Motivational Elements in Computer Games for Learning Mathematics

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Abstract—One of the main drawbacks of delivering new teaching lessons in e-learning systems is the lack of motivation for using those systems. This paper analyses which elements of computer games for learning mathematics have a beneficial effect on intrinsic motivation and give students continuous feedback in order to improve the learning process. While the control group has access to the basic version of the educational computer game, the experimental group uses the version enriched with additional motivational elements which include enhanced graphics for indulging in the game, messages of support while playing the game, and the possibility to compare results with fellow peers in terms of trophies and medals won.

Keywords—E-learning, m-learning, Mathematics, educational computer games, motivation

1 Introduction

Generally speaking, e-learning systems primarily target users belonging to the same user group (students, workers, etc.), and then adapt to individuals within these groups. E-learning systems should, therefore, be designed for the users who share common interests (through intrinsic motivation) and in a way that they are accepted by the majority of individuals within these groups.

E-learning systems have numerous advantages as a supplement to traditional learning methods, but also as a substitute for traditional learning (e.g. in situations in which one is not able to attend classes, or in situations in which a large number of participants has to take part in the educational process simultaneously, etc.). However, as given in Table 1, from a student's perspective, one of the major disadvantages of e-learning systems is poor motivation for using them [1].

Table 1. Advantages and disadvantages of using e-learning systems

	Advantages	Disadvantages
Students	Interactivity	Alienation
	Availability	Need for self-organization
	Group independence	Poor motivation
	Self-evaluation and progress evaluation	The lack of physical contact with teachers

While the inability to attend classes can be caused by bad weather conditions, illness, etc., the COVID-19 pandemics led to a sudden increase in using e-learning systems as a primary form of knowledge acquisition which replaces all other teaching methods and forms on a global level.

2   Related Work

Student motivation is an important factor in successful implementation of e-learning systems [2]. The metric of importance in these systems is the student engagement in using the content, and gamification is one of the ways which can affect it positively [3].

Gamification could be defined as using game-design elements in a non-game context [4].

Although there are numerous definitions of games, features related to interactivity, graphics, story-telling, rewards, competition, virtual environment, and the notion of a "victory" do not define the game in itself, but only reinforce the following common features which can be found in each and every game [5]:

- Goal – relates to the specific result that players aim to achieve. It provides players with the sense of purpose.
- Rules – set up ways of accomplishing goals. Rules facilitate creativity and strategic thinking.
- Feedback – informs players on their proximity to the goal. It can be implemented through scores, levels, or the level of progress. Real-time feedback serves as a promise that the goal is accomplishable and boosts motivation for playing.
- Voluntary participation – players voluntarily accept goals, rules and feedback. Starting a game and quitting it in one's own rhythm makes otherwise stressful and challenging activity perceived as pleasant and safe.

The results of numerous research studies which include learning by playing computer games in primary and secondary schools, as well as higher education institutions, in most cases point out the positive effects that such an approach brings. These effects are reflected in learning outcomes and in increased motivation [6, 7, 8]. In primary schools motivation can be positively affected by friendly competitiveness, but elements of fun which are incorporated with graphics, audio, story-telling, humour, and game characters are likewise important [9].

It can be assumed that engagement and efficiency in learning through computer games depend on the game design [10].

Learning through computer games sometimes takes place even in those games which are primarily meant for fun, such as Angry Birds. One can find connections between mathematical ideas and concepts on one hand, and game parts on the other hand (related to the calculation of paths). Therefore, the game acts as a motivational element since applying the knowledge of Mathematics results in better progress [11].

Higher levels of intrinsic motivation in computer games can also be achieved when different types of interaction and self-organization between players take place over some sort of social networks [12].

Furthermore, in primary and secondary schools computer games can be used for simulating conflicts which occur in everyday life situations. By recognizing and controlling their emotions while in simulated conflicts, students acquire emotional competence [13]. Computer games can also be used for learning of safety education by pre-school children, e.g. encountering safety issues such as crossing the road when the light turns yellow [14].

3   Research Questions

One of the research questions is in what way a model of learning through educational computer games should be applied as one form of assessment, i.e. how can students continuously get feedback on their learning progress. Additional questions considered are related to adapting e-learning systems to young generations. This research study, therefore, analyses motivational elements which can affect the frequency of use of educational computer games. The following null hypothesis is formulated: there is no difference in the number of played games between the control and experimental groups in the scenario in which the experimental group plays enriched version of the educational computer game which has supplemental graphical elements needed to indulge in roles, messages of support, and several competitive elements. The working hypothesis assumes the difference in the number of games played between the two groups.

