Comparison of two Different Game Mechanics Applied to Learning of Electromagnetism

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Abstract: The paper presents two educational escape games, Tournament of J. C. Maxwell and Chest of Lord Maxwell, which were designed with the same topic and educational goal in mind: to consolidate and deepen knowledge about magnetism and electromagnetism, and to develop communication skills, teamwork skills, problem solving skills, experimental skills and analytical thinking. Both games were used in the teaching of electromagnetism in an upper secondary school. Data were collected through observation of the game process, administration of questionnaires to students and teachers, and interviews with students. The aim of this research is to compare two different game mechanics used to address the same subject matter and educational objective. The comparison will focus on the perception of the games by the students and the teachers who have incorporated the game into their teaching.

Keywords: Game-Based Learning, Non-Digital Educational Game, Upper-Secondary Education, Electromagnetism, Skills Development

1. Introduction

Escape games are “live-action team-based games in which players encounter challenges in order to complete a mission in a limited amount of time.” (Veldkamp et al, 2020) In recent years, escape games have become a phenomenon as a non-virtual entertainment activity popular with people of all ages. Parallel to their immense popularity in the entertainment industry, escape games are gaining popularity as learning environments in primary, secondary, higher education and professional development programmes (Sanchez, Plumettaz-Sieber, 2018). In escape game literature, all activities, tasks or challenges within an escape game are called puzzles. Puzzles usually follow the simple path: problem – solution - reward (Veldkamp et al, 2020). Successful puzzle solving in educational escape games relates to learning objectives. The unique combination of puzzles, environment and overall mission aims to reach the flow state of players – state of mind characterized by intense focus and pleasure, where players are immersed in an intrinsically motivating task (Csíkszentmihályi, 1990).

While recreational escape games are mostly suitable for groups of 3 to 7 people, teachers often must prepare an escape game for whole class or some larger group of students. This can be achieved in several ways:

- By preparing the same escape game in multiple rooms, so each team plays in its own room.
- By preparing tasks at stations in a larger space, teams use the same stations but arrive at different times, so they don't clash.
- Placing all the equipment and tasks for one team in a chest. Each team has its own chest, so all teams can play simultaneously in one room. (Veldkamp et al, 2020)

In the 2021 review, Lathwesen and Belova examined a total of 93 journal articles, book chapters, and conference papers in both English and German concerning escape games in STEM education. According to the review, there is a paucity of proposals pertaining to the fields of physics and biology education, as well as interdisciplinary studies. The utilisation of experiments within the context of chemistry, physics and biology escape games was identified as a beneficial practice, as it facilitates the development of specific experimental skills. However, escape games incorporating experiments are time-consuming and less readily adaptable. The majority of escape games appear to have been designed with the specific requirements of a particular course or institution in mind. It would therefore be beneficial for the STEM educational community to adopt a more systematic approach to the coverage of standard school or higher education topics, which are taught in many different countries around the world. (Lathwesen, Belova, 2021)

2. The Games

In light of the aforementioned considerations, we decided to design 2 games with same objective and focused on the same topic – magnetism and electromagnetism. The educational objective of the games is to consolidate and deepen knowledge on the topic of magnetism and electromagnetism, and to develop communication skills,

teamwork skills, problem-solving skills, experimental skills and analytical thinking. However, the games differ in terms of their game mechanics, motivational factors, and the way they provide feedback to players. In both games, the whole class is engaged into the game, participants are divided into groups of two to five individuals, and the games are designed for one lesson (45 minutes). In following paragraphs, game mechanics of the games will be described, followed by the overview of physics content and skills that are developed through the games.

