Sudoku-Based Educational Games for Developing STEM Skills

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Abstract: This paper presents the design and implementation of Sudoku-based educational games aimed at developing learners' mathematical and STEM-related skills, including computational thinking. The games incorporate traditional Sudoku puzzles enhanced with interactive elements and are tailored to various age groups and skill levels. The study applied a quantitative survey method involving participants from primary and secondary schools (sample sizes ranging from 17 to 43), who engaged in four distinct learning scenarios. Feedback collected via Likert-scale surveys assessed students' motivation, engagement, and perceived educational value. Preliminary studies showed that described Sudoku-based activities are well-received among students and teachers and have the potential to enhance students' motivation and engagement. This innovative approach highlights the potential of game-based learning to promote mathematical literacy, scientific literacy, development of computational thinking and bridges the gap between entertainment and education.

Keywords: Educational game, Game-Based learning, Computational thinking, Mathematics, Sudoku

1. Introduction

Games have been used as a learning tool since ancient times (Vankúš, 2005), and their integration into formal education is still of great importance today. Game-based learning utilises the natural motivation, engagement and sense of competition that comes from play to support the achievement of educational objectives. Numerous studies have emphasised the positive impact of this approach on learning outcomes (Vankúš, 2021). There are numerous implementations of game-based learning in mathematics and STEM (Deeb and Hickey 2019; Mikulić Crnković, Traunkar and Crnković, 2022; Erşen & Ergül, 2021; Moon et al., 2024). The use of games in mathematics is particularly important because it addresses a problem of mathematical anxiety. Many students find math intimidating or boring and games make it fun and reduce stress. Statistically significant reduction in math anxiety following game-based interventions was reported in (Dondio et al., 2023) where non-digital games were more effective than digital ones. Due to the positive effects on motivation, understanding and retention of concepts, there are many attempts to use game-based techniques in teaching mathematics (Vankúš, 2005; Vankúš, 2021; Divjak & Tomić, 2011).

This paper presents the design and implementation of Sudoku-based educational games aimed at improving STEM skills. While the traditional Sudoku has already been used in the classroom (Balakrishnan, 2015; Adaramaja & Ogunniyi, 2022), this study contributes to the field of game-based learning by transforming the classic Sudoku into an engaging learning tool. By incorporating dynamic, interactive and multiplayer elements, the redesigned game builds on the familiar benefits of traditional Sudoku and offers a more immersive experience. This approach not only makes mathematics more enjoyable for students but also supports the achievement of the key learning outcomes of the curriculum. Furthermore, in accordance with suggestions of (Dondio et al., 2023) the game incorporates social interaction and adaptability to better support math-anxious students.

2. Background

2.1 Computational Thinking and Mathematics

The foundations of computational thinking are laid in preschool, where children participate in activities that build essential pre-mathematical skills (Botički, Pivalica and Seow, 2018). These include sorting and comparing objects, arranging objects in a specific order, following multi-step instructions, recognising patterns, navigating spatial relationships, and visually grouping or evaluating objects. As children progress into formal schooling, these foundational skills should be further developed through increasingly complex tasks. Computational and analytical thinking is about breaking down complex problems into smaller, more manageable pieces and developing step-by-step strategies — or algorithms — to solve them. This includes skills such as abstraction, decomposition, algorithmic thinking, evaluation and generalisation (Shute, Sun and Asebell-Clarke, 2017). One of the ways to develop computational thinking and mathematical skills is by solving mathematical puzzles such as Tangram, Sudoku, Pentomino and many others.

Sudoku is a logic-based mathematical puzzle in which players have to fill a grid with numbers according to certain rules. Sudoku is a typical example of a recreational mathematics puzzle, but the game is also used in the classroom because it achieves multiple educational goals and promotes a range of cognitive benefits while being engaging and adaptable to different ability levels. It helps students develop strategies and test hypotheses, which is crucial for the development of computational thinking. It also requires minimal resources and no specialised training to implement. For all these reasons and advantages, Sudoku is used as an educational game in the classroom (Norte and Lobo, 2008; Balakrishnan, 2015; Adaramaja, et al., 2011). There are also examples of Sudoku inspired games (Urek, H., 2020; García-Ortega at al. 2025) which are used in classrooms to teach SI prefixes and chemistry. These games have the same gameplay as Sudoku, except that the numbers are replaced by words. The results show that students' comprehension, retention and engagement have improved. As far as we know, there are no examples of Sudoku-based educational games that change the gameplay of Sudoku.

