Innovative Approach to Enhancing STEM Skills through Educational Games: Work in Progress

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***Abstract*—This innovative practice paper describes a work in progress on creating and applying educational games that develop mathematical and computational thinking within the project *Science&Math educational games from preschool to university* – SciMaG. Using educational games, especially in STEM fields, is an effective way to engage students and promote key skills across different age groups and environments. Such activities promote problem solving, logical thinking, strategic planning, and other important skills and can be used with students of different age groups in the classroom, in extracurricular activities, or at home. STEM science outreach activities organized as part of science festivals and similar events can be an excellent opportunity for a game-based approach. However, organizing events for large numbers of participants can pose a logistical challenge in terms of volunteer availability. This paper presents the results of a study in which game-based activities to develop mathematical and computational thinking were integrated into a science outreach event for primary school students on the occasion of Pi-Day. The innovative aspect of the approach is reflected in the use of a combination of games (commercial, newly developed games, and games inspired by commercial ones) which have an interesting math basis and require mathematical or computational thinking skills as well as in the introduction of peer teaching through attracting high-school students as volunteers for the organized event. In the evaluation of the approach, the perceptions of the primary school students (N_S=295), their teachers (N_T=19), and the high-school students participating as volunteers in the organized event (N_V=11) were examined using a questionnaire-based study. All groups of participants responded positively and confirmed educational potential of the games. Results confirmed that the activities were well-received and that such events have the potential to enhance learning experiences in STEM. The results also provide valuable insights and motivation for further development of educational games within the SciMaG project.**

Keywords—STEM, games, computational thinking, science outreach, SciMaG project.

I. Introduction

Critical reasoning, along with mathematical and computational thinking, are essential skills in various industries, particularly in science, engineering, and mathematics. These skills include understanding mathematical and IT concepts, as well as the ability to apply them in diverse contexts and use digital information effectively and responsibly [1]. Computational thinking skills are valuable across various fields, not just computer science, as they involve systematic and analytical problem-solving [2], [3]. These skills are essential in STEM education, helping students understand and tackle real-world problems, and preparing them for STEM degrees and careers [4]. Educational games and Game-Based Learning (GBL) are effective approaches for teaching key concepts and developing STEM skills in an engaging way [5]. Despite a growing number of science outreach activities using these methods, research indicates a continued demand from both students and teachers for more such activities [6], [7], [8].

The research presented in this paper was conducted as part of the *Science&Math educational games from preschool to university* (SciMaG) project, which involves the development of educational games that can be adapted for different age groups and content areas, building on the earlier *InAMath* project [9]. The paper presents an innovative approach to enhancing STEM skills with game-based activities in a science outreach event. Focusing on mathematical and computational thinking, an event for primary school students was organized on the occasion of Pi-Day. The approach aims not only to improve students' skills, but also to motivate teachers to include game-based activities in their lessons, and to involve high-school students as volunteers so that they too can benefit from the experience. The findings, based on the analysis of the questionnaires collected during the event, can benefit educators, curriculum developers and policy makers by providing evidence-based strategies for the inclusion of GBL in STEM education. In addition, the paper informs educators and researchers seeking inspiration for innovative ways to enhance development of STEM skills and promote science with a game-based learning approach by providing insights into the practical implementation of educational games and the potential of peer teaching to improve learning outcomes.

II. Related Work

To increase student motivation and engagement in STEM education, educational games and the GBL are increasingly being used [1], [10]. This includes integrating gameplay elements into educational content, using gamified learning experiences [11], and involving students in game development [12], [13]. GBL activities enhance skills like problem-solving, logical thinking, and strategic planning [14], [15], [16], while leveraging students' interest in games to inspire curiosity and creativity [17], [18]. Educational games that develop STEM skills can be applied in classrooms [19], extracurricular activities, at home, and during science outreach events [20].Science outreach activities serve as an innovative method to address STEM challenges and enhance scientific literacy by connecting science with education [21], particularly through

science festivals and similar events. These activities offer a valuable opportunity for the GBL approach, although organizing them for large numbers of participants can be challenging due to volunteer needs [21], [22]. The involvement of high-school students alongside university teachers [23] as volunteers not only supports these events, but also provides the younger volunteers with valuable experience and skills. The International Day of Mathematics (IDM) and Pi-Day celebrations [24] provide an excellent opportunity to combine popularization activities with GBL, while international events like the Science Picnic [25], the Maker Faire [26], and the European Researchers' Night [27] further raise awareness of science. These events engage participants with hands-on experiments, demonstrations, and interactive exhibits, encouraging curiosity and enthusiasm for STEM subjects [28], [20].

