average understanding of the topic. It was found that only 3 students (9.68%) believed that lectures alone provided a sufficient understanding of this course material. The responses to statement S9 highlight the importance of problem-solving in practical lessons. The average score of 3.1 marks an improvement over the average score for S8. However, a mean of 3.1, accompanied by a median and mode of 3, indicates that students believe they have only a moderate understanding of the topic of improper integrals, even after attending lectures and practical lessons. In the last statement (S10), participants were asked to share their opinions on the difficulty level of improper integrals. The average score of 3.35 suggests that students generally perceive improper integrals as somewhat difficult but not overwhelmingly so.

A correlation analysis was conducted using Kendall tau non-parametric correlation coefficients to uncover the relationship between the statements. The heatmap visualizes the correlation matrix using Kendall tau values, effectively illustrating the strength of relationships between the variables (Figure 8).

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 1.000 | 0.255 | -0.045 | 0.032 | 0.263 | 0.124 | 0.159 | -0.087 | 0.071 | 0.343 |
| S2 | 0.255 | 1.000 | 0.156 | 0.080 | -0.164 | -0.299 | 0.057 | -0.153 | -0.277 | 0.241 |
| S3 | -0.045 | 0.156 | 1.000 | 0.232 | -0.018 | 0.058 | 0.053 | -0.029 | -0.018 | 0.099 |
| S4 | 0.032 | 0.080 | 0.232 | 1.000 | 0.187 | 0.160 | 0.381 | 0.109 | 0.121 | 0.028 |
| S5 | 0.263 | -0.164 | -0.018 | 0.187 | 1.000 | 0.580 | 0.446 | -0.003 | 0.077 | 0.085 |
| S6 | 0.124 | -0.299 | 0.058 | 0.160 | 0.580 | 1.000 | 0.191 | 0.140 | 0.052 | -0.050 |
| S7 | 0.159 | 0.057 | 0.053 | 0.381 | 0.446 | 0.191 | 1.000 | -0.063 | 0.251 | 0.098 |
| S8 | -0.087 | -0.153 | -0.029 | 0.109 | -0.003 | 0.140 | -0.063 | 1.000 | 0.591 | -0.006 |
| S9 | 0.071 | -0.277 | -0.018 | 0.121 | 0.077 | 0.052 | 0.251 | 0.591 | 1.000 | 0.021 |
| S10 | 0.343 | 0.241 | 0.099 | 0.028 | 0.085 | -0.050 | 0.098 | -0.006 | 0.021 | 1.000 |

**Figure 8.** Correlation heatmap for the first part of the questionnaire. (Both the calculation of the correlation coefficients and the generation of the heatmap were carried out using Jupyter Notebook.)

This approach was selected for several reasons. First, the relatively small sample size renders traditional parametric methods less reliable, as they can produce unstable results with limited observations. Additionally, our dataset does not meet the normality assumption, which is essential for many parametric tests. By employing Kendall tau, we can analyse correlations without this requirement, leading to a more accurate reflection of the relationships among the variables. Kendall tau focuses on the ordinal ranks of the data, making it particularly suitable for analysing Likert scale responses, which are ranked but not necessarily equidistant. This method allows us to gain insights into the strength and direction of associations while accommodating the nature of our data. The main diagonal features all values of 1. The colour scale of the heatmap distinctly differentiates strong, moderate, and weak correlations, facilitating the interpretation of the data. Strong correlations are not observed. Moderate correlations, typically defined as those between 0.3 and 0.7, show interesting relationships, such as between S8 and S9 (0.59) and between S5 and S6 (0.58). Other moderate correlations are observed between S5 and S7 (0.45), S4 and S7 (0.38), and S1 and S10 (0.34). The remaining correlations are weak.

The second section of the questionnaire focused on the specific aspects of Blue Yeti. The questions are shown in Table 7. The first nine questions were answered on a 5-point Likert scale. The results indicate high levels of satisfaction among the majority of respondents. Table 8 contains descriptive statistical data for the sample, and Figure 9 shows box plots. The last question (Q10) was open-ended.