2.2 Sudoku-Based Educational Games

2.2.1 Preliminary results and motivation

The scenarios described in this paper were created as an extension of the activities described by Holenko Dlab et al. (2024). Changes to the scenarios as well as new games and new scenarios were made based on the follow-up analysis described in (Holenko Dlab M. at al., 2024). The paper (Holenko Dlab M. at al., 2024) describes the activities carried out as part of the Pi-Day celebrations through extracurricular activities. Among others, the following activities were carried out: Assemble and Play Sudoku (in different grid sizes).

Total of 95 1st and 2nd graders played Assemble and Play Sudoku in a 4x4 grid on Pi-Day (the tasks were simple mathematical arithmetic problems). In addition to this game, the students also played the Race of Disobedient Robots game and evaluated both activities together. Here are their ratings: *I liked the games.* (AVG: 2.82; SD: 0.48); *It was fun for me*. (AVG: 2.74; SD: 0.58); *I want to play such games again.* (AVG: 2.68; SD: 0.68). Considering the popularity of highly rated games, game-based learning activities were designed based on proven, engaging activities that align with specific curriculum topics.

During Pi-Day, 64 7th grade students played *Assemble and Play Sudoku* in a 9x9 grid (vector problems). In addition to this game, they also played *Mathematics in other words*. The students rated the game *Assemble and Play Sudoku* with an average score of 2.44 (SD: 1.18). In addition, the students completed an evaluation in which they expressed their opinion on both games together. The following two statements and the corresponding student responses were of particular interest: *I believe that by playing such games, I can learn something new*. (AVG: 3.61; SD: 1.14); *Activities like this motivate me to learn mathematics and computer science*. (AVG: 2.88; SD: 1.14). As vectors are a fundamental and demanding concept in mathematics, it is necessary to rethink the way vectors are taught and to develop new innovative activities for this purpose. With this in mind, the activity carried out on Pi-Day was adapted for implementation in the classroom when teaching vectors. A total of 85 5th grade students played the game *Assemble and Play Sudoku* in a 6x6 grid on Pi-Day (simple, age-appropriate math problems). In addition to this game, students also played some commercial games (SET, Spot It, Tantrix). Students rated the game *Assemble and Play Sudoku* with an average score of 3.35 (SD: 1.55), while the commercial games were rated with an average score of 3.43 (SD: 1.55). Students also completed a rating and provided the following responses: *I believe that by playing such games, I can learn something new.* (AVG: 3.45; SD: 1.28); *Activities like this motivate me to learn mathematics and computer science.* (AVG: 2.81; SD: 1.33). From these ratings, it was concluded that the game had potential (as the rating was very similar to that of commercial games) and development of new games and scenarios was started. A new game, *Turtle Plays Sudoku*, was designed, with more attention paid to the rules and gameplay. The newly designed scenarios were also used to test how well-designed tasks affect students' attitudes. Interesting tasks from the Kangaroo without borders competition, an international maths competition to promote problem-solving skills, and the Beaver competition, a global competition for computational thinking to promote logical thinking, were therefore included in the activities.

2.2.2 Assemble and Play Sudoku

Assemble and Play Sudoku is a simple game based on the well-known Sudoku puzzle. The game consists of two phases. In the first phase, tasks must be solved to determine the initial positions and values in the Sudoku table. Figure 1 shows wooden 9x9 Sudoku table designed for *Assemble and Play Sudoku game*.

The second phase can be realised in two ways: the Sudoku table is filled in according to the Sudoku rules (version 1) or the player chooses whether to fill in the table according to the Sudoku rules or to solve additional tasks that reveal new positions and new values in the table (version 2).

The game can be prepared with cards/tasks for different topics and can be integrated into the educational process in different ways through learning scenarios.