III. Pi-Day Event with Educational Games for Enhancing STEM Skills

This section describes a Pi-Day event held on March 14, 2024, at an elementary school in Croatia, aimed at enhancing STEM skills through educational games and promoting science. The theme of this year's IDM was *Playing with Math*, which fitted well with the aims of the SciMaG project. Game-based activities focused on mathematical and computational thinking were conducted in the school's gym, shown in Fig. 1. The event was met with great interest and 295 students from 15 classes took part. Each class, accompanied by their teachers (N_T=19), played games for an hour according to a predetermined schedule. Among participants were 1st-4th grade students (N_{S1}=212), i.e., 7- to 11-year-olds, and 5th to 7th grade students (N_{S2}=83), i.e. 11- to 13-year-olds.

Fig. 1. Activities in the school's gym.

The innovative approach in designing the activities for the event lies in the combination of commercial, newly developed games, and games inspired by commercial ones, all of which have an interesting math basis and require math skills, or mathematical or computational thinking skills. The types of games selected include those that have been used to promote STEM with great success according to the literature: Board games [6], [29], [2], card games [30], [31], [32], and games with educational robots [33], [34], [3]. The aim of combining a variety of games is to create dynamic learning experiences that appeal to the students' diverse interests. The games were led by the SciMaG project team and high- school student volunteers (N_V=11) who had previously received training on the mathematical concepts and principles behind the games. To be able to explain the rules clearly and help others understand the best strategy for the game, they need to gain a deeper understanding of the concepts and principles behind the games and master computational thinking. This peer-teaching approach is also an innovative element that not only involved the students in volunteering, but also helped them develop social and organizational skills, which provided them with the opportunity to enhance both their academic and personal development.

A. Commercial games

Several commercially available games (*SET* [35], *Spot it!* [36], and *Tantrix* [37]) were selected for the 4th and 5th grade students. The aim is to keep students interested in these games and wanting to play them again at home or at school. Although mathematical knowledge is not required for a successful gameplay, students can be introduced to complex mathematical concepts in an interesting way by explaining the background of each game (e.g., topics from combinatorics, graph or probability theory, linear algebra). The game *SET* challenges players to quickly identify unique sets of cards, each with different attributes (shape, color, number and shade). The rules of the game require that each attribute within a set must be either completely the same or completely different. This process encourages mathematical and critical thinking, as players must make quick decisions based on logical reasoning, and algorithmic thinking, as players need to use abstraction and follow a systematic approach to identifying valid sets. In *Spot It!*, players identify the one common symbol between any two cards from a deck where each pair of cards has exactly one matching symbol. This encourages pattern recognition, spatial reasoning, and the ability to make quick decisions, as players have to quickly compare symbols of different sizes and orientations under time constraints. *Tantrix* challenges players to form endless loops of matching colors on hexagonal tiles, encouraging critical reasoning (assessing different possibilities and choosing the best option, considering not only the current move but also future possibilities). It also encourages mathematical thinking by challenging players to recognize patterns, and develops computational thinking through the need to follow certain placement rules.

B. SciMaG games inspired by commercial games

The 3rd, 4th, and 7th grade students also played a newly developed game called *Mathematics in other words*. The rules of the game are taken from the game *Alias* [38], but new cards have been created with terms related to specific mathematical content. This approach takes advantage of the familiarity of the commercial game while adapting it to specific learning objectives. The cards have different colors depending on the grade and only cards that correspond to the students' grade are used. This way, students only have to explain the terms they have already learned while playing. Articulating terms in their own words enhances students' comprehension and strengthens their ability to analyze and describe the properties and relationships of concepts, thereby developing mathematical thinking. For example, to accurately describe a *disc*, students must distinguish it from a circle and state that it is a set of points whose distance from the center is less than or equal to the radius.

C. SciMaG games

Newly developed educational games within the SciMaG project have been specifically tailored to the knowledge and age of students attending the Pi-Day event. 1st, 2nd, 5th, and 7th

grade students played the game *Prepare and solve Sudoku* (in different grid sizes). In general, Sudoku encourages critical reasoning by requiring players to use logical deduction and recognize patterns to ensure that each number from 1 to 9 appears exactly once in each row, column and 3x3 sub-grid. Following the game's strict placement rules encourages mathematical and computational thinking by requiring a systematic (iterative) approach to problem solving. Before solving Sudoku, the game *Prepare and solve Sudoku* required students to first prepare and solve math problems (e.g., vectors and coordinate system for 7th graders) to determine the initial positions and seed numbers which contributed to the development of spatial ability and geometric thinking skills.