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**Table 7.** Questions in the second part of the questionnaire.

| No. | Questions |
|---|---|
| Q1 | How would you rate the graphics and design of the game Blue Yeti? |
| Q2 | How would you rate the enjoyability of gameplay in Blue Yeti? |
| Q3 | How would you rate the difficulty level of Blue Yeti? |
| Q4 | To what extent did you find the competitive aspect of Blue Yeti motivating? |
| Q5 | How interesting did you find the game Blue Yeti compared to the problems solved during practical lessons? |
| Q6 | To what extent did playing Blue Yeti help you learn or review the comparison test for improper integrals? |
| Q7 | In your opinion, how much more challenging would the game become if convergent and divergent integrals were not marked by different colours? |
| Q8 | Overall, how positive would you rate your experience with the game Blue Yeti? |
| Q9 | How interested would you be in playing Blue Yeti or similar games in the future? |
| Q10 | In your opinion, is there anything that should be modified in Blue Yeti (e.g. design, difficulty, additional rules, etc.)? If so, what changes would you propose? |

Specifically, the game's design and enjoyability both received positive feedback. The high mean of 4.61 for question Q1, combined with a median and mode of 5, strongly indicates that the majority of respondents view the graphics and design of Blue Yeti positively. The relatively low standard deviation (0.67) and variance (0.45) suggest that most respondents have similar views on the topic, reflecting a consensus on the quality of the graphics. The ratings for Q2 suggest that Blue Yeti is considered an enjoyable game by most players, with a good concentration of scores around 4. The mean score of 4.23 indicates that, on average, players find the gameplay quite enjoyable. This is a positive sign for the game's reception. A standard deviation of 0.72 indicates moderate variability in the ratings.

**Table 8.** Descriptive statistics for the second part of the questionnaire.

| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 4.61 | 4.23 | 3.39 | 3.87 | 4.52 | 4.06 | 4.45 | 4.61 | 4.29 |
| Median | 5 | 4 | 3 | 4 | 5 | 4 | 5 | 5 | 4 |
| Mode | 5 | 4 | 3 | 4 | 5 | 4 | 5 | 5 | 4 |
| Std. Deviation | 0.67 | 0.72 | 1.02 | 0.88 | 0.77 | 0.81 | 0.72 | 0.62 | 0.74 |
| Variance | 0.45 | 0.51 | 1.05 | 0.78 | 0.59 | 0.66 | 0.52 | 0.38 | 0.55 |
| Minimum | 3 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 2 |
| Maximum | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

According to the participants' responses to question Q3, the game is perceived as neither easy nor difficult. The mean score of 3.39 indicates a moderate level of difficulty. However, the standard deviation of 1.02 reveals considerable variability in the ratings, suggesting that perceptions of the game's difficulty range widely, with some participants finding it easier and others much more challenging. Responses to question Q4, which addressed the competitive aspect of Blue Yeti, reflect a generally positive outlook. The mean rating of 3.87 indicates that participants found this aspect somewhat motivating, while the median of 4 suggests that at least half the respondents rated it positively. However, the standard deviation of 0.88 and the range of responses from a minimum of 2 to a maximum of 5 indicate that not all participants felt equally driven by the competitive element of the game.

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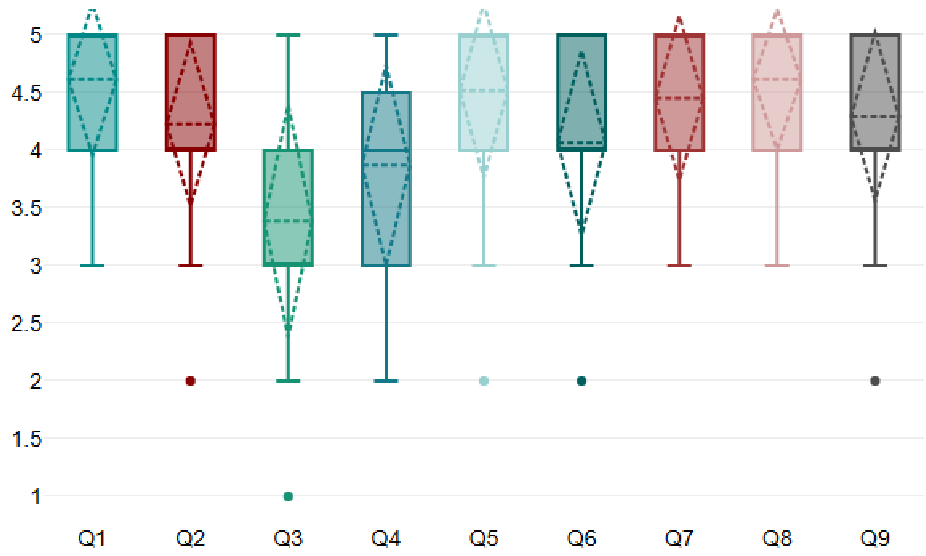