Figure 1: Assemble and Play Sudoku wooden table

2.2.3 Turtle Sudoku

Turtle Sudoku is a board game based on Sudoku that is played by 3 players (or 3 groups of players). It is a game in which each player receives a pencil in their own colour: red, green and blue. Each player receives a figurine, and three task sets (red, green and blue set). In addition, a shared empty 6x6 Sudoku table with three marked arrows (red, green and blue arrow) is placed so that all three players can reach it. Each colour task is divided into two parts: the first part describes the movement of the figure through the Sudoku table, where starting position is indicated with an arrow, and the second part contains tasks whose solutions are numbers between 1 and 6.

The game is divided into three phases, as follows. In the first phase, each player solves the task of their colour such that the first phase is over when one player solves all their tasks. Each player enters their solutions in the shared Sudoku table, outlining the number with their own colour. Phase two consists of each player solving the other players' problems, with each player having the opportunity to correct (or complete) the other players. Phase two is time limited.

After the second phase, each player writes the numbers in the common table in the following way: the number is written with the player's colour and the outline is marked with the colour of the task, i.e. if the red player corrects the blue player, he writes the number with the red pencil and outlines it with the blue pencil, if the outline is not already marked.

Before the third phase, each player receives the following points: 2 points for solving your own tasks correctly (i.e. for each correct number written in the correct place and outlined with the same colour as the number) and 3 points for correcting another player's task (i.e. for each correct number written in the correct place and outlined with a different colour than the number written).

In the third phase, the players complete the Sudoku according to the usual Sudoku rules by writing the numbers in the common table in their own colour. At the end, each correct number in phase 3 is awarded one point. The player with the most points is the winner of the game.

2.3 Learning Scenarios

2.3.1 Orient yourself in Sudoku

The learning scenario is based on the game *Assemble and Play Sudoku* (4x4 grid) and is intended for students at the very beginning of elementary education (in Croatia, this is the first grade of elementary school). In addition to developing computational thinking and pre-mathematical skills, this scenario achieves outcomes in the area of spatial orientation, which forms the basis of many STEM disciplines. The tasks are designed so that you have to move the figure in the given order (up, down, left, right) and "walk" through the Sudoku table, with the starting position marked with an arrow.

The activity is divided into two parts: an introductory activity where students are familiarised with the rules of the game *Assemble and Play Sudoku* (version 1) and the movements in the Sudoku table, and the second activity has been developed as an activity for pairs, so that each student gets his/her own cards and when playing the game *Assemble and Play Sudoku* each pair solves the same Sudoku, i.e. the initial values in the Sudoku table are shared between two players. Each player receives 2 points for the correct number in the correct position in phase 1 (i.e. 2 points for correctly solving the respective task) and 1 point for each correct number in the Sudoku table in phase 2 of the game (i.e. for each correct number when solving the Sudoku puzzle). The two players compete against each other and try to collect as many points as possible.

During the 45-minute lesson in three classes at the Elementary School Fran Franković, Rijeka, Croatia, the introductory part of the activity was completed by having each student "walk" through the Sudoku table, following the given instructions and solving all the tasks to obtain the starting numbers in the Sudoku table. Afterward, all students completed the Sudoku puzzle.

If the students are familiar with the rules of the game *Assemble and play Sudoku*, the introductory activity can be skipped or shortened. All the cards prepared for this activity can be found in (SciMaG: Assemble and Play Sudoku (2025)). Some of the cards are shown in Figure 2.

