Development and Validation of Integer Boggler: A Basis for a Mobile Game-Based Application

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***Abstract*—The study aimed to develop and validate the integer boggler as an instrument for the retention and improvement of freshman high school students' skills in integers to draw its implications to mathematics education and its potential for a mobile game-based application. The Research and development method was employed. Questionnaires were given to five mathematics teachers to evaluate the game's feasibility, objectives, rules, procedures, and relevance. The experts gave a strong agreement on the easy and affordable construction of the equipment, clarity, and attainability of its objectives, rules and procedures, and the relevance of the game. Fifty (50) students who participated in the experiment were classified as average and below average performers in operations on integers based on their pretest and percentage. The pretest results of the participants revealed a wide range of errors among students, with an overall error rate exceeding 50%. After the intervention, the post-test results showed a significant reduction in errors across all categories, with the overall error rate decreasing by 29%. This indicates that the intervention was effective in addressing student misconceptions and improving their understanding of the topic. The mean score of students significantly enhanced from the pretest to the posttest, increasing from 44.98 to 47.62. A t-test confirmed this significant difference. This suggests that the intervention effectively improved student retention in the four operations. The t-test for independent samples explains a more substantial increase in the gain scores of the below-average group in multiplication and division of integers. Employing the t-test for correlated samples, the delayed post-test showed the game's effectiveness in the student's retention of the rules and operations on integers. It was concluded that the boggler can be used as a remediation or enhancement activity in integer operations. Thus, it encourages mobile app developers to use the game as a basis for a new application while urging teachers, students, school heads, curriculum developers, and other math enthusiasts to play and promote the game.**

***Keywords*—math game, integers, retention, math operations, math education**

I. Introduction

Mathematics is enjoyable to teach. This is true when the students have almost retained all that is taught, and their performance is satisfactory and better. Otherwise, it is frustrating. Despite long years of teaching experience, exposure to training and seminars, giving advice and motivation to students, and using simple language and different techniques and strategies, many students still perform poorly. Many high school students find Algebra, Geometry, and Trigonometry challenging subjects. While essential for math, traditional resources like textbooks and workbooks don't encourage problem-solving skills and retention. Math is necessary for general and specialized science, accounting, and engineering education despite being tedious and difficult. Dowker [1] stressed that an integrated approach is needed to motivate students to learn math in a more relaxed environment, thus eliminating persistent math anxiety, the lack of math application skills, and poor standardized test performance.

The limitations of traditional mathematics teaching methods, particularly integer operations, have been well-documented in educational research. These conventional approaches often rely heavily on textbooks and repetitive exercises, which may fail to capture students' interest or promote a deep understanding of the material. Numerous studies have identified critical issues with these traditional methods. For instance, Bofferding and Richardson [2] showed that students frequently rely on procedural knowledge, neglecting the conceptual understanding needed to solve integer problems effectively. This tendency towards rote learning and memorization can impede students' ability to apply mathematical concepts in various unfamiliar situations.

Traditional instructional methods often lack the interactive and engaging elements that are crucial for keeping students motivated. Research by Alzabut [3] highlighted that many students find math classes tedious and uninteresting, resulting in subpar academic performance, even among those with significant intellectual potential. This challenge is especially relevant in teaching integer operations, where abstract concepts can be difficult for students to comprehend when using conventional methods alone.

One of the significant aims of mathematics education is to provide students with the opportunities to be involved in meaningful and enjoyable math activities. Games are valuable in helping students to improve their math skills interactively. Using board games and card games along with cooperative learning are ways that students can become involved in a positive mathematical environment [4, 5]. Math games come in many forms, like board games, card games, online games, interactive games, and math video games. Games are highly motivational to students and can be used effectively to practice specific skills [6]. Math games allow students to use their critical thinking skills to make connections in math concepts and increase their speed and accuracy in solving problems. Well-designed games draw students in, interest them, and challenge them to engage in the task [7, 8].

In contrast to traditional instructional methods, Game-Based Learning (GBL) and the integration of mobile technology present viable alternatives that warrant consideration. GBL capitalizes on the engaging characteristics of games to enhance student motivation and improve learning outcomes. Empirical research has demonstrated that educational games can significantly

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augment students' problem-solving abilities and conceptual comprehension. For example, a study conducted by Adipat *et al.* [9] revealed that environments fostering game-based learning promote increased student engagement and collaboration, thereby facilitating enhanced educational outcomes. Likewise, Giannakas *et al.* [10] highlighted the potential of mobile game-based learning to offer context-sensitive and personalized academic experiences, which are crucial for effective mathematics instruction.

For this reason, this study investigated the possible effects of using a developed math game to ensure high school students' retention and improvement of skills in the operations of integers. The proposed educational approach, utilizing game-based learning through a game called Integer Boggler, aligns with contemporary educational paradigms. By incorporating elements of play and interactive technology, Integer Boggler aimed to overcome the deficiencies of traditional teaching methodologies and enhance students' proficiency in mathematics. Numerous studies have consistently indicated that GBL promotes improved retention of mathematical concepts and heightened levels of student engagement. This pedagogical approach renders the learning process more enjoyable and fosters the development of critical thinking and problem-solving skills, which are indispensable for mastering integer operations.

According to the National Council of Teachers of Mathematics (NCTM) [11], students need proficiency with basic facts and must be adept in reasoning, problem-solving, and mathematical communication. Hence, a strong foundation in basic mathematical skills should be strengthened. Mathematics is a commutative subject; previously learned principles and skills become the building blocks for new skills. Integer is one of the building blocks of algebra, and algebra is the key to success in higher mathematics courses [12].

Most mathematics teaching activities primarily focus on the conceptual level, which involves understanding the underlying principles and ideas behind mathematical concepts. However, when students receive instruction that emphasizes only this level of understanding, they often struggle to retain the information. This lack of retention can lead to feelings of frustration as students realize they have not fully mastered the material. As a result, many students may begin to encounter significant challenges when learning mathematics, which can hinder their overall academic progress. Over time, repeated experiences of difficulty and frustration can lead to the development of a fear of mathematics, known as math anxiety. This fear can discourage students from engaging with the subject, further exacerbating their struggles [13, 14].