2.1 Tournament of J. C. Maxwell

Tournament of J. C. Maxwell (tournament game) is an educational escape game. The game mechanics are inspired by the game Diver (Haverlíková, 2006). The game comprises 15 stands distributed throughout the school building. Each stand is associated with a different task. By successfully completing the task, students are provided with the location of the subsequent stand. If the response is accurate, the subsequent stand is situated on the main path leading to the finish of the game. If the response is incorrect, the subsequent stand provides a hint to the preceding task, requiring the students to return and identify the correct answer. Students are divided into groups of two to five individuals, with the objective of passing the stands in the shortest possible time and with the correct answers. Figure 1 illustrates the path of the stands. All stands are marked with letters. The purple stands mark the start and finish of the game. The orange stands represent the main path (task stands), while the blue stands are the clue stands. The green arrows indicate the correct responses, while the red arrows indicate incorrect responses. If a team responds correctly to all the tasks, they will only visit the orange stands, and the word MAXWELL can be formed from the letters on their path. To prevent the accumulation of teams at the stands, communication between teams, distractions from the game, and drop in attention span, it is essential that each team's order on the main path be mixed up.

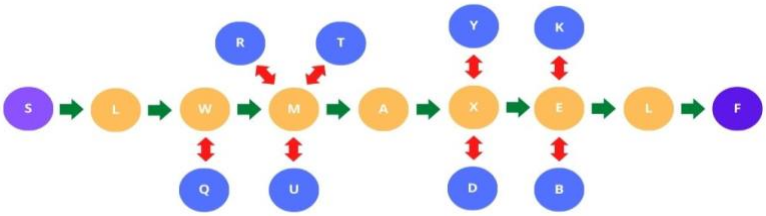

Figure 1: Path of the stands.

2.2 Chest of Lord Maxwell

Chest of Lord Maxwell (chest game) is an educational game in a real (non-digital) environment. It is an escape game, but the goal is not to escape the room; rather, it is to unlock and explore the chest. In exploring the chest, players must solve several physical puzzles. Figure 2 shows a schematic arrangement of the puzzles. The game is designed for groups of 2-5 people. Each group gets its own chest locked with a 3-digit numerical lock. All the necessary resources for the game are included in the chest. This allows multiple groups to play simultaneously in the same room without interfering with each other. The first puzzle, indicated by the blue square, is fixed to the chest and solving it will provide the players with a code to open the chest. Once opened, they will find several more puzzles, indicated by the green squares, and a smaller box locked with a 5-digit number lock. By solving the puzzles, players obtain the individual digits of the code required to open the box. The box contains a qualitative explanation of Maxwell's equations and a reward.

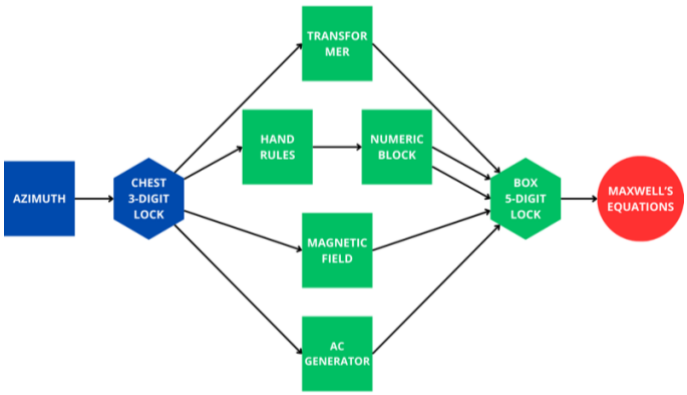

Figure 2: Schematic representation of the puzzles arrangement in the game.

2.3 Physics Content and Skills Developed Through the Games

Game tasks were based on the standards defined for teaching of physics in upper secondary schools in Slovakia for the topic of magnetism and electromagnetism. Simultaneously, the tasks aim to develop certain skills. Table 1 presents the overview of physics content and skills that are developed by the tasks of both games.

Table 1: Overview of physics content and skills developed through the games.