**Figure 9.** Box plots for the second part of the questionnaire. (The figure was created using DATA*tab*.)

Students rated the interest level of Blue Yeti very positively, with a mean score of 4.52 and a median of 5, which suggests that at least half the respondents found the game highly interesting. Despite a minimum score of 2, the majority rated the game's interest level favourably, indicating that Blue Yeti effectively captures participants' interest, making it a compelling alternative to traditional problem-solving activities.

The descriptive statistical data for Q6 suggests that playing Blue Yeti was perceived as helpful for learning or reviewing the comparison test for improper integrals. The mean, median and mode all indicate that participants rated their experience positively, with most scores clustered around 4 or higher. However, the standard deviation of 0.81 indicates some variability in responses, meaning not everyone had the same level of satisfaction. The minimum score of 2 highlights that while the majority found value in the game, a few respondents were less convinced of its effectiveness. Despite this variability, the data show that Blue Yeti has a generally favourable impact on participants' learning experiences related to improper integrals.

The responses regarding the challenge level of the game Blue Yeti - in the absence of colour coding for convergent and divergent integrals - reveal a strong consensus among participants. Most students agree on the necessity of colour coding for clarity. The mean rating of 4.45 and the variance of 0.52 indicate that most respondents believe the game would become significantly more difficult without this feature. These results reinforce the idea that the colour marking of cards facilitates the understanding of convergent and divergent integrals during the game. In Blue Yeti GBL, the colour coding of cards advances the learning process, enabling players to bridge the gap between their current understanding and higher levels of comprehension more quickly within the context of ZPD.

Participants generally perceived their experience with Blue Yeti positively. The mean rating of 4.61 for Q8 suggests that most students found the game enjoyable and beneficial. The mode of 5 shows that the highest rating was the most frequently chosen one, while the standard deviation of 0.62 indicates low variability in the responses.

The data for Q9 reflect a strong overall interest in playing Blue Yeti or similar educational games in the future, as evidenced by a mean rating of 4.29. The standard deviation of 0.74 indicates that some participants expressed lower levels of interest, pointing to a degree of diversity in individual preferences.

The second part of the questionnaire was analysed using Kendall tau non-parametric correlation coefficients to examine the relationships among the questions. The heatmap (Figure 10) illustrates the correlation matrix, which highlights the Kendall tau values. Strong correlations are not observed.

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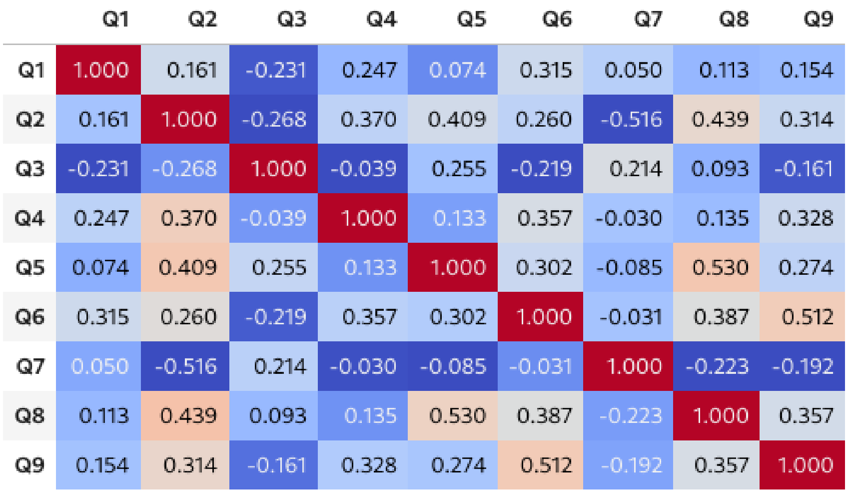
Several moderate correlations exist, including the following: Q5 and Q8 (0.530), Q6 and Q9 (0.512), Q2 and Q8 (0.439), Q2 and Q5 (0.409), and Q2 and Q4 (0.370). The remaining correlations are weaker.



| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 |
|---|---|---|---|---|---|---|---|---|---|
| Q1 | 1.000 | 0.161 | -0.231 | 0.247 | 0.074 | 0.315 | 0.050 | 0.113 | 0.154 |
| Q2 | 0.161 | 1.000 | -0.268 | 0.370 | 0.409 | 0.260 | -0.516 | 0.439 | 0.314 |
| Q3 | -0.231 | -0.268 | 1.000 | -0.039 | 0.255 | -0.219 | 0.214 | 0.093 | -0.161 |
| Q4 | 0.247 | 0.370 | -0.039 | 1.000 | 0.133 | 0.357 | -0.030 | 0.135 | 0.328 |
| Q5 | 0.074 | 0.409 | 0.255 | 0.133 | 1.000 | 0.302 | -0.085 | 0.530 | 0.274 |
| Q6 | 0.315 | 0.260 | -0.219 | 0.357 | 0.302 | 1.000 | -0.031 | 0.387 | 0.512 |
| Q7 | 0.050 | -0.516 | 0.214 | -0.030 | -0.085 | -0.031 | 1.000 | -0.223 | -0.192 |
| Q8 | 0.113 | 0.439 | 0.093 | 0.135 | 0.530 | 0.387 | -0.223 | 1.000 | 0.357 |
| Q9 | 0.154 | 0.314 | -0.161 | 0.328 | 0.274 | 0.512 | -0.192 | 0.357 | 1.000 |

**Figure 10.** Correlation heatmap for the second part of the questionnaire. (Both the calculation of the correlation coefficients and the generation of the heatmap were carried out using Jupyter Notebook.)

### *7.3. Answer for Research Question RQ2*

Regarding Q10, most participants either left the open-ended question unanswered, indicating no additional comments, or used the text field to provide positive feedback about the game, noting that its design and functionality are well-developed and require no changes. Only four students proposed minor adjustments to the visual elements of the card deck and the logistics of the gameplay session. No suggestions were made concerning the game's rules or educational content. Some of the responses received:

- *"I was very satisfied with the appearance of the game."*
- *"I don't think it needs any changes."*
- *"I think it is skillfully executed and well-crafted."*
- *"The drawing of the Yeti turned out surprisingly well."*

The research question RQ2, concerning student perceptions of Blue Yeti, is answered using participants' responses to the open-ended question and descriptive statistics from Q1, Q2, Q3, and Q8. These data indicate generally favourable student perceptions, with overwhelmingly positive views on the game design (Q1) and the overall experience (Q8), a moderately difficult game experience (Q3) with considerable individual variation, and a high level of enjoyment (Q2).

Additionally, Q6 suggests that the game effectively contributes to learning, further supporting the favorable student perceptions regarding the game's value as an educational tool.

In summary, students display strong approval of the Blue Yeti game, with minor suggestions for improvement, affirming its effectiveness in providing an enjoyable and educational experience.

### *7.4. Answer for Research Question RQ3*

The research question RQ3 cannot be answered directly, as it inquires about students' attitudes towards the inclusion of games - particularly that of Blue Yeti - in learning. However, the questionnaire included several statements that indirectly gauged students' receptiveness to using games in learning. Figure 8 reveals a medium correlation between S5 and S6. This relationship indicates that those who rated S5 (occasional use of skill-building games in practical lessons) highly were also more likely to rate S6 (use of skill-building games outside of class) positively. The strong overall agreement with statements S5 and S6 (concerning the use of games in and outside of class, respectively) and the positive responses to Q9 (regarding interest in playing similar games in the future) suggest a highly favourable reception of Blue Yeti, with many students expressing a desire to engage in similar activities in both