4   Methodology

The learning strategies which are implemented in the model are taken out of guidelines provided in draft versions of the following documents: Comprehensive Curricular Reform, and the National Curriculum of the Inter-subject Topic "Learning to Learn" of the Ministry of Science and Education of the Republic of Croatia [15].

The implemented strategies include problem solving and memorization. The strategies for problem solving which are represented in the game developed for the purpose of this research are the following:

- Being imaginative in problem understanding (e.g. embracing the problem, situation or process)
- Simulating and testing certain parts of problems and processes (attempts and check-ups)
- Taking into consideration various possible solutions and different ways of approaching solutions
- Re-evaluating assumptions
- Guessing, checking-up, adapting
- Taking a different approach
- Checking the selected solution

While the strategy of asking for help is implemented through an adapted social network, the strategy of memorization is used through repeating all the way up to the state of overlearning.

In line with the draft of the Framework for the Evaluation of the Learning Process and Outcomes in Primary and Secondary School Education [16], there are three assessment methods: assessment for learning, assessment as learning, and assessment of the learned. Assessment for learning and assessment as learning facilitate gaining insight into learning and teaching, recognizing strengths and weaknesses in learning, and planning future learning and teaching. They do not result in grades. Assessment of the learned is a summative assessment. It assesses the level of student accomplishment at the end of a unit and usually results in a grade. With regard to the purpose, assessments can be:

- Diagnostic (conducted prior to the process of learning and teaching in order to estimate quality and the level of knowledge and skills which enables teachers to teach based on what students really know, and not on what they assume that the students know), and
- Formative (does not result in a grade and is conducted while learning and teaching with the purpose to give feedback on student progress and to improve future learning and teaching by recognizing strengths).

By implementing the learning strategies through information-communication technology, which can facilitate the development of metacognitive processes and self-assessment of the acquired knowledge, the proposed model gives instant feedback to both teachers and students. Since the model is based on the use of educational computer games in e-learning systems, a computer game "Zagonetke mudrog lisca" (Riddles of the Wise Fox) has been developed for the purpose of this research. The initial screen is shown in Fig. 1. Players ("Igrač") log in by using their nicknames ("Nadimak"). The game covers primary school Mathematics through solving problems involving Roman numerals and it is fully adapted to m-learning.

Fig. 1. Initial screen of the game "Zagonetke mudrog lisca"

4.1 Motivational elements and inter-group differences

The game "Zagonetke mudrog lisca" has 15 difficulty levels. In comparison to the control group, the experimental group has supplemental components integrated into the model with the aim to boost intrinsic motivation:

1. Additional graphical elements for indulging in the game – enhanced graphics which emphasizes and additionally explains the story related to the robot Matko and the fox Luki, which are the main characters in the game
2. Motivational messages – textual encouragement and support while playing
3. Competitive elements – the possibility of additional comparison of student results through trophies and medals; trophies and medals are visible in the game from the very moment the student wins them and this applies to each and every level during the game, but also after the game (Fig. 2)

To indulge in roles, prior to the start of the game the students are additionally engaged in the story about the robot Matko who was captured by the fox Luki. Different excerpts about them are shown within the course of the game, but also in the introductory part and in its extended form at the beginning of the game, and in a shortened version at the end of the game if all the levels are finished.

Motivational messages written by the robot Matko at each level are selected from a subset of positively labelled lemmas in the lexicon CroSentiLex [17]. The minimum level of positive sentiment of the selected words is 0.68. Dependent on the level, the messages include some of the following phrases: It's great to be fast! We are getting closer, we are halfway through! We will be awarded a silver medal! Yessss..., we are two-thirds of the way there! Winning is awesome! Just two levels away! Brilliant, solve this and the gold is ours!, etc.

a) Control group b) Experimental group

Fig. 2. Interface of the final screen for a) the control group and b) the experimental group in "Zagonetke mudrog lisca"

Fig. 3 shows interface of each competitive element: a) "Pehari i medalje" (Trophies and medals), b) Top 20, and c) feedback on the progress in comparison to other students which can be accessed by pressing the button "Kako napredujem?" (Show my progress). The information provided under Show my progress is the following: the number of times the player has played the game (row 1), the player's average score

per game (row 2), the player's average level (row 3). The worst and best scores obtained on a global level, i.e. when all players are taken into consideration, are also given next to the player's scores.