To address these issues effectively, it is essential to incorporate both remediation and enrichment activities in the mathematics curriculum. Remediation activities can help struggling students solidify their foundational knowledge and skills, while enrichment activities can provide advanced learners with opportunities to explore mathematical concepts in greater depth. By implementing a balanced approach that includes both types of activities, educators can create a more supportive and effective learning environment that fosters a positive attitude toward mathematics for all students [15, 16].

Many college instructors find it particularly troubling that their students struggle with the operations of integers, especially considering that this subject is typically introduced and taught in high school mathematics courses. This difficulty often arises from students' inability to recall the specific rules and procedures associated with integer operations, which can significantly impact their overall performance in college-level math [17]. To help address this challenge, it would be beneficial to provide students with engaging enrichment activities designed to reinforce their understanding and skills in handling integers. These activities could be flexible in timing and format, allowing students to practice at their convenience and make learning more enjoyable. Incorporating games, puzzles, or online exercises could serve as practical tools to improve their operational proficiency.

It is essential to recognize that even students with a natural aptitude for mathematics may experience difficulties and cannot always ensure complete accuracy in their work. This highlights the need for regular and consistent practice, which can improve speed and accuracy when performing integer operations. Ultimately, it is essential for even the most gifted math students to thoroughly master the foundational concepts, as this knowledge serves as a cornerstone for more advanced mathematical understanding and problem-solving [18, 19].

This study was conducted with the objective of developing and validating a new educational game called "Integer Boggler," explicitly aimed at enhancing the retention and improvement of skills in operations involving integers for Grade 7 students. The research focused on addressing critical challenges that students face in mastering this mathematical concept. The specific objectives of the study were outlined as follows:

1) Development of the Integer Boggler: This involved designing a game that includes a set of twenty-five numbered cubes representing integers ranging from −9 to 9, along with a unique signed cube to facilitate operations involving positive and negative numbers. The game also includes a durable tray with a cover for easy storage, numbered wheels to track scores or rounds, a timer to add a competitive element and a comprehensive game manual that outlines the rules, objectives, and playing instructions.
2) Expert Validation: The researchers sought validation from experts in education and game design to ensure the game's effectiveness and feasibility. This validation process focused on evaluating the practicality of the game equipment, clarity of the educational objectives, comprehensiveness of the rules and procedures, and overall relevance of the game to the curriculum. Feedback from these experts was crucial in refining the game for its intended educational purposes.
3) User Validation: The final objective involved gathering feedback from actual users—Grade 7 students—on their experiences with the game. This assessment aimed to determine if the Integer Boggler effectively corrected common errors made by students in integer operations, improved their skill levels, and enhanced their retention of the concepts taught. The researcher also measured students' performance to evaluate how well the game accommodated varying abilities in handling integers and whether it positively impacted their learning outcomes.

The results of this study are anticipated to offer valuable insights for mobile application developers, providing them with a research-based educational game designed to address the pressing issue of learning poverty, particularly in mathematics. This game aspires to create engaging and practical solutions that support students in mastering critical mathematical skills.

II. Methodology

A. Research Design

This study employed the method of Research and Development (R&D) within the educational field, focusing on the systematic approach to developing and enhancing educational processes and tools [20, 21]. It concerns developing and validating a mathematical game as an instrument for the retention and improvement of skills in addition, subtraction, multiplication, and division of integers. The entire concept of this approach was based on the idea of helping students master the operations of integers through a research-based game. Furthermore, the one-shot experimental design validated the game's effectiveness to the students. Using a one-shot experimental design to evaluate a game intervention in math is advantageous due to its simplicity, efficiency, and ability to provide immediate feedback. This design is easy to implement, requiring only a single group of participants exposed to the intervention, making it ideal for preliminary studies [22].

The researcher worked on the equipment and drafted the game manual construction procedures. The manual includes the game's objectives, rules, and procedures. Then, the developed instrument was presented to experts in the field for evaluation, suggestions, comments, recommendations, and approval.

After administering the pretest to the students, the results were analyzed to determine their common errors and difficulties, which guided the researcher in giving corrective instructions. An integer boggler was used with the teacher's guidance and corrective instructions during the students' free time. About one hour was spent each day, lasting for ten (10) days. The next day, after the ten-day playing period, the post-test was administered to determine the effectiveness of the integer boggler as an instrument for improving skills in the operations on integers and comparing the average and below average gain scores. After two weeks, the delayed post-test was given to measure the students' retention of skills in addition, subtraction, multiplication, and division of integers.

B. Participants

The subjects of this study were Grade 7 students from a state university laboratory school. A pretest was administered to one hundred seventy-two (172) students, grouped based on their performance. Students with scores below −1 z-score were classified as the lowest-performing group, while those with z-scores between −1 and +1 were considered the average group. Only the low-performing and average groups were included in the study, as this allowed for a more precise assessment of corrected errors and improvements. After grouping and securing signed waivers for participation, only fifty (50) students were selected to participate in the experiment.

The participants had prior knowledge of the operations of integers. After grade 7, they will be engaged in solving systems of linear equations, quadratic equations, rational algebraic expressions, and many more. These topics involve basic knowledge of the operations of integers. The low-performing students must have mastery of the four operations on integers in order to learn the said topic quickly. Similarly, the students from the average group should be enriched and improved in their skills for better performance in math. Thus, they were exposed to integer boggler.

C. Research Instrument

A teacher-made test was used for the pretest, post-test, and delayed post-test. The pre/post-test determined the common errors and difficulties of the students, while the delayed post-test verified the subjects' retention of the four skills. The items contained in the pretest and posttest were based on the table of specifications made by the researcher. The researcher carefully selected the items from different algebra textbooks and workbooks. The pre/post-test is a multiple type of test. The pretest was used to identify the common errors and difficulties of the students in adding, subtracting, multiplying, and dividing integers. It is a multiple-choice test that consists of four (4) parts. Test I is a 15-item test on the addition of two-digit integers, Test II is a 15-item test on the subtraction of two-digit integers, Test III is a 15-item test on the multiplication of one-digit and two-digit integers, and Test IV is a 15-item test on the division of two-digit by one-digit integers. The delayed posttest was a sixty (60)-item test on one to three-digit addition, subtraction, multiplication, and division of integers.