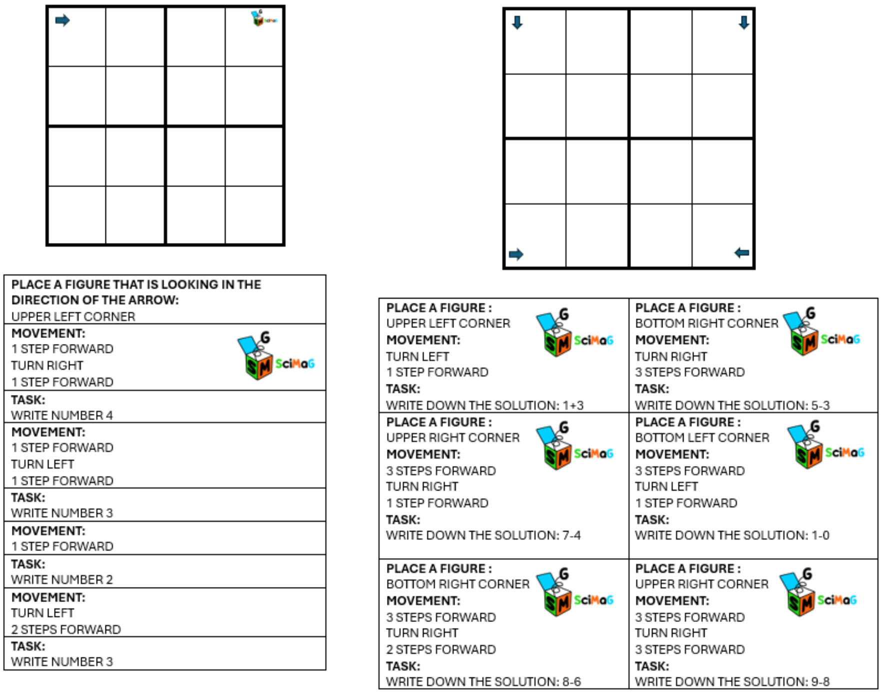

Figure 2: Orient yourself in Sudoku (introductory part and cards for second activity)

2.3.2 Kangaroo plays Sudoku

This scenario is also based on the *Assemble and Play sudoku* game (version 2, 9x9 grid) with the aim of preparing students for the Kangaroo without Borders competition in supplementary mathematics classes (grades 3 and 4; grades 5 and 6).

The activity can be used both in regular mathematics classes and in extracurricular activities, as the tasks develop computational thinking and problem-solving skills.

This activity was conducted at Elementary School Sveti Matej Viškovo (grades 3 and 4; grades 5 and 6), Croatia, in the following way. Pupils were divided into groups, and all groups solved the same task. The tasks were divided into two envelopes: one for the initial set and one for each subsequent position in the Sudoku table. In the first part, the teacher drew a problem from the envelope, and each group solved the same problem. The first group to solve the problem correctly wrote down the number in the Sudoku table in their own colour. The student who solved the problem then explained the solution to the entire classroom.

2.3.3 Sudoku in the coordinate system

Another learning scenario based on the game *Assemble and Play Sudoku* (version 1, 9x9 grid). The aim of this scenario is to visualise vectors in a coordinate system and to repeat the procedures related to calculating with vectors.

The students are divided into five groups. Each group receives an envelope with 7-8 problems. The Sudoku grid is provided with coordinate positions, so that the bottom row is marked *(0,0)*, *(1,0)*, ..., *(8,0)* and the top right field is marked *(8,8)* (i.e. the Sudoku table is arranged in the coordinate system). To solve the task, the student must visualise the given vector in the coordinate system and select its representative based on the given starting point, for example. An example of the task is: "*Let A(3,2), B(1,0), C(3,5). Find the point D so that the vectors AB and DC are equal. Write the number 6 in the field marked with the positions of point D.*" Each student receives a blank Sudoku table to help them visualize the vectors and solve the problem. All the tasks used in this activity can be found in SciMaG: Assemble and Play Sudoku (2025).

After they have solved all the problems, one student from each group writes the solutions in the Sudoku table on the board, each group with its own colour. Each group receives 2 points per correct number in their colour. If one of the groups solves their own problems while other groups are struggling with the problems, the students help each other. After evaluating the initial values in the Sudoku table, each group chooses a representative to solve the Sudoku puzzle on the board (by writing the numbers in the group colour), competing with representatives from four other groups. In phase 2, one point is awarded for each correctly written number. At the end, the points from phases 1 and 2 are added together and the group with the most points is declared the winner.

2.3.4 Turtle and Beaver Playing Sudoku

This scenario is based on the game Turtle Sudoku and is designed for preparation for the Beaver competition (grades 3 and 4) and activities that develop computational thinking in regular and extracurricular activities.