Physics Content	Tournament of J. C. Maxwell		Chest of Lord Maxwell	
	Skill Development	Task	Skill Development	Puzzle
magnetic field of a wire right-hand rule for a wire	picture analysis	W	problem-solving skills picture analysis	Hand rules
right-hand rule for a coil Lenz's law	problem-solving skills graph analysis analytic skills	X		
magnetic field of a coil right-hand rule for a coil	problem-solving skills equipment-manipulation skills analytic skills	E		
magnetic field of permanent magnets magnetic field lines	picture analysis	M	picture analysis	Magnetic field
Earth's magnetic field	compass usage	A	azimuth determination	Azimuth
usage of electromagnetism transformation ratio	experimental skills equipment-manipulation skills	L_1	experimental skills equipment-manipulation skills	Transformer
usage of electromagnetism	experimental skills equipment-manipulation skills – in a new situation	L_2		
Working principle of AC generator			Reading comprehension skills	AC generator
			Spatial orientation skills, analytical thinking	Numeric block

3. Research

The research was conducted in two phases. The initial phase of the study involved the testing of the tournament game. The second phase focused on the chest game. Subsequently, we analysed and compared findings from both phases with the goal to compare two different game mechanics applied in the teaching of the topic of electromagnetism in upper-secondary school. The comparison will focus on the perception of the games by students and teachers who have used the game in their teaching.

3.1 First Phase

Tournament of J. C. Maxwell game was subjected to a preliminary examination in February 2022 at the Bilingual Grammar School in Bratislava. A total of 55 students from four different classes participated in the implementation of the game as part of their regular physics lessons. The game was incorporated into the curriculum as a preparation for the summative assessment. Following the conclusion of the game, a discussion was held with the students to solicit feedback on the game. One week after implementation, an online questionnaire was sent to all participating students. The questionnaire focused on the difficulty and understandability of the game, teamwork, benefits of the game, and student attitudes towards the game. A total of 37 students completed the questionnaire voluntarily. The findings from this part of the research were presented at the GIREP Conference 2022 in Ljubljana, Slovenia (Janiga, Haverlíková, 2022). They will be published in the Springer book series Challenges in Physics Education. In addition, we posed some questions to the teachers

with the intention of evaluating the game from their perspective. The questions addressed the extent to which the objective was achieved, the level of engagement among students, the benefits and drawbacks of the game, and the teacher's attitude towards the implemented game.

3.2 Second Phase

The testing of the Chest of Lord Maxwell was conducted in December 2023 and April 2024 at three grammar schools in Bratislava. A total of 142 students participated in the implementation of the game. The course of the game was observed, and following its conclusion, an online questionnaire (the same as in the first phase) was sent to the participating students. Students completed it voluntarily, in their free time. This questionnaire focused on the difficulty and understandability of the game, teamwork, the benefits of the game, and the students' attitudes towards the game. The same questions as in the first phase were addresses to the participating teachers.

School A is the same institution where the initial phase of the research was conducted. A total of 90 students from six different classes participated in the research. The game was implemented within the context of the physics class as a form of preparation for the summative assessment. A total of 12 students from this school completed the questionnaire. The low return rate of the questionnaire may have been since the implementation of the game and the administration of the questionnaire took place just before the start of the Christmas holidays.

School B is a grammar school with Hungarian language as a primary language. Students understand Slovak, but Hungarian is their preferable language. A total of 30 students from two different classes participated in the research. The game was included in the curriculum six months after the topic was covered. A total of seven students from this school completed the questionnaire. The low return rate of the questionnaire may be attributed to the language barrier, given that the questionnaire was in Slovak, while the students attend a school where Hungarian is the language of instruction. Despite the possibility of completing the questionnaire in Hungarian, it is possible that the language barrier discouraged students from doing so.

A total of 22 super senior students at school C participated in the research. The game was introduced into the physics curriculum two years after the topic had been covered. A total of 22 students from this high school completed the questionnaire.

4. Findings

4.1 First Phase

Findings from this part of the research were presented at the GIREP Conference 2022 in Ljubljana, Slovenia (Janiga, Haverlíková, 2022). They will be published in the Springer book series Challenges in Physics Education. Therefore, we present here only a summary. The findings suggest the tournament game achieved its intended difficulty level, perceived as challenging but achievable by most students. Teamwork and physical exertion were not seen as significant difficulty factors. While most students understood the game's instructions and rules, some reported confusion due to the use of multiple communication channels (oral, written, visual). The understandability of tasks was generally high, with minimal issues reported. Although some students indicated difficulties with clues, further investigation revealed they simply hadn't visited the stands with the clues. The game was perceived as enriching by a large majority of students. The most frequently reported benefits included applying existing knowledge (71.8%), gaining new physics knowledge (61.5%), and discovering new perspectives (56.4%). Students identified teamwork, communication, and efficient work distribution as strengths of their teams, while acknowledging weaknesses like communication breakdowns and knowledge gaps. Roles primarily focused on task completion and explanation, with less emphasis on leadership, motivation, or writing. Interestingly, students in non-problem-solving roles perceived themselves as less valuable. In general, students shown positive attitudes towards the game, mainly focusing on teamwork, physical movement and the form of the game.