Validating the developed game is essential for drawing conclusive evidence. The game's effectiveness was determined through experts' evaluation and students' performance after playing the game.

1) Face validation

The evaluation of the developed game was conducted by a panel of five experienced mathematics educators whose extensive backgrounds in teaching render them suitably qualified to assess its feasibility, objectives, rules, procedures, and relevance. These educators have interacted with students with varied proficiency levels in mathematical concepts, particularly in operations involving integers. The assessment was performed utilizing a 5-point Likert scale to quantify their evaluations.

The results, as presented in Table 1, indicate that the mathematics teachers assigned an overall mean rating of 4.72 to the game's feasibility, reflecting a high level of acceptability. The evaluators expressed strong agreement regarding the ease of construction of the equipment, minimal production costs, and the availability of necessary materials and substitutes. Moreover, they deemed the time required to assemble the device reasonable.

Regarding the game's objectives, a total mean rating of 4.80 was recorded, signifying a consensus among the evaluators that the goals are clearly articulated, achievable, and sufficiently challenging. The game's rules and procedures garnered a total mean rating of 4.78, indicating high acceptability. The evaluators unanimously agreed that the rules are grounded in objective criteria and are easy to comprehend, while the procedures are presented in clear, sequential language and include illustrative examples. Additionally, a summary of regulations about the operations on integers, accompanied by various illustrative examples, is provided, enabling players to engage with minimal guidance from the instructor.

The evaluators also rated the game's relevance highly, assigning it a total mean rating of 4.82. They noted that the integer boggler facilitates interactivity, as players must maintain focus throughout the game. Each participant possesses an equal theoretical opportunity to win and remains actively engaged until the game's conclusion. The design allows for multiple potential solutions, enabling players to explore various combinations. The game can accommodate two or more participants and is versatile enough to be played in diverse settings. It is accessible to students specializing in mathematics and anyone with a foundational understanding of integers.

The educators acknowledged the coherence of the game's title and format, asserting that it fosters a unified perception that is not swayed by chance. These elements, combined with the excitement and enjoyment generated by the game, contribute to its potential as an engaging educational tool.

The feedback and recommendations provided by experts were systematically analyzed to enhance the quality of the game's equipment and procedures.

Table 1. Experts' overall evaluation of the integer boggier

Criteria	Mean	Interpretation
Feasibility	4.72	Highly Acceptable
Objectives	4.80	Highly Acceptable
Rules and Procedures	4.78	Highly Acceptable
Relevance of the Game	4.82	Highly Acceptable

2) Validation through analysis of students' performance

After the face validation, the pretest/posttest was validated through an item analysis after the dry run to sixty (60) grade 8 students. The test results underwent item analysis using Friedenberg's item difficulty and the Kuder-Richardson 20 reliability coefficient.

Table 2. Response analysis of individual items of the pilot instrument

Operation	Index Range		K.R.	Number of Removed/Revised Items
	Difficulty	Discrimination		
Addition	0.55–0.91	0.18–0.91	0.93	2 of 15
Subtraction	0.50–0.91	0.36–0.91	0.96	3 of 15
Multiplication	0.59–0.86	0.18–0.82	0.90	3 of 15
Division	0.32–0.91	0.18–0.73	0.92	7 of 15

*K.R. (Kuder-Richardson 20)

Table 2 presents the range of index values for each operation during the pilot testing. An adequate difficulty index is between 44.50 and 74.50, while the discrimination index ranges from 0.3 to 1.0 Friedenberg [23]. Items that fall within these acceptable ranges were retained, whereas those outside were either revised or rejected. Additionally, since the Kuder-Richardson values are equal to or greater than 0.90, the items for each operation are generally considered acceptable and excellent [24].

The revised instrument had become crucial in measuring the effectiveness of the integer boggler by monitoring students' performance when playing the game: the corrected students' errors, the level of improvement it caused, the retention of skills in the operations on integers, and student's performance based on their abilities. It was done by letting the subjects of the study play the integer boggler for a period of ten days with a total of ten (l0) hours: two (2) hours for the orientation and eight (8) hours for the game proper.

D. Statistical Treatment

Frequency count and percentage were used to determine the errors and difficulties students experience in adding, subtracting, multiplying, and dividing integers. The corrected errors of the students show the effectiveness of the game. The mean scores of the pretest and post-test were compared for significant differences to determine the level of improvement it caused. The mean scores of the post-test and delayed post-test were compared for significant differences to know if there was retention on the four skills. The t-test for the difference between means of correlated data was used to test the first two null hypotheses. The t-test for the difference between means of independent data was used to test the difference between the gains scores of the average and below-average groups.

E. Data Gathering Procedure

Several conditions and factors were meticulously considered during the experiment to minimize potential bias. The game sessions took place simultaneously in a spacious, well-lit room, allowing for careful control over the time and physical environment. As a facilitator, the researcher ensured that each participant received the same comprehensive orientation and instructions, setting a consistent foundation for the activities [25].

In some sessions, students were free to choose their playmates, fostering a sense of autonomy and comfort. However, the researcher intentionally mixed up the groupings after a certain period to encourage interaction and adaptability, allowing students to engage with different classmates throughout the experiment. To maintain an impartial atmosphere, the researcher created a neutral setup that encouraged students to express their play styles and preferences without interference. As the game progressed, students took responsibility for scoring their own performance, reflecting on their progress, while the researcher attentively observed from one side of the room, noting behaviors and interactions that emerged during the sessions [26, 27].