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classroom and out-of-classroom settings. The overwhelmingly positive responses to the questions assessing design, enjoyability, and overall game experience (Q1, Q2, Q5, Q8) provide indirect support for a positive answer to RQ3. The medium correlation between Q2 (enjoyability of Blue Yeti) and Q8 (overall positive experience with Blue Yeti) indicates that those who found the game more enjoyable (higher score on Q2) were also likely to report a more positive overall experience (higher score on Q8), as shown in Figure 10. This is a logical and expected result: if someone enjoys the game, they are likely to have a more positive overall experience. The relationship between Q5 (the interest factor of Blue Yeti compared to the problems solved in the practical lessons), Q2 (enjoyability), and Q8 (overall positive experience) should be interpreted in conjunction with the correlation between Q2 and Q8. When responses to Q5 are high (students found the game more interesting than practical lessons), the scores for Q2 and Q8 are expected to be higher. This suggests that if a student finds the game more interesting, they are more likely to find it more enjoyable and to rate their overall experience positively. Thus, the relationship between Q5, Q2, and Q8 can be interpreted as a chain: finding the game interesting (Q5) leads to greater enjoyment (Q2) and a more positive overall experience (Q8). Students who enjoy and appreciate the game are more likely to welcome its integration into their learning process. In the questionnaire, a high proportion of students expressed interest in engaging in GBL activities similar to Blue Yeti, both within and beyond classroom settings.

### *7.5. The Medium-term Effects of the Blue Yeti GBL and Answer for Research Question RQ1 (b)*

To measure the medium-term effects of the Blue Yeti GBL, we examined the distribution of scores obtained by students on a three-part task included in the second midterm exam. The highest possible score achieved in the assessment was 6 points. In order to address research question RQ1 (b), the following hypotheses were formulated:

- *Null hypothesis:* There is no difference between the experimental and control groups with respect to the dependent variable.
- *Alternative hypothesis:* There is a difference between the experimental and control groups regarding the dependent variable.

Table 9 presents the descriptive statistical data for both the experimental and control groups, which facilitates easy comparison between their performances. This table includes key metrics such as means, standard deviations, and sample sizes, offering insight into the overall performance of each group. The data summarised in Table 9 are important for understanding the distribution of scores and establishing the foundations for the statistical analysis.

**Table 9.** Descriptive statistics for the experimental and control groups.

| | Experimental Group | Control Group |
|---:|:---:|:---:|
| *N* | 31 | 32 |
| Mean | 3.03 | 1.78 |
| Median | 3 | 2 |
| Mode | 2 | 2 |
| Std. Deviation | 1.78 | 1.34 |
| Variance | 3.17 | 1.79 |
| Minimum | 0 | 0 |
| Maximum | 6 | 4 |

The average score of the experimental group (3.03) is significantly higher than that of the control group (1.78), indicating that participants in the experimental group generally outperformed those in the control group on the exam task. Additionally, the medians of the two groups reflect a higher central tendency for the experimental group. The experimental group also had a higher maximum score (6) compared to the control group (4). Furthermore, with a standard deviation of 1.78 and a variance of 3.17, the experimental group displayed more variability in scores than the control group. Figure 11 illustrates the box plots for both groups, providing a visual representation of their score distributions.

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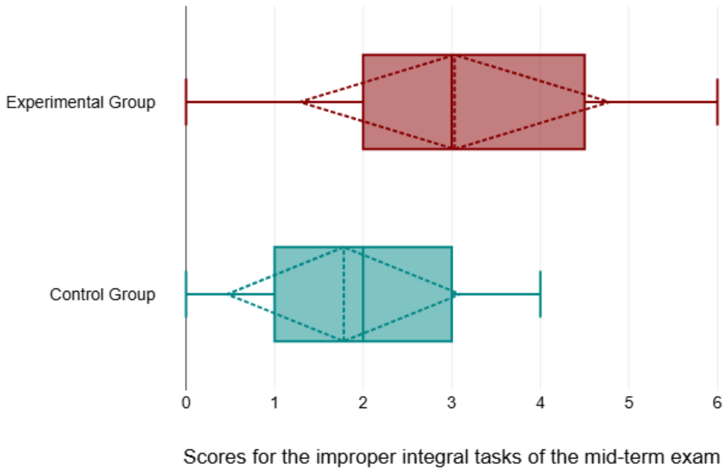


**Figure 11.** Box plot for the distribution of the scores in the midterm exam. (The figure was created using DATA*tab*.)

These results clearly indicate a difference in performance between the experimental and control groups, supporting the alternative hypothesis that the two groups yield different outcomes for the dependent variable. Statistical testing was conducted to further validate this conclusion.

The first step involved determining whether the samples followed a normal distribution. The Kolmogorov-Smirnov, Shapiro-Wilk and Anderson-Darling tests were used (see Table 10), revealing that the data does not conform to a normal distribution. The low $p$-values (lower than 0.05) obtained for the Shapiro-Wilk and Anderson-Darling tests suggest that the data significantly deviates from normality.