4.2 Second Phase

4.2.1 Observation

Observation revealed that all students were highly motivated from the outset of the game. In school C, there was a notable degree of competitiveness among the students. In schools A and B, smaller groups of three to four players were formed, while in school C, groups of four to six players were formed. In the case of smaller groups, there was a reduced need to divide puzzles and solve multiple puzzles simultaneously. If players encountered difficulties with a puzzle, they exhibited signs of frustration. In such instances, the players were queried regarding their solution procedures and provided with hints. From the observations made, it became evident that students faced the greatest difficulties with non-physics content puzzles (solving the numeric block and comprehending the method for extracting the code from the puzzles). In school A, 90% of the groups were able to solve all the puzzles and open the box within 45 minutes. The success rate at schools B and C was found to be significantly lower, with only 50% of the groups able to solve the puzzles and open the box within 45 minutes. If a group was unable to complete the game, a joint discussion was held with all groups to identify the solutions to the puzzles and to open the boxes collectively.

4.2.2 Students Questionnaire

The initial section of the questionnaire focused on how students perceived the difficulty of the game in its various aspects. The results are presented in Figure 3. The game was perceived as the most challenging in terms of the students' knowledge of physics. Conversely, they considered it the least challenging in the areas of teamwork and physical movement. This is consistent with the design intention of the game, which was to create a challenging experience in the areas of physics knowledge, skills, and logical thinking. The game requires minimal physical movement and can be mastered by an individual. A comparison of student responses from each school revealed that students at school C rated the difficulty of the game on physics knowledge as more challenging on average than students at school A and B (a bit hard) This distinction was reflected also in the ratings of overall difficulty. No significant differences were observed between the schools in other aspects of the game. It appears that the discrepancy in responses may be attributed to the fact that students at school C are superseniors, and that it has been approximately two years since they last encountered the topic in physics. In contrast, students at school A were presented with the game immediately after the topic was covered, while students at school B were presented with the game six months after the topic was covered.

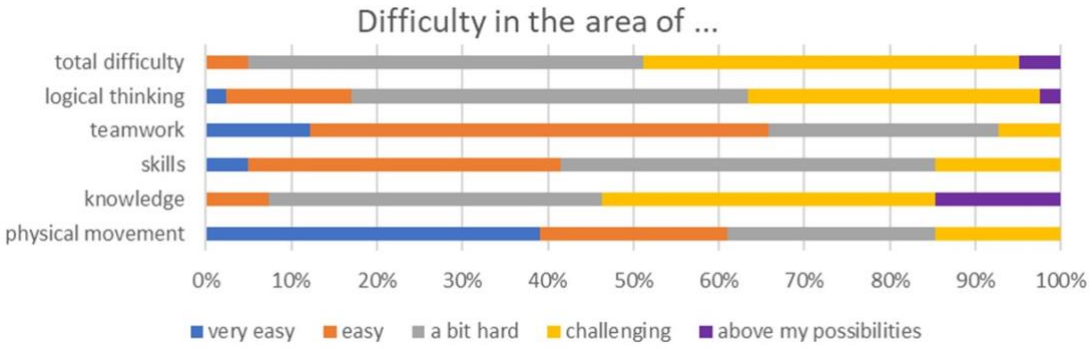

Figure 3: Relative numbers of students' evaluation of the game difficulty.