This activity is carried out by dividing the students into three groups and each phase of the game is limited in time: phases 1 and 2 are limited to 15 minutes and phase 3 to 10 minutes. Each set of tasks consists of 6 tasks from previous years of the Beaver competition, with the orientation steps written in the syntax of the FMSLogo programming language.

3. Methodology

The aim of this study is to assess the motivation, engagement and perceived learning benefits of Sudoku-based educational games for different age groups and to identify key factors for their implementation in the classroom.

The study applied a quantitative research approach by using a survey to gather feedback from participants about their experiences with the Sudoku-based educational games. This method was chosen to gain insights into how the activities were perceived in terms of their educational value and appeal, and to enable comparison with findings from previous experiments. The primary research question guiding the investigation was whether students perceived the Sudoku-based activities as motivating, beneficial to learning, and recommendable.

3.1 Procedure and Participants

The study involved participants from primary and secondary schools in Croatia who took part in the implementation of four different Sudoku-based learning scenarios. The implementation of each learning scenario was carried out during regular or supplementary mathematics classes in schools or during school fieldwork at the Faculty of Mathematics. Students first participated in the Sudoku-based activities, which were facilitated by researchers and their classroom or mathematics teachers following the scenario.

In the first scenario, *Orient yourself in Sudoku*, first graders from Elementary School Fran Franković participated (N=43). In the second scenario, *Kangaroo plays Sudoku*, fourth, fifth and sixth grade students from Elementary school Sv. Matej Viškovo participated (N=17). The third scenario, *Sudoku in the coordinate system*, was conducted in two rounds: seventh grade students from Elementary School Trsat (N=22) and seventh grade students from Elementary School Čavle (N=17). The fourth scenario, *Turtle and Beaver Playing Sudoku*, was conducted in three rounds in the elementary school and one round in the secondary school. The participants were fifth graders from Elementary School Čavle (N=24), fifth graders from Elementary School Jurja Dobrile – Scuola elementare "Juraj Dobrila" Rovinj (N=18), fifth and sixth graders from Elementary School Vladimir Nazor Pazin (N=19) and high school students from Grammar School Andrija Mohorovičić Rijeka (GAM) (N=26).

3.2 Instrument and Data Collection

The survey used in this study consisted of 10 statements (Table 2) aimed at capturing different dimensions of students' experiences with the Sudoku-based educational activities. For the participants in Scenario 1, only three statements were used due to their age (Table 1).

Responses were collected using a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Each item examined a specific aspect of the learning experience, including interest and enjoyment of participation, clarity of instructions, perceived educational value, motivation for learning mathematics and computer science, willingness to participate in similar activities and recommend them to others, and perception of integration of such activities into regular classes. Additionally, students were asked to rate the activity on a separate 5-star scale.

Data was collected either via Microsoft Forms, which facilitated digital submission and processing, or via paper surveys when required.

To assess the attitudes of first graders (participants of scenario 1), a simplified three-point scale featuring illustrated faces was used. Students were asked to circle the face that best represented their feelings about each statement (Figure 3).

Figure 3: Scale with drawn faces used in survey for younger students

The collected data was then processed and analysed using descriptive statistics. This allowed comparisons to be made between implementation rounds when multiple rounds were conducted.

4. Results

The results for the first learning scenario, *Orient yourself in Sudoku*, are shown in Table 1. This scenario involved first grade students (N=43) and focused on assessing their general attitude towards participating in the game-based learning activity. The overall results indicate a positive reception of the activity. The highest mean score was for fun (M=2.9, SD=0.37), closely followed by students liking the game (M=2.88, SD=0.44). The results also indicate that students showed a generally positive inclination toward future participation (M=2.77, SD=0.56).

Table 1: Attitudes towards participation in the GBL activity based on scenario 1

Statements - Scenario 1 (N=43)	M	SD
I liked the game.	2.8	0.44
It was fun for me.	2.9	0.37
I want to play such games again.	2.77	0.56

The results for the second learning scenario, *Kangaroo plays Sudoku*, are shown in Table 2. In this scenario, participants (N=17) evaluated their experience of the game-based learning activity using a wider range of statements. The overall results show that the activity was very positively received. High mean scores were achieved for the fun and engagement statements, with the highest scores ranging from M=4.59 (SD=0.77) to M=4.76 (SD=0.55). Participants also rated the clarity of instructions highly (M=4.59, SD=0.84) and gave strong ratings for perceived educational value (M=4.35, SD=0.84). The motivational impact on learning mathematics and computer science was slightly lower, but still positive (M=4.00, SD=0.91). The overall rating of the game was also high (M=4.59, SD=0.60). However, a lower mean score was found for the presence of such activities in the regular curriculum (M=3.47, SD=1.38).