Educational robots were used in the 1st and 2nd grade games to increase the students' motivation to participate. For example, in the *Race of Disobedient Robots* game, students first had to follow rules to build a road, then work out code to control the robot, and finally control the robots that participated in the race. This activity fosters problem-solving, logical reasoning, and spatial awareness as students design the road and apply their programming skills to successfully create and debug their code to control their robot. A *Pi-rhythm treasure hunt* was organized for the 3rd grade students. The students developed mathematical thinking skills by collecting clues based on the digits of Pi. They had to accurately recognize and sequence these digits to unlock a treasure chest. They also had to use pattern recognition to find and enter the correct password, which strengthened their understanding of number sequences and problem-solving skills.

IV. Evaluation

A questionnaire-based study was conducted to assess the success of the Pi Day event and to evaluate participants' perceptions of enjoyment, motivation, skill development, and interest. This study included feedback from students, teachers, and high- school student volunteers to gain a comprehensive overview of the impact of the event. Participants evaluated their event experiences and perceptions using series of statements. Younger students (1st-4th grade) indicated their feelings by choosing from three faces with descriptions (“No,” “I don’t know,” “Yes” [39]), while older students (5th-7th grade), teachers, and volunteers used a 5-point Likert scale (1 - Strongly disagree to 5 - Completely agree). Additionally, 5th and 7th grade students rated the games they played on a scale of 1 to 5, with 5 being the highest score. In addition, one open-ended question was included to collect additional comments and suggestions from all participants. The paper-based questionnaire was given to participants during the Pi-Day event or the following day for younger students to reduce recall bias. Descriptive statistics, the mean (M), standard deviation (SD), minimum (Min) and maximum (Max), were used to analyze the quantitative data from the responses.

V. Results and Discussion

A. Survey of students

The results of a survey of younger students (1st to 4th grade) are shown in Table I. The high mean values for all three statements indicate a positive perception of the Pi-Day event. These results are to be expected, given the natural inclination of younger students towards games and interactive activities.

TABLE I. Perception of 1st to 4th Grade Students

Statements	N_{S1}	M	SD	Min	Max
I liked the games.	212	2.86	0.42	1	3
It was fun for me.	212	2.81	0.51	1	3
I want to play such games again.	212	2.67	0.66	1	3

While the majority of students expressed both enjoyment of the games and a desire to participate in similar activities again, a small percentage of students (5%), did not find the games appealing. Possible reasons could include different individual preferences, level of engagement, or specific challenges encountered by certain students during the activities.

The 5th to 7th grade students were also positive about the games played during the event, recognizing the benefits of participating in the event and the opportunities to play such games in class (Table II). Most students saw the games as an opportunity to learn and acquire new knowledge or skills (M=3.98) and expressed the opinion that games are not represented enough in class (M=3.86). Furthermore, students would like to have the opportunity to play games like the ones they played on Pi-Day in class (M=4.29). These results suggest that integrating educational games into learning environments can create engaging and enjoyable experiences for students, with the potential to facilitate skill development. This finding aligns with research reported in [1] indicating that the engaging nature of games can positively influence student perceptions and create a dynamic and engaging learning environment that meets diverse learning needs, increases student motivation and improves achievement. Students expressed their willingness to recommend participation in similar events to their peers (M=4.06), which may also indicate that they are convinced of the value and benefits of participating in such events. These results align with findings from [29], which emphasize that extracurricular experiences, like events such as Pi-Day, significantly influence students' interest in STEM fields.

Most of students found games appealing (M=3.94) and understood the rules of the games well (M=4.03). This is important because if the rules of the game are clear to the students, they can follow the course of the game and actively participate, as reported in [29]. When rating the games they played, 5th to 7th grade students gave a mean rating of 4.13 for the *Commercial games* category, indicating a positive perception of these games. The *SciMaG games inspired by commercial games* category received a higher mean rating of 4.55, suggesting that students found the game based on *Alias* even more engaging or entertaining. *SciMaG games* received a lower average rating of 3.78, indicating a slightly less positive perception compared to the other two categories. This implies that the established rules of the game *Alias* may have contributed to its higher perceived enjoyment among students compared to the unfamiliar mechanics of the newly introduced games. This finding highlights the importance of familiarity with game mechanics and rules to ensure effectiveness of GBL approach.

Several students who responded to the open-ended question suggested the inclusion of educational robots and micro:bits as well as teamwork to make these games more interesting, offering a valuable direction for future work since the use of educational robots can improve STEM skills.