After administering the pretest to the 50 participants, the researcher tabulated the scores to determine the common errors and difficulties of the students in addition, subtraction, multiplication, and division of integers. The students were exposed to the game for two weeks. To enhance students' operational skills, the researcher guided them by giving corrective feedback for the errors they committed. This also suggests that the teacher's assistance is needed when the students are having their formative tests. The researcher let the players ask questions to each other to encourage peer teaching.

The posttest was administered after the two-week playing session to determine the improvement of the students on the four operations. Two weeks after the experiment, the delayed posttest was conducted to measure the skills retained among the students.

F. Ethical Considerations

This study rigorously followed ethical guidelines to ensure the well-being and rights of all participants. Before their involvement, parental approval was obtained through a signed waiver, and participants were explicitly informed that their participation was voluntary. Furthermore, they were assured that they had the option to withdraw from the study at any time if they felt uncomfortable, and measures were in place to protect them from any potential harm.

To maintain confidentiality and respect participants' privacy, the research data was securely stored and only accessed by authorized personnel. Their rights were carefully safeguarded to uphold scientific integrity and ethical standards.

Moreover, great importance was placed on the proper communication of results to avoid any instances of plagiarism or research misconduct. This entailed clear and transparent reporting to ensure the integrity of the research process and findings.

III. Result and Discussion

A. The Integer Boggler

The integer boggler, shown in Fig. 1, is like the famous word factory game, and the researcher modified it by replacing the letters with integers. It is played with a tray of 25 numbered dice, shaken to get 25 random integers. The players' primary objective is to get the highest score at the end of the third round (10 minutes per round) or to be the first player to reach the designated point limit in a tournament game.

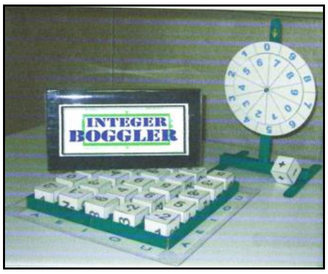

Fig. 1. The integer boggler set.

The players should have 25 numbered cubes (integers from −9 to 9), a tray with a cover, a timer, numbered wheels, a signed cube, paper, and a pen. At least two players and, at most, eight can play each piece of equipment.

1) Game procedures

Each player will need a pencil and paper. Cover the base and shake up the cubes.

1) For the zahlen (the value to be solved for), spin the numbered wheels. The big wheel is for the tens digit and the small one is for the unit digit.
2) Roll the signed cube for the sign of the zahlen.
3) Open the cover and run the timer.
4) Using the four operations, search for a combination of two (2) or more integers that will satisfy the zahlen.
5) Zahlen are evaluated from integers that are adjoining horizontally, vertically, or diagonally to the left, right, or up-and-down. However, no cube may be used more than once within a single operation.
6) When you find a combination, write it down.
7) Vowels are aligned in each column. Write the vowel corresponding to your first integer on the evaluation for every combination.
8) Keep solving for the zahlen and write down the combinations until the time is up.

2) Game rules

- Calculator computation (not PEMDAS) shall be used.
- Multiplication and division of zeroes are not allowed.
- Commutativity shall be observed. 2+ (−3) +5 and 5+ (−3)+2 are like combinations.
- The 5-minute timer will start once the cover of the boggler tray is opened.

3) Scoring and winning

- When the timer runs out, all players should stop writing.
- Each player, in turn, then reads and shows his/her list.
- The scoring is n−1, where n is the number of used cubes.
- The winner is the player 1) who earned the most points when the game has stopped or 2) who is the first to reach the "tournament" assigned final score.

4) Things to remember

- Do not touch the cube or the grid while the timer runs.
- When writing your list, follow the vowels opposite your position. (each player has their respective columns)
- If on the same column, there are like integers, look at the following integers to show the correct pattern.
- The zero (0) integer has no point, but you can use it to bridge needed cubes/integers by addition or subtraction.
- The integers must be adjoining in a 'chain'. (Integer cubes in the chain may be adjacent horizontally, vertically, or diagonally).
- Every list must contain at least two integers.
- Looking for as many combinations as possible is a good strategy; considering that longer combinations will score the most is worth considering.

B. Playing the Integer Boggler

Fig. 2 shows an example of a combination of dice After shaking and opening the integer boggler. Assuming that the given zahlen is −23, the list in Table 1 shows a correct evaluation of the zahlen.

8	-7	9	-1	-6
-7	-3	-6	6	8
5	6	-1	6	-7
-2	6	0	3	5
-2	8	3	-7	3
A	E	I	O	U

Fig. 2. Sample boggler combination.

A total of 42 points were obtained from the list in Table 3. Interestingly, the digit zero (0) was not counted due to an existing rule. However, it was an essential element that linked two integers that could be included in the combination.

Table 3. Sample integer combinations

Integer Combinations	Awarded Points
A: (−2)(5) + (−7)−8 − (−3) + (−1)	5
A: 8 + (−7)(5)(−2)− 6− 6 + (−1)	6
E: 6(−3) + (−6)− (−1)	3
E: 6 + 0 + (−1)(−6) + 6 − (−1)	4
I: 3 + 0 + (−1)(−6) − 6 − 5	4
I:−6 + (−3) + (−7)− 5 + (−2)	4
0: (−7)(3) + (−7) + 5	3
0: (6)(3)(−1) + (−6) − (−1)	4
U:(3)(3)(−1) + (−6)−9− (−1)	5
U:(5)(−7)+6−(−6)	3

C. *Students' Performance*

1) *Corrected students' errors*

The evaluation of the students' corrected errors involved a detailed comparison of the number of mistakes made on each test item before and after they engaged in the game. This approach allowed for a precise analysis of the game's impact on their understanding and performance, highlighting the specific areas of improvement in their knowledge and skills.

a) *Addition of integers*

The number and percentage of errors made by students in the addition of integers during the pretest and posttest are compared in Table 4. In the pretest, the percentage of mistakes students made when adding zero and negative integers (e.g., 0 + (−7)) was 34% of the total items. Many students who erred on this item answered zero, believing that zero is greater than any negative integer. Some answered with a positive integer, such as 7, while others incorrectly said negative zero.