The third learning scenario, *Sudoku in the coordinate system*, was carried out in two rounds with two different groups of students. The overall results show that the scenario was positively received in both rounds, with students in round 2 generally rating all statements higher than students in round 1. In round 1, mean scores ranged from 2.73 to 3.86, while in round 2 they ranged from 3.06 to 4.50. There were significant improvements in the statements about the clarity of instructions and the perceived learning value. For example, the statement on clarity increased from an average of 3.53 (SD=1.09) in round 1 to 4.50 (SD=0.61) in round 2. The overall perception of learning benefit and enjoyment also improved in the second round. Further positive changes were observed in other statements, such as motivation to learn and willingness to recommend the activity. The overall rating of the game rose from 3.73 to 4.24, with lower standard deviations in round 2 indicating a more consistent positive experience.

The results for the fourth learning scenario, *Turtle and Beaver Playing Sudoku*, are shown in Table 3. This scenario was conducted in three rounds with different groups of students. The overall results show that the activity was positively received in all three rounds, with noticeable improvements between rounds. In round 1, mean scores ranged from 2.54 to 4.13, while in round 2 they ranged from 3.33 to 4.18, and in round 3 from 3.53 to 4.53, reflecting a clear upward trend. Over the rounds, mean scores for enjoyment and interest consistently increased. The clarity of instructions fluctuated, but improved significantly in round 3. The perceived educational value remained high across all rounds. Motivation to learn mathematics and computer science improved significantly from round 1 to round 2 and remained stable in round 3. Willingness to participate in similar activities and recommend them to others also increased. Game rating increased from 3.50 in round 1 to 4.37 in round 3. The relatively higher standard deviations in round 1 indicate more varied responses initially, while later rounds show more uniform positive experiences.

Table 2: Attitudes towards participation in the GBL activity based on Scenario 2 and Scenario 3

	Scenario 2 (N=17)		Scenario 3 R1 (N=22)		Scenario 3 R2 (N=17)	
Statements	M	SD	M	SD	M	SD
I found the game interesting.	4.59	0.77	3.50	0.94	3.88	0.58
I felt good while participating.	4.71	0.57	3.55	1.03	4.18	0.86
I had fun.	4.76	0.55	3.45	1.12	3.88	0.76
The rules of the game were clearly explained to me.	4.59	0.84	3.53	1.09	4.50	0.61
I believe that by playing such games, I can learn something new.	4.35	0.84	3.86	1.06	4.35	0.76
Activities like this motivate me to learn mathematics and computer science.	4.00	0.91	2.73	1.32	3.06	0.87
I would like to participate in similar activities in the future.	4.71	0.46	3.73	1.29	3.59	0.77
I would recommend participation in similar events to other students.	4.71	0.57	3.55	1.12	4.00	0.84
Such games are not sufficiently represented in regular teaching.	3.47	1.38	3.82	0.9	4.24	0.81
Game rating	4.59	0.60	3.73	1.14	4.24	0.81

Additionally, the same scenario was implemented with secondary school students from GAM (N=26). Results showed exceptionally high scores for all statements, with mean scores ranging from 3.92 to 4.77. The highest scores were for overall enjoyment and satisfaction (M=4.77, SD=0.42–0.50). Clarity of instructions and perceived educational value were also rated highly. Compared to elementary students, secondary students gave consistently higher ratings in all dimensions, especially for enjoyment, motivation, and willingness to recommend.