**Table 10.** Different statistical tests to check the normality.

| | Experimental Group | | Control Group | |
|---|---|---|---|---|
| | Statistics | $p$ | Statistics | $p$ |
| Kolmogorov-Smirnov | 0.19 | 0.202 | 0.16 | 0.355 |
| Shapiro-Wilk | 0.91 | 0.013 | 0.9 | 0.008 |
| Anderson-Darling | 1.04 | 0.01 | 1.2 | 0.011 |

As the normality assumption was not met, the Mann-Whitney U-test was used to compare the performance of the experimental and control groups. This test is robust because it is not sensitive to the absence of a normal distribution and to differences in variances. Table 11 shows the results of the Mann-Whitney U-test.

**Table 11.** Mann-Whitney U-test.

| | U | $z$ | asymptotic $p$ | exact $p$ | $r$ |
|---|---|---|---|---|---|
| Mann-Whitney U-test | 303.5 | -2.69 | 0.007 | .009 | 0.34 |

The results of the Mann-Whitney U-test reveal a statistically significant difference between the performance of the two groups. The U statistic obtained was 303.5, which corresponds to a $z$ score of -2.69. This negative $z$-value signifies that the ranks of one group are significantly lower than those of the other, pointing to a noteworthy disparity in performance. The asymptotic $p$-value of 0.007, along with the exact $p$-value of 0.009, both fall below the conventional alpha level of 0.05. This strong statistical evidence allows for the rejection of the null hypothesis, which posited that there would be no difference in the median scores between the groups. Consequently, these findings support the alternative hypothesis, asserting that there is a significant difference in the outcome measure.

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Furthermore, the effect size, measured by $r$, is 0.34, indicating a medium effect. This suggests that the difference observed is not only statistically significant but also practically relevant, implying a moderate impact of the intervention associated with the experimental group, which answers research question RQ1 (b). These results highlight the potential positive influence of the Blue Yeti GBL on students' scores, warranting further investigation and consideration in future research.

## 8. Conclusions and Recommendations

Many theorems in mathematics with significant applications in science and technology depend on the properties of improper Riemann integrals [63]. One of the key applications of improper integrals is in probability distributions. Determining quantities such as the cumulative distribution or expected value typically requires integrals over infinite intervals. Improper integrals are a powerful mathematical tool with many real-life applications, particularly in fields that deal with infinite or undefined quantities [64]. For these reasons, it is crucial for prospective professionals to gain a strong understanding and make proper use of the concept of improper Riemann integrals.

Russo et al., in their systematic review of non-digital maths games, concluded that integrating higher-order thinking games should be a key area for future research. These games can promote critical thinking, problem-solving, reasoning, and analytical skills. Expanding into higher-order thinking games can broaden the educational benefits of gaming and support a wider variety of learning objectives [80]. This research investigated the effectiveness of Blue Yeti as a tool for facilitating the learning of the direct comparison test for improper integrals. Pre- and post-tests conducted before and after gameplay showed a significant improvement in students' performance, indicating a positive impact of the GBL session on their understanding of the topic. Furthermore, the results of the second midterm exam demonstrated that the experimental group, who had played Blue Yeti beforehand, outperformed the control group on improper integrals.

The participants rated the game's graphics and design very highly, suggesting a strong positive impression of its visual aspects. The gameplay was also considered highly enjoyable. Although not as overwhelmingly positive as the design ratings, this still points to a largely positive experience. The difficulty level of Blue Yeti was perceived as moderate, providing a suitable challenge. However, it is important to note that considerable variation was discovered in individual perceptions of difficulty. Students overwhelmingly rated their overall experience with Blue Yeti positively. Data strongly suggests that the Blue Yeti GBL was a successful and enjoyable learning experience for most participants. A systematic review conducted by Hui and Mahmud strongly affirms that GBL has a positive impact on students' learning of mathematics [81]. The results of the Blue Yeti GBL are consistent with those of other GBL experiments in today's mathematics education.