When adding a negative integer and zero (e.g., −4 + 0), most students who made mistakes thought the answer was zero. This misconception arose from the belief that zero holds no value and is greater than any negative integer. Other responses included positive integers and, again, zero.

In cases where students were tasked with adding two negative integers (e.g., −3 + (−2)), many incorrectly assigned a positive sign to their final answer after summing the absolute values. Some students attempted to subtract the absolute values but then incorrectly assigned either a positive or negative sign.

For adding a negative and a positive integer where the absolute value of the negative integer is more significant (e.g., −8 + 5), most students incorrectly added the absolute values. They assigned a negative sign rather than subtracting the absolute values. In contrast, when adding a negative integer and a positive integer where the absolute value of the positive integer is greater (e.g., −5 + 8), many students added the absolute values and assigned possibly a positive or negative sign. Others attempted to subtract the absolute values but mistakenly assigned a negative sign to their answers.

In situations involving adding a positive integer and a negative integer where the absolute value of the positive integer is greater (e.g., 9 + (−5)) and where the absolute value of the negative integer is greater (e.g., 5 + (−9)), most students added the absolute values, leading to further mistakes with incorrect signs.

When faced with adding three integers with differing signs (e.g., −2 + 8 + (−5)), most students struggled with deciding the order of operations, possibly overwhelmed by the presence of multiple signs. Consequently, the percentage of errors in the pretest was 65% of the total items.

In the posttest, their errors ranged from 8% to 40%, with their difficulty in the identified categories decreasing by 20% to 39%. The overall percentage of errors dropped to 22%, reflecting a reduction of 29%. This indicates that playing the integer boggler game was effective in correcting their mistakes and alleviating their difficulties in adding integers.

Table 4. Corrected errors in the addition of integers

Category	Pretest		Posttest		Difference (%)
	Errors	%	Errors	%	
1. 0 + (−a)	17	34	4	8	26
2. −a+ 0	15	30	5	10	20
3. −a+ (-b)	88	59	30	20	39
4. −a+ b, |−a|> |b|	41	41	17	17	24
5. −a+ b, |−a|< |b|	60	60	32	32	28
6. a+ (−b), |a| > |−b|	48	48	17	17	31
7. a+ (−b), |a| < |−b|	47	47	23	23	24
8. Three addends	65	65	40	40	25
Overall	381	51	168	22	29

b) *Subtraction of integers*

Table 5 presents a comparison of the number and percentage of students' errors in the subtraction of integers between the pretest and posttest. When asked to subtract a negative integer from zero (e.g., 0 − (−5)), half of the students believed that the sign of the subtrahend would remain the same as the sign of the difference. This misconception stems from the idea that negative integers are less than zero. The other students answered either zero or negative zero.

In the case of subtracting zero from a negative integer (e.g., −5 − 0), half of the students mistakenly changed the negative sign to a positive one. They seemed to recall a rule about changing signs but forgot that it does not apply in this context. The remaining students also answered either zero or negative zero.

When subtracting a negative integer from another negative integer, where the absolute value of the minuend is greater than that of the subtrahend (e.g., −6 − (−4)), as well as in cases where the absolute value of the subtrahend is more significant (e.g., −4 − (−6)), most students added the absolute values and assigned either a positive or negative sign, some students subtracted the absolute values but attached the incorrect sign.

In subtracting a positive integer from a negative integer (e.g., −7 − 3), most students added the absolute values and assigned a positive sign. A few subtracted the absolute values and assigned either a positive or negative sign. This confusion likely arose from their mistake of following the rule for adding signs that were unliked, as the minuend and subtrahend have different signs.

When subtracting a negative integer from a positive integer (e.g., 4 − (−5)), some students incorrectly subtracted the absolute values of the minuend and subtrahend, presumably because they mistakenly followed the addition rule for unlike signs. A few others added the absolute values of the minuend and subtrahend but assigned a negative sign.

In cases where the subtraction involved two positive integers, with the minuend being less than the subtrahend (e.g., $1 - 8$), a few students added the minuend and subtrahend and assigned either a positive or negative sign. Others subtracted the subtrahend from the minuend but incorrectly assigned a positive sign.

In problems involving three terms (e.g., $-9 - (-2) - 6$), the majority of students encountered difficulties stemming from challenges in subtracting two integers. In the pretest, the students' error rates in the eight categories ranged from 41% to over 60%, indicating significant difficulty across the board. The overall error percentage was 60%, which confirms that they experienced substantial challenges in integer subtraction.

In the posttest, the error rates ranged from 12% to 46%, demonstrating that the activity using the integer boggier helped students reduce their errors by 4% to 39% across the eight categories. The overall error percentage decreased to 32%, resulting in a reduction of 28%. The integer boggier proved effective in helping students minimize their errors in subtracting integers.

Table 5. Corrected errors in the subtraction of integers

Category	Pretest		Posttest		Difference (%)
	Errors	%	Errors	%	
1. 0− (−a)	25	50	23	46	4
2. −a−0	25	50	6	12	38
3. −a − (−b), |−a|> |−b|	84	56	38	25	31
4. −a− (−b), |−a|< |−b|	84	84	54	54	30
5. −a− b	68	68	29	29	39
6. a− (−b)	40	40	29	29	11
7. a− b, a < b	41	41	20	20	21
8. Three terms	79	79	41	41	38
Overall	446	60	240	32	28

c) Multiplication of integers

Table 6 compares the number and percentage of errors made by students in multiplying integers during the pretest and posttest. When multiplying negative integers with zero (e.g., (0)(−31)), some students mistakenly wrote "negative zero," showing they still struggle with the zero property of multiplication. Others incorrectly answered with a nonzero integer, such as −31. In cases where a positive integer is multiplied by a negative integer (e.g., (14)(−23)), some students made errors in their calculations, with a few adding a positive sign incorrectly. For multiplying two negative integers (e.g., (−37)(−42)), students often assign a negative sign to the product, likely due to confusion with the addition of like signs. Some also made mistakes in their multiplication. When multiplying more than two factors with mixed signs (e.g., (6)(−14)(12)), many students applied the wrong sign to the product. It was noted that if there were more positive factors, their answers tended to be positive, and vice versa for negative factors. Only a few made multiplication errors. In the pretest, the percentage of errors across fifteen categories ranged from 26% to 56%. This shows that students have difficulty determining the correct sign for the product, especially with multiple factors and different signs. The overall error rate was 39%.