The second aspect under investigation was the understandability of the game. The students were requested to assess the degree of understandability of selected parts of the game. The results are presented in Figure 4. The students expressed high levels of satisfaction with the clarity of the rules, instructions, and clues provided during the game. A small number of students indicated that these aspects were not readily understandable. These were one student from school B and one student from school C. The problems could have been caused by a language barrier (school B) or by the fact that a few students missed the beginning of the lesson and only joined the game during the lesson (school C). In the case of the puzzles, students rated clarity as the aspect with the lowest level of understanding (acceptable or with only a few problems). Several students indicated in the questionnaire that they found the puzzles less understandable. However, they were aware that non-explicit assignments are an inherent aspect of the mechanics of escape games.

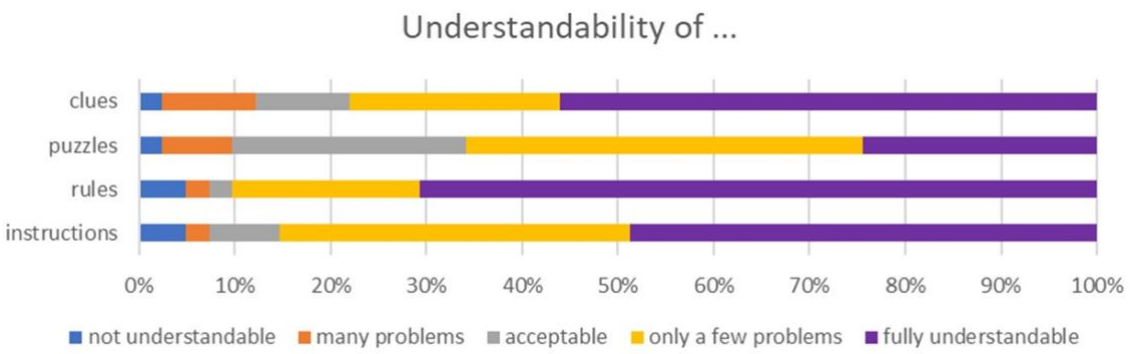

Figure 4: Relative numbers of students' evaluation of the game understandability.

In the third section of the questionnaire, students were requested to reflect on the game's potential for enrichment. Students indicated that the game facilitated the acquisition of new physics knowledge (75.6%), the acquisition of new experiences (53.7%), the development of novel perspectives on the topic (48.8%), the application of knowledge (39.0%) and the development of skills (24.4%). Only two students indicated that the game had no benefits for them. A comparison of the responses of the students from each school revealed that while in schools A and B the students' responses are evenly distributed among all aspects except skills, in school C 86.4% of the students identified acquiring physics knowledge as a benefit, while in the other aspects the frequency of responses is below 50%. We believe that this difference is caused by the significantly longer time that has passed in group C since the topic was discussed in class.

The fourth section of the questionnaire addressed the subject of teamwork, encompassing the strengths and weaknesses of the team, leadership, and the roles of each member within the team. The students identified teamwork, communication, peer-learning, work distribution, decision-making, speed, and peer motivation as the strengths of their teams. The students identified a few weaknesses in their teams, including a lack of knowledge and communication. The most frequently reported roles of team members were related to task solving, specifically solving and explaining. A small number of students reported roles as writer or motivator.

The fifth section of the questionnaire addressed the students' attitudes towards the game. Figure 5 displays the students' appreciations of selected aspects of the game. Furthermore, 54,8% of students indicated that they discussed the game with other players after the game, while 23.8% discussed it with students who did not play the game, 23.8% of respondents indicated that they did not revisit the game in their thoughts.

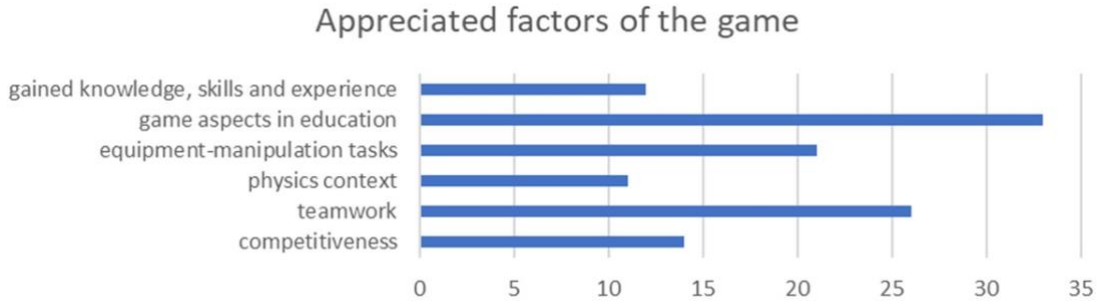

Figure 5: Absolute numbers of students appreciating selected factors fo the game.