A notable finding of Vankúš's systematic review on the influence of GBL in mathematics education is that the majority (84%) of the 57 journal articles analysed highlight the positive effects of GBL on students' affective domain. These results primarily show increases in motivation and engagement, as well as improvements in students' attitudes towards mathematical content and its instruction [82]. Participants of the Blue Yeti GBL expressed receptiveness to incorporating game-based learning in their mathematics education, both within and outside of the classroom. The positive effects of Blue Yeti GBL in the affective domain align with prior research in this field. Overall, Blue Yeti proved to be an effective tool for enhancing students' understanding of the comparison test for improper integrals and was well-received by students as a valuable learning experience.

In addition to non-digital didactic games, the benefits of digital games should not be overlooked, which is why a digital version of Blue Yeti is being developed and fine-tuned [83]. Note, however, that the digital Blue Yeti game is designed exclusively for individual practice, as we believe it cannot serve as a substitute for face-to-face play and game-based learning. In Blue Yeti GBL, the MKO plays a pivotal role in facilitating the learning process and fostering knowledge development. The knowledge and experience of the MKO enrich the learning experience of the participants, enabling them to solve new problems and develop their creative thinking. The MKO's presence during play boosts learners' motivation, as personal interactions and positive feedback heighten their interest in learning. As participants gain confidence in their knowledge, they become capable of applying their acquired skills independently, so the role of the MKO may gradually diminish, allowing for independent thinking. Beyond providing academic guidance, the MKO encourages social interactions that help participants develop communication, teamwork, and collaborative problem-solving skills. To further explore the effectiveness of the learning process, it might be interesting to implement a control group study in the future, where the learning experience of the experimental group is extended by incorporating the digital version of Blue Yeti for independent practice outside the classroom.

The landscape of educational games in higher mathematics is diverse, but still relatively unexplored. The field of research is dynamic, with ongoing investigations into game design, implementation strategies, and the impact of GBL on different learning outcomes. The success of Blue Yeti, as demonstrated in this paper, highlights the potential of well-designed non-digital games to make meaningful contributions to this evolving field.

## Limitations

This study has certain limitations that should be taken into account. Due to the small sample size and the specific methodology employed, the findings cannot be generalised to a broader population of students. Such constraints are common in educational research. Consequently, a more extensive study with a larger sample is necessary to draw further conclusions and obtain definitive results. A larger, more representative sample would significantly strengthen the study's findings and allow for more robust statistical analyses. The study's focus on first-year computer science students from a single university further restricts the generalisability of its results.

The participation of students in the experimental group was voluntary, potentially attracting those with pre-existing positive attitudes toward games or those seeking supplementary learning methods. This self-selection bias could have skewed the results, making it difficult to determine whether the observed improvements were solely due to the game or influenced by the pre-existing characteristics of the participants. A more representative sample would involve random assignment of participants to experimental groups.

Research has shown that male and female students may exhibit different learning styles, preferences, and motivations in mathematics learning [84,85]. A higher proportion of male students in the sample may influence group dynamics and the nature of interactions during learning activities, potentially leading to different engagement and outcomes compared to a more gender-balanced group.

The current study only examined the short- and medium-term retention of knowledge gained through GBL combined with the Blue Yeti card game. A longer-term study would provide more insight into how well the effects of GBL activities are sustained over time. In addition, the same lecturer taught both the experimental and control groups and the instructional style of the teacher, along with the specific use of the Blue Yeti card game, may have influenced the outcomes. While the study concluded that GBL was more effective than the traditional teaching method in the control group, the limitations of the presented teaching technique may have affected the results.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| GBL | Game-Based Learning |
| CG | Card Game |
| ECG | Educational Card Game |
| MKO | More Knowledgeable Other |
| ZPD | Zone of Proximal Development |

## Appendix A. Midterm Exam Tasks

Improper integrals were the focus of the first question on the second midterm exam. Our intention was to eliminate any randomness and allow for a comparative analysis of the outcomes between problems involving convergent and divergent improper integrals. Therefore, the second midterm exam included three different improper integrals: one divergent and two convergent. The convergence property of all the integrals could be determined using the direct comparison test for improper integrals. The tasks were as follows:

Do the following improper integrals converge? Justify your answer! (*6 points*)

$$(a)\int_{1}^{+\infty}\frac{2x}{3x-1}\,dx; \qquad (b)\int_{1}^{+\infty}\frac{\arctan x}{x^4}\,dx; \qquad (c)\int_{1}^{+\infty}\frac{\sin^2 x}{2^x}\,dx$$

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