In the posttest, the percentage of errors dropped by 6%, resulting in an overall error rate of 14%. This decrease demonstrates the effectiveness of the integer boggler in improving students' multiplication skills with integers.

Table 6. Corrected errors in the multiplication of integers

Category	Pretest		Posttest		Difference (%)
	Errors	%	Errors	%	
1. (0)(−a)	20	40	9	18	22
2. (−a)(o)	16	32	10	20	12
3. (a)(−b)	16	32	4	8	24
4. (−a)(b)	16	32	7	14	18
5. (−a)(−b)	13	26	4	8	18
6. (−a)(b)(c)	23	46	5	10	36
7. (a)(−b)(c)	19	38	10	20	18
8. (a)(b)(−c)	15	30	5	10	20
9. (−a)(−b)(c)	22	44	7	14	30
10. (−a)(−b)(−c)	24	48	6	12	36
11. (a)(−b)(−c)	17	34	6	12	22
12. (−a)(b)(c)(d)	24	48	4	8	40
13. (−a)(b)(−c)(d)	25	50	7	14	36
14. (−a)(−b)(c)(−d)	28	56	10	20	36
15. (−a)(−b)(−c)(−d)	13	26	10	20	6
Overall	291	39	104	14	25

d) Division of integers

Table 7 compares students' errors in dividing integers from the pretest to the posttest. Students struggled with concepts such as division by zero and zero divided by an integer. Some mistakenly answered "undefined" for 0 divided by an integer and provided incorrect answers when reversing the roles of zero and the integer. Others simply wrote the integer itself as the answer. When dividing two-digit positive integers by one-digit negative integers, some students incorrectly placed a positive sign on the quotient instead of a negative sign. Similar errors occurred with three-digit and four-digit integers.

Table 7. Corrected errors in the division of integers

Category	Pretest		Posttest		Difference (%)
	Errors	%	Errors	%	
l. 0 ÷ (a), where a≠0	42	84	33	66	18
2. a÷ 0, where a≠0	24	48	16	32	16
3. a÷ −b, where b≠0	17	34	3	6	28
4. a÷−b, where b≠0	23	46	6	12	34
5. a÷−b, where b≠0	26	52	11	22	30
6. −a ÷ −b, where b≠0	16	32	6	12	20
7. −a ÷ b, where b≠0	23	46	7	14	32
8. −a ÷ b, where b≠0	18	36	6	12	24
9. −a÷−b, where b≠0	21	42	6	12	30
10. −a ÷−b, where b≠0	25	50	5	10	40
11. −a÷ −b, where b≠0	22	44	8	16	28
12. a ÷ b, where b≠0	10	20	4	8	12
13. a÷ b, where b≠0	12	24	6	12	12
14. a÷ b, where b≠0	22	44	9	18	26
15. 0 ÷0	25	50	8	16	34
Overall	326	43	134	18	25

2) The level of improvement caused

To empirically investigate the impact of the educational game Integer Boggler on students' performance in integer operations, a t-test for correlated samples was conducted at a significant level of 0.05. Boxplots were generated for both the pre-test and post-test scores to confirm the absence of outliers. Furthermore, the Shapiro-Wilk test of normality was applied to the differences in scores for each operation, indicating that the distributions are approximately normal, as all p-values exceeded the 0.05 (SW = 2.234) significance threshold. Consequently, employing a t-test for correlated samples is justified, as the necessary assumptions for the test were satisfied. The findings, which are summarized in Table 8, reveal the following results:

In the addition operation, the mean score of students increased from 7.12 to 11.52. The null hypothesis, which posited no difference in students' scores before and after the intervention, was rejected based on the computed t-value of 9.880, which exceeded the critical t-value of 2.012. This indicates a statistically significant improvement in students' performance in integer addition following gameplay with Integer Boggler.

For subtraction, there was also a notable increase in the mean score, from 6.02 to 9.20. The null hypothesis was rejected again, as the computed t-value of 7.916 surpassed the critical t-value of 2.012. These results suggest that the t-test successfully distinguished between the pretest and post-test scores, with the post-test exhibiting a higher mean. This finding indicates a significant enhancement in students' performance in integer subtraction as a result of engaging with Integer Boggler.

In the multiplication operation, the mean score showed an increase from 9.52 to 12.28, corresponding to a significant difference of 2.76 between the pretest and post-test means. The null hypothesis was similarly rejected, with a computed t-value of 6.079 exceeding the critical t-value of 2.012. This outcome demonstrates a significant improvement in students' performance in integer multiplication after participating in Integer Boggler.

With respect to division, students' mean scores rose from 8.64 to 11.98. The null hypothesis was rejected due to a computed t-value of 7.52, which also exceeded the critical t-value of 2.012. The t-test results confirmed a significant distinction between pretest and post-test scores, favoring the post-test with a higher mean score. Consequently, this indicates that students' performance in integer division significantly improved following their engagement with Integer Boggler.

Finally, the analysis of combined scores revealed a substantial difference of 13.68 between the pretest and post-test means, with overall mean scores increasing from 31.30 to 44.98. The null hypothesis was rejected once more, as the computed t-value of 12.920 was greater than the critical t-value of 2.012. These results collectively indicate that the t-test significantly differentiated the pretest and post-test means, similarly favoring the post-test with a higher average score. Thus, it can be concluded that students' performance across the four operations involving integers significantly improved after their participation in Integer Boggler.