4.2.3 Teachers Questionnaire

All three teachers involved in the research have concluded that the intended aim of the game has been fulfilled. The students demonstrated their ability to solve problems and consolidate their knowledge of the topic of electromagnetism. The format of the game necessitated collaborative effort and communication between the students. To solve the problems, students were required to engage in analytical thinking, including the identification of the task, the solution of the problem, and the acquisition of the code. Teachers from schools B and C posted that including the game in the sequence immediately following the teaching of the topic of electromagnetism would have been more beneficial.

Furthermore, the teachers were impressed by the level of student engagement. The teachers asserted that the small group work and game format facilitated the involvement of students who were previously quiet or inactive

in the teaching process. However, they emphasised the significance of the way students were allocated to groups to prevent the combination of students with inadequate physics knowledge. Failure in the game could result in frustration and a further decline in interest in physics.

The game's primary benefit, according to the teachers, is its capacity to engage students. The format of the game introduced a novel element to the usual structure of physics teaching. "Another significant advantage is that it encourages students to develop critical thinking, rather than merely memorise the content they have learned in class." Furthermore, one teacher emphasised the historical aspect of the game, stating, "I also appreciate the historical background of the game and the overall story provided for the chest, as this can also engage pupils who do not have a very positive relationship with physics."

All teachers expressed a desire to incorporate the game into their future teaching practices.

4.3 Comparison of the Perception and Evaluation of the Games

The data collected in phases one and two of the research, comprising observations, questionnaires completed by students and teachers, and interviews with students, was used to make an initial comparison of the perceptions of the two games. A comparison was made between the two games from the perspectives of the students and the teachers.

4.3.1 Students' Perspective

In terms of difficulty, students rated both games similarly in all aspects. Of particular interest is the aspect of physical movement, as the chest game requires almost no physical effort, whereas the tournament game involves rapid movement within the school building. An important strategy to win is not just to solve the problems correctly, but to solve them as quickly as possible. Two-thirds of the students who played the tournament game identified movement as an appreciated factor. Several of them reported that incorporating movement into this activity helped them to focus, think, and engage better in the game. They referred to it as a nice change in the routine of the lessons.

In the case of understandability, again, the students' ratings are very approving except for the clarity of the task assignment. In this aspect, the understandability of the tournament game assignments was rated at a higher level (only a few problems) than the understandability of the chest game puzzles (acceptable). As also noted by some students in the questionnaires, the puzzles of the chest game were not given explicitly, as it is an escape game, which may have caused that some students rate them as less understandable. A second factor that may have caused this difference is the specificity of the research sample. Most of the data collected from the second phase of the research came from school C, where the research was conducted with superseniors. Hence, with students who played the game approximately 2 years after having studied the topic. This point will need to be explored in the future with emphasis on selecting the same research sample for both games.

A significant aspect that was commended by both students and educators was the method of motivation. Tournament of J. C. Maxwell is designed as a team competition. Consequently, the motivating factor was competitiveness. In the case of the game Chest of Lord Maxwell, the motivating factor is the desire to explore the unknown and to open the locked chest. Both forms of motivation were identified by the students as being effective. In the case of the chest game, the motivating factor of competitiveness was also evident. Groups competed to explore the chest in the shortest possible time. However, the game was not designed with this in mind, and this factor is not encouraged in any way during the game. In the case of the tournament game, there have been instances where some teams have prematurely concluded the competition because they lacked the confidence to prevail against the other team. The anticipated motivational effect of competitiveness was, in fact, the opposite of what was intended. It is therefore of great importance that the composition of the teams is carefully considered in these games.