TABLE II. PERCEPTION OF 5TH TO 7TH GRADE STUDENTS

Statements	N_{S2}	M	SD	Min	Max
I found games interesting.	83	3.94	0.86	1	5
The rules of the games were clearly explained to me.	80	4.03	1.07	1	5
I believe I can learn new things through these games.	83	3.98	0.89	1	5
Such games are not represented enough in class.	83	3.86	1.02	1	5
I would like to play such games in class.	83	4.29	0.94	1	5
I would recommend others participation in similar events.	82	4.06	1.00	1	5

B. *Survey of teachers*

The results of a survey of teachers who accompanied students to the Pi-Day event are shown in Table III. The teachers' perception of the event and its possible impact on the students are very positive. Teachers observed that students had fun during the activities (M=4.74). They strongly believe in the motivational potential of such events for learning (M=4.79) and increasing students' interest in science (M=4.79). Teachers expressed a desire to incorporate Pi-Day activities into their teaching (M=4.63), suggesting that they recognize the value of game-based activities for their own practice and should therefore be considered a valuable component in teaching strategies. The perceived value of the activities organized during the Pi-Day event is also reflected in the teachers' strong interest in participating in similar events with their students in the future (M=4.74) and their willingness to recommend participation to colleagues (M=4.89). These results encourage further work on the development of activities and learning scenarios to support teachers in the inclusion of games in their daily practice.

Teachers observed that students had fun during the activities (M=4.74, SD=0.44). They strongly believe in the motivational potential of such events for learning (M=4.79, SD=0.41) and increasing students' interest in science (M=4.79, SD=0.41). Teachers expressed a desire to incorporate Pi-Day activities into their teaching (M=4.63, SD=0.48), suggesting that they recognize the value of game-based activities to their own practice. This is consistent with similar research in STEM fields [1], [14], [16] indicating that GBL can improve teaching efficacy and the achievement of learning outcomes.

TABLE III. TEACHERS' PERCEPTION OF THE PI-DAY EVENT

Statements (N_T=19)	M	SD	Min	Max
The students had fun playing games.	4.74	0.44	4	5
Such events motivate students to learn.	4.79	0.41	4	5
Such events can increase students' interest in science.	4.79	0.41	4	5
I would like to include GBL activities from Pi-Day into my teaching.	4.63	0.48	4	5
I would like to participate in similar events with my students in the future.	4.74	0.44	4	5
I would recommend colleagues to participate in similar events.	4.89	0.31	4	5

C. *Survey of high school student volunteers*

The results of a survey of students who volunteered to help with the Pi-Day event are shown in Table IV. They also confirmed that the primary school students had fun playing games (M=4.64). Most of volunteers agree that such events can motivate students to learn (M=4.36). The results show that they perceived the benefits of volunteering on such event. The majority of respondents agreed that their participation in the activities facilitated their understanding of the mathematical concepts behind the games used in an enjoyable manner (M=4.45) and resulted in enhancements to their organizational and communication skills (M=4.55). Furthermore, the results show their strong interest in future participation in similar events (M=4.82), and willingness to recommend such activities to their peers (M=4.64), which indicate a high level of satisfaction and enjoyment experienced during the event. This finding is consistent with [40], which indicates that volunteer motivation for outreach activities is driven by their enjoyment. Since the use of GBL requires good preparation and good control of the implementation of the activities, it is important that a sufficient number of people lead the activities. Therefore, it is beneficial if students are available as volunteers to provide support. The positive impact also underlines the importance of involving student volunteers in such events, as their involvement not only supports the activities but also enhances their personal development and understanding of the subject matter.

TABLE IV. VOLUNTEERS' PERCEPTION OF THE PI-DAY EVENT

Statements (N_V=11)	M	SD	Min	Max
The students had fun playing games.	4.64	0.48	4	5
Such events motivate students to learn.	4.36	0.77	3	5
I understood the math concepts behind the games in a fun way.	4.45	0.66	3	5
I improved my organizational and communication skills.	4.55	0.89	2	5
I would like to participate in similar events in the future.	4.82	0.39	4	5
I would recommend other students to participate in similar events as volunteers.	4.64	0.64	3	5

VI. CONCLUSIONS

Feedback from all participants in the Pi-Day event was positive, indicating that the activities were well received, engaging and fun for the students. Participants recognized the educational value of the games and expressed interest in future similar events. Students appreciated the fun learning experience, while teachers found the event effective in enhancing STEM skills and expressed a desire to use game-based activities in their teaching. Volunteers recognized the event's benefits for both student learning and their own development. These results suggest that events like Pi-Day offer valuable interactions between students and scientists and introduce students to unique content and activities. For the SciMaG project, a key finding is that these events help teachers see the benefits of game-based activities for skill development and motivate them to integrate such methods into their teaching. However, the transferability of these practices may be constrained by participants' interests, school support, organizational issues, and resource availability.

Further work will examine why some students did not find the games enjoyable, aiming to inform future design of SciMaG games, and explore methods to increase student enjoyment by familiarizing them with the game mechanics. Students recommended improving the games by adding educational robots, and micro:bits, and encouraging teamwork to increase engagement. In response, the SciMaG project will incorporate

this feedback to develop educational games, including the creation of detailed scenarios for use in and out of the classroom.

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