Table 8. T-test dependent results for level of improvement

Operation	Mean Score		*MD	t
	Pretest	Posttest		
Addition	7.12	11.52	4.4	9.88
Subtraction	6.02	9.2	3.18	7.916
Multiplication	9.52	12.28	2.76	6.079
Division	8.64	11.98	3.34	7.52
Overall	31.3	44.98	13.68	12.92

*Mean Difference

3) Retention

One of the key indicators for evaluating the effectiveness of the integer boggler is the retention of students' skills in addition, subtraction, multiplication, and division of integers. To measure this retention, the researcher compared the students' scores from the post-test and the delayed post-test. To ensure accurate measurements, no interventions were conducted by either the researcher or the students' teachers related to the topics assessed during the two-week interval between the post-test and the delayed post-test. The students continued their regular routines, and the researcher returned precisely two weeks later. The post-test and delayed post-test scores were analyzed using a t-test for correlated samples at a 0.05 level of significance to determine the differences between the means of correlated samples. As part of the assumption check before conducting the t-test for correlated samples (or dependent samples), the data sets were examined for outliers using a boxplot. Additionally, the Shapiro-Wilk test for normality revealed that the distribution of the differences between the posttest and delayed posttest scores was approximately normal (SW = 3.273, p > 0.05). The results are summarized in Table 9.

In addition, when involving integers, a notable improvement was observed in students' mean scores, which rose from 11.52 to 12.42. The analysis revealed a computed t-value of 4.277, which significantly exceeded the critical t-value of 2.012. This compelling result led to the rejection of the null hypothesis, which proposed no meaningful difference existed between the post-test and delayed post-test scores. The findings strongly indicated that the t-test effectively distinguished the outcomes, favoring the delayed post-test with a higher mean score. This demonstrates that students' proficiency in adding integers improved immediately following engagement with the Integer Boggler game and persisted two weeks later.

In the case of subtraction, students also experienced a significant enhancement in their mean scores, climbing from 9.2 to 9.78. This upward shift resulted in the rejection of the null hypothesis, with the computed t-value of 2.497 surpassing the critical t-value of 2.012, indicating a substantial improvement in students' abilities.

However, a different narrative emerged from the analysis of multiplication scores, as documented in Table 9. Here, only a modest difference of 0.36 was noted between the means of the posttest and delayed posttest, with scores rising from 12.28 to 12.64. Despite this increase, the null hypothesis was retained because the computed t-value of 1.142 was below the critical t-value of 2.012. This suggests that, while students retained the knowledge acquired through the Integer Boggler game, their performance in multiplying integers did not reflect a significant change two weeks post-intervention.

On the other hand, in the division of integers, students demonstrated a commendable improvement, with mean scores escalating from 11.98 to 12.78. The null hypothesis was once again rejected, as the computed t-value of 3.585 comfortably surpassed the critical t-value of 2.012. This analysis revealed a significant disparity between the posttest and delayed posttest scores, affirming that the delayed posttest achieved a higher mean score. Students' skills in dividing integers showed notable advancement even two weeks after their engagement with the Integer Boggler game.

Finally, when considering the overall performance, students' mean scores rose remarkably from 44.98 to 47.62. With a computed t-value of 4.188 exceeding the critical t-value of 2.012, the null hypothesis was again discarded. This conclusive evidence confirmed that the t-test successfully differentiated between the post-test and delayed post-test scores, where the post-test consistently exhibited a superior mean score. Overall, these findings highlight a substantial enhancement in students' performance across all four operations with integers, demonstrating significant progress two weeks after their involvement with the Integer Boggler game.

Table 9. T-test dependent results for retention

Operation	Mean Score		*MD	t
	Posttest	Delayed		
Addition	11.52	12.42	0.90	4.277
Subtraction	9.20	9.78	0.58	2.497
Multiplication	12.28	12.64	0.36	1.142
Division	11.98	12.78	0.80	3.585
Overall	44.98	47.62	2.64	4.188

*Mean Difference

4) Performance of average and below-average students

In the actual experiment, all participants received the same treatment and intervention, ensuring that the conditions were uniform across the board. However, prior to the start of the experiment, the researchers carefully categorized participants into two distinct groups: those classified as average and those identified as below average, based on their scores from a pretest. This categorization process involved the use of z-scores, which allowed for a standardized and objective classification of participants based on their initial performance metrics.

A critical element of the study involved comparing the performance outcomes of students in both groups after they had experienced the integer boggler game. This comparison was fundamental to understanding the differential impact of the game on each group. By analyzing how well students from both classifications performed, the researchers aimed to identify which group derived greater benefits from the game experience. The results of this analysis provided valuable insights into the game's effectiveness, particularly in relation to the participants' initial performance levels and how those levels influenced their learning and engagement with the game.

To analyze the data, a t-test for independent samples was employed, which is a statistical method used to assess whether there are significant differences between the means of the two groups. Prior to conducting the t-test, necessary assumption verifications were performed. These checks included the use of boxplots to visually assess the distribution of scores and the Shapiro-Wilk normality test to statistically determine if the distributions were normal. The findings of this analysis are summarized in Table 10, which illustrates that the scores for both groups adhered to a normal distribution, as indicated by Shapiro-Wilk p-values exceeding the 0.05 significance threshold.

Table 10. T-test independent results for average and below-average students

Operation	Mean Gain Score		MD*	t
	Average	Below Ave.		
Addition	4.84	3.96	0.88	0.988
Subtraction	3.28	3.08	0.20	0.247
Multiplication	1.36	4.16	2.80	−3.399
Division	1.84	4.84	3.00	−3.817
Overall	7.56	12.28	4.72	−2.395

*Mean Difference

When examining the addition of integers, the computed t-value was 0.988. At a 95% confidence level, this t-value is deemed insignificant, suggesting that there was no noteworthy difference between the performance of the average and below-average groups. This result implies that both groups experienced a comparable level of improvement following the intervention. Notably, a slight mean difference of 0.88 was observed, which favored the average group, indicating a marginal advantage in performance improvement.

In the context of subtraction, the computed t-value was 0.247, also falling under the category of insignificance at the 95% confidence interval. This finding reinforces the notion that both groups demonstrated similar improvement levels in their ability to subtract integers after participating in the integer boggler activity.