Each of the game provides feedback to students in different ways. In the case of the tournament game, students receive immediate feedback on their solution. If students choose the correct answer the game navigates them to the next task. If they answered incorrectly, the game navigates them to a stand where they get a hint and return to the previous stand to solve the task again. In the case of the chest game, students get 5 numbers from the five puzzles that make up the numerical code for the lock. If they solve the puzzles correctly, they open the chest. If the chest does not open, the students know that they do not have the correct code, but they do not know which of the numbers is incorrect and therefore which puzzle they did not solve correctly. Thus, the

feedback in this game is neither immediate nor sufficiently addressable. As a result, this requires students to be more resilient to frustration and more assisted by the teacher.

The importance of teamwork was identified as an appreciated factor in both games. The application of teamwork in the context of a game can result in a reduction in the perceived difficulty of the game, the maintenance of motivation, and the prevention of frustration. It facilitates peer-to-peer discussion and learning among students.

4.3.2 Teachers' Perspective

From the teacher's point of view, one of the most important aspects in deciding, whether to include a game in teaching, is the difficulty of the game in terms of preparation. In the case of the tournament game, the preparation process is more challenging due to the necessity of planning the location of the stands within the building, preparing the tasks within the envelopes, and then placing the envelopes and all the materials into the school. In contrast, the preparation for the chest game is relatively straightforward. The teacher is required to prepare the chests only once, after which they simply need to be checked before the lesson and brought into the classroom. Conversely, he must purchase the chests and numerical locks.

The format of Chest of Lord Maxwell allows for the entire class to participate in the game simultaneously and in the same location. This enables the teacher to monitor their students' activities, observe them at work, and address any issues that may arise. In the case of the tournament game, students are dispersed throughout the school building, and the teacher is unable to monitor their progress, identify any difficulties they may be experiencing, or help as needed.

5. Conclusion

The objective of this research was to examine how students and educators perceive the integration of two games with different game mechanics in physics education. The comparison enabled the identification of several key factors that should considered during the development and implementation of the game.

It is essential to establish an appropriate level of difficulty for the game, ensuring that it is neither too straightforward nor too challenging for players. The incorporation of non-explicit tasks serves to augment the complexity and duration of the game. It is recommended that in-game feedback be provided in a prompt and accessible manner. The incorporation of teamwork is a highly valued element, as it serves to mitigate the perception of difficulty, bolster motivation, and facilitate peer-to-peer learning. Nevertheless, the composition of the team is a crucial aspect that demands careful consideration. The efficacy of the teaching process is contingent upon the alignment of the learning and game goals, as well as the time required for preparation and implementation of the game. The format of the game has an impact on the role of the teacher during the game, which may be that of an observer, moderator or helper.

Given the limited sample size and the notable discrepancies between the samples, it is not feasible to generalise the conclusions drawn from this study. It is our intention to reinstate these two games in the classroom, with a particular focus on the selection of appropriate research samples.

References

Csikszentmihalyi, M. (1990) "*Flow: The Psychology of Optimal Experience*" Harper & Row: New York, USA, 1990.

Haverlíková, V. (2006) "Educational games in physics" *Informal Learning and Public Understanding of Physics : International GIREP Seminar. 3rd, Ljubljana, 2005*.

Janiga, L. and Haverlíková, V. (2022) "Identification of the factors influencing game-based learning in a game The Tournament of J. C. Maxwell", *GIREP 2022, Ljubljana, Slovenia – Book of Abstracts*, pp 36-37.

Lathwesen, C. and Belova, N. (2021) "Escape Rooms in STEM Teaching and Learning—Prospective Field or Declining Trend? A Literature Review", *Education Sciences*, Vol. 11.

Sanchez, E. and Plumettaz-Sieber, M. (2018) "Teaching and learning with escape games form debriefing to institutionalization of knowledge", *7th International Conference GALA 2018,* December 5–7, 2018, Palermo, Italy, pp 242-253.

Veldkamp, A., van de Grint, L., Knippels, M. and van Joolingen, W. (2020) "Escape education: A systematic review on escape rooms in education", *Educational Research Review*, Vol. 31.