Table 3: Attitudes towards participation in the GBL activity based on Scenario 4

	Scenario 4 R1 (N=24)		Scenario 4 R2 (N=18)		Scenario 4 R3 (N=19)		Scenario 4 GAM (N=26)	
Statements	AVG	SD	AVG	SD	AVG	SD	AVG	SD
I found the game interesting.	3.3	1.2	4.06	0.7	4.3	0.5	4.7	0.5
I felt good while participating.	3.6	1.2	3.72	0.7	4.0	0.9	4.5	0.6
I had fun.	3.2	1.4	4.06	0.6	4.2	1.1	4.5	0.5
The rules of the game were clearly explained to me.	3.7	0.9	3.33	1.1	4.5	0.6	4.3	0.6
I believe that by playing such games, I can learn something new.	4.1	1.0	4.18	1.0	3.8	0.9	4.3	0.7
Activities like this motivate me to learn mathematics and computer science.	2.5	1.2	3.72	1.1	3.5	1.0	3.9	1.0
I would like to participate in similar activities in the future.	3.0	1.2	3.56	1.1	4.1	0.9	4.4	0.7
I would recommend participation in similar events to other students.	3.5	0.9	3.83	0.8	4.0	1.0	4.5	0.6
Such games are not sufficiently represented in regular teaching.	3.7	1.1	3.89	0.8	3.6	1.3	4.5	0.6
Game rating	3.5	1.1	3.94	0.9	4.3	0.9	4.7	0.4

5. Discussion

The results demonstrate the positive reception and motivational impact of Sudoku-based learning scenarios and suggest that game-based activities can be perceived as entertaining and engaging at an early stage of education and form an important basis for fostering motivation for STEM learning at later stages.

The high scores for fun, engagement, clarity of instructions and educational value indicate that the game-based learning activities were well received across all scenarios and age groups. The improvements observed in repeated rounds of the scenarios, such as clearer explanations and more refined sequences of activities, support the idea that fine-tuning game-based activities can increase their effectiveness. The increasing willingness of students to participate in similar activities and recommend them to others indicates a growing acceptance and enthusiasm for such learning approaches.

The relatively lower score for the presence of game-based activities in the regular curriculum highlights a gap between the potential benefits of these activities and their current integration into the formal teaching. The results also suggest that secondary school students may be better able to recognise the educational aspects of the activity and engage more intensively with the problem-solving elements, indicating the adaptability and effectiveness of the activities across different age groups.

The study has several limitations. Most scenarios involved small sample sizes (less than 30 participants), with the exception of scenario 1, which limits the generalisability of the results. In addition, no control groups were included, which limits the possibility of attributing the observed effects with certainty to the game-based learning activities alone. The analysis was based solely on descriptive statistics (means and standard deviations), which may be less reliable given the small samples and limits deeper statistical inferences. These limitations should be kept in mind when interpreting the results and emphasise the need for future studies with larger participant groups and more rigorous experimental designs.

6. Conclusions and Plans for Future Work

Traditional Sudoku offers several clear advantages that make it a strong candidate for use in the classroom. However, to effectively support educational goals and enhance student motivation, the activity must be thoughtfully designed and implemented. Throughout the development process, teaching scenarios were refined through iterative testing, with final versions receiving significantly higher ratings than earlier prototypes. Student feedback from surveys consistently indicated that the game was fun, engaging, and a valuable learning tool. These findings underscore the importance of iterative design and evaluation in creating effective educational games, especially for teaching complex concepts. Two key conclusions are highlighted below. First, when implementing group-based activities, it is essential to establish clear behavioural guidelines. This includes assigning specific roles such as a team leader or a student responsible for writing on the board and clarifying when and how tasks should be performed. Well-defined roles help ensure smooth collaboration and reduce confusion. Second, students must fully understand the rules of the game before they can successfully engage in independent play and achieve the intended learning outcomes. The younger the students and the more complex the game, the more time and attention should be dedicated to explaining the rules clearly and thoroughly.

Iterative refinements in explaining the rules, organising students into groups and session structure improved engagement and learning outcomes. Feedback from educators showed that they were more confident in delivering these activities independently, emphasising the importance of thoughtful design and support for the successful integration of educational games.

Future work will focus on developing new scenarios tailored for high school and university students. Additionally, a comparative study will evaluate the effectiveness of these teaching scenarios by assessing the results of learning in an experimental group and comparing them to those of a control group, which will receive traditional instruction.

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