Conversely, when addressing multiplication, the computed t-value was −3.399, which achieved significance at the 95% confidence interval. This statistically significant result indicates a clear divergence between the two groups, revealing that the below-average group experienced a more substantial improvement compared to the average group. The mean difference in this context was 2.80, clearly favoring the below-average group, thus suggesting that the integer boggler was particularly effective for these students in enhancing their multiplication skills.

Similarly, the analysis of division yielded a computed t-value of −3.817, which was also significant at the 95% confidence level. This finding aligned with the results from multiplication, reinforcing that the below-average group gained more from the integer boggler intervention compared to their average counterparts. The marked mean difference observed in the division was 3.00, further illustrating the effectiveness of the game in assisting below-average students with their division skills.

Finally, an overall assessment of the differences between the average and below-average groups yielded a computed t-value of −2.395, which was significant at the 95% confidence interval. This result provides compelling evidence that the two groups indeed differed substantially in their levels of improvement. The negative t-value indicates that the below-average group's progress exceeded that of the average group, with an overall mean difference of 4.72 in favor of the below-average group. These findings strongly suggest that the integer boggler is particularly beneficial for students with below-average performance across all four operations involving integers, emphasizing its role as an effective educational tool in enhancing mathematical skills for struggling learners [28].

IV. Conclusion and Recommendations

Following an in-depth analysis and careful evaluation of the study's findings, several significant conclusions emerged about the impactful role of game-based learning in mathematics education. These conclusions highlight the transformative potential of integrating games into the learning process, demonstrating how such approaches can enhance student engagement, improve retention of mathematical concepts, and foster a more interactive and enjoyable learning environment.

The user-friendly design and affordability of materials associated with the game render it highly accessible. This accessibility ensures that educators and institutions, regardless of available resources, can implement game-based learning without encountering significant financial or logistical obstacles. Furthermore, the straightforward nature of the game's rules and procedures facilitates its widespread adoption by minimizing the learning curve for both instructors and learners [28].

The design of the game incorporates clear, achievable, and challenging objectives, thus fostering an engaging and motivating learning environment. This characteristic is particularly significant in the context of mathematics education, where student motivation often presents a substantial challenge. By providing a relevant and enjoyable learning experience, the game effectively sustains students' interest and enthusiasm for acquiring mathematical concepts [28].

Empirical findings from the study underscore the game's effectiveness in enhancing students' operational skills with integers. This evidence suggests that game-based learning can serve as a powerful pedagogical tool for addressing specific mathematical difficulties. The provision of immediate feedback and opportunities for practice within a low-stakes environment enables students to rectify errors and cultivate confidence in their abilities.

Additionally, the observed improvement in delayed post-test scores indicates that the game not only facilitates learning but also enhances knowledge retention. This retention is a critical component of effective educational practices, as it ensures that students are capable of recalling and applying learned content over time. The game's capacity to reinforce learning through repeated practice and engagement may lead to long-term mastery of mathematical operations.

The study indicates that the game's impact varies according to individual learners' weaknesses and needs, highlighting its potential for personalized learning. Educators can customize the game to meet the specific challenges of individual students, rendering it a versatile instrument in diverse classroom settings. This personalized approach contributes to ensuring that all students, regardless of their initial proficiency, can benefit from game-based learning.

In conclusion, the study emphasizes the transformative potential of game-based learning in mathematics education. By enhancing accessibility, engagement, and efficacy, games can play a pivotal role in assisting students in overcoming difficulties with mathematical concepts and operations. As educators continue to explore and refine game-based learning strategies, they can utilize these insights to improve their pedagogical practices and ultimately enhance student outcomes [29].

Although the study's results are compelling and backed by empirical evidence, there are several potential limitations that may undermine the validity of its findings. The limited sample size, alongside the specific grade levels involved, restricts the generalizability of the results, thereby diminishing their applicability to the broader student population. Moreover, the one-shot experimental design employed in the study, which lacks a comparison to alternative treatments or control groups, complicates determining whether the observed improvements are attributable to the intervention or other extraneous factors. Various external variables, such as student motivation and parental support, could have influenced the study's outcomes. These factors significantly affect students' performance and the game's effectiveness [29].

Consequently, future research should include larger sample sizes, employ more rigorous experimental designs, and control for external variables to yield a more nuanced and comprehensive understanding of the impact of "Integer Boggler" on enhancing skills in integer operations. Cohen's d can also be considered, as it quantifies the magnitude of the difference between groups. This helps determine whether the observed effects are practically significant, especially when considering the sample size.

Based on these findings, a series of recommendations have been formulated. Elementary and high school math educators may consider integrating the game as a resource to support students who struggle with integer operations, while also providing a challenge for those performing at an average level. This game offers an excellent opportunity for students to improve their skills and deepen their understanding of addition, subtraction, multiplication, and division involving integers.

Moreover, school administrators might explore the inclusion of similar games in academic competitions and annual events to foster student participation and engagement in these enriching activities. Authors and publishers of math textbooks for elementary and high school levels should contemplate incorporating games for both remediation and enrichment in each lesson, creating a more enjoyable learning environment.

Mobile game developers have the opportunity to create an innovative program that enhances accessibility for smartphone users, ensuring that a wider audience can enjoy the game without the need for specialized equipment. This program would facilitate online engagement, allowing players to connect and participate in the game from the comfort of their own homes, regardless of their geographical locations. By eliminating the requirement for physical presence, this initiative not only fosters an environment conducive to distance learning but also significantly boosts the game's versatility and inclusivity, making it a welcoming space for all players.

Future research could investigate the potential effects of the game's design on other mathematical topics, such as the four fundamental operations, by using algebraic expressions instead of integers. This could yield valuable insights into the game's impact on broader mathematical concepts. Expanding the game to encompass subjects like fractions, decimals, and algebraic equations could further increase its educational value, offering a comprehensive resource for mathematics education. By exploring these avenues, educators and developers can continue to innovate and refine game-based learning strategies, ensuring they cater to the diverse needs of students.

Conflict of Interest

The author declares no conflict of interest.

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