a) Trophies and medals ("Nadimak" refers to the nickname)

b) Top 20 ("Mjesto" refers to the place in the game, "Nadimak" to
the nickname, and "Bodovi" to the average score)

c) Show my progress

Fig. 3. Interface of each competitive element in the experimental
group version of the game "Zagonetke mudrog lisca"

In the competitive version of the game, the experimental group students could win trophies or medals in one of the following ways:

- Bronze medal is awarded if the player finishes level 5
- Silver medal is awarded if the player finishes level 10
- Gold medal is awarded if the player finishes all levels with a maximum of three mistakes
- Trophy is awarded if the player finishes all levels without mistake

Students of both groups can compete with their fellow peers and compare results in the Top 20 list. Rankings in Top 20 are based on student average scores. Otherwise the same student could take up all the places in the Top 20 list which might negatively affect motivation regarding competitiveness among students.

Game levels are ordered by difficulty and the type of task. Each level contains an incorrectly formulated mathematical problem, i.e. incorrect Roman numeral equation,

which needs to be corrected by moving matchsticks used for representing both Roman numerals and mathematical operators.

All the matchsticks are movable, i.e. it is possible to move those which form numerals as well as those which represent mathematical operations or the equality operator. Some riddles can be solved in multiple ways. Students have 50 seconds per level to solve a given problem. The progress bar with time elapsed and time remaining is shown at the bottom of the screen. If a task is solved correctly, the remaining time is added to the total score.

Since the levels and tasks are fixed, i.e., restarting the game results in exactly the same tasks of exactly the same order, solutions can be memorized by heart.

The algorithm applied in creating a level consists of the following steps:

1. Set up matchsticks to form an incorrect equation
2. Set up invisible sprites which react to matchsticks if they form part of a correct answer
3. Add drag & drop event to all the matchsticks
4. Start the countdown and listen to events
5. After each action save the following record:
   (a) Timestamp
   (b) Duration
   (c) Source object of action
   (d) Target object of action
6. Give feedback after each move on the correctness of the move
7. End the game if the time elapses or if three incorrect moves are made

In order to detect positions which satisfy conditions for the correct solution, each matchstick is given a physical body which can interact with other bodies, i.e. sprites (which are set to invisible in the positions which form correct answers). The overlap is checked after the matchstick has been moved by drag&drop functionality of the game development framework Phaser [18].

4.2 Dataset

Students log in anonymously using only their nicknames based on the model of the Anonymized Social Network-based Mobile Game System for Learning Mathematics [19].

The research is conducted on the sample of 104 students attending grades 5-8 of a primary school in the Republic of Croatia. The students are between 11 and 14 years old and they take classes in Mathematics. The time period covered refers to the academic year 2017/2018, and includes one week prior to winter holidays, three weeks of holidays, and two weeks after holidays.

5 Data Analysis and Results

Students of each grade are divided into control and experimental groups. The experimental group plays the version of the game which contains more motivational elements compared to the control group. It is described in detail in subsection 4.1. The statistics related to the number and gender of students, as well as the number of students who take additional classes in Mathematics, are given in Table 2, which is provided for the purpose of group homogeneity analysis. Additional Mathematics serves as an indicator of the student's ability to learn advanced topics in Mathematics.

Any individual class is assigned to exactly one group in a way that one parallel class is assigned to the control group, and another to the experimental group. This division lead to the ratio 1:1 in the control and experimental groups for all but the fifth grade in which the experimental group has two students less than the control group.

Table 2. Description of the sample

Grade	Group	Gender		Additional Mathematics	
		m	*f*	*yes*	*no*
5th	control	7	6	3	10
	experimental	6	5	7	4
6th	control	9	7	3	13
	experimental	9	7	3	13
7th	control	7	4	1	10
	experimental	8	3	2	9
8th	control	6	7	3	10
	experimental	8	5	1	12
Total:		60 (57.69%)	44 (42.31%)	23 (22.12%)	81 (77.88%)

Homogeneity between the groups regarding the distribution of gender is evaluated by applying the chi-square statistical test. We obtain the values of $\chi2 = 0.392$, $p = 0.531257$, meaning that the groups do not show statistically significant differences in their distribution between the two categories. For additional Mathematics we obtain $\chi2 = 0.6617$, $p = 0.41595$, meaning that the differences are again statistically insignificant. These results support the conclusion that groups are homogeneous regarding both, gender and taking additional classes in Mathematics, i.e. statistically significant differences have not been detected in the distributions.

The number of students who finished at least the first level of the game is 34 for the control group and 37 for the experimental group. These students are defined as active students within the respective groups. The experimental group has a higher number of active students (72.55%) compared to the control group (64.15%), as shown in Fig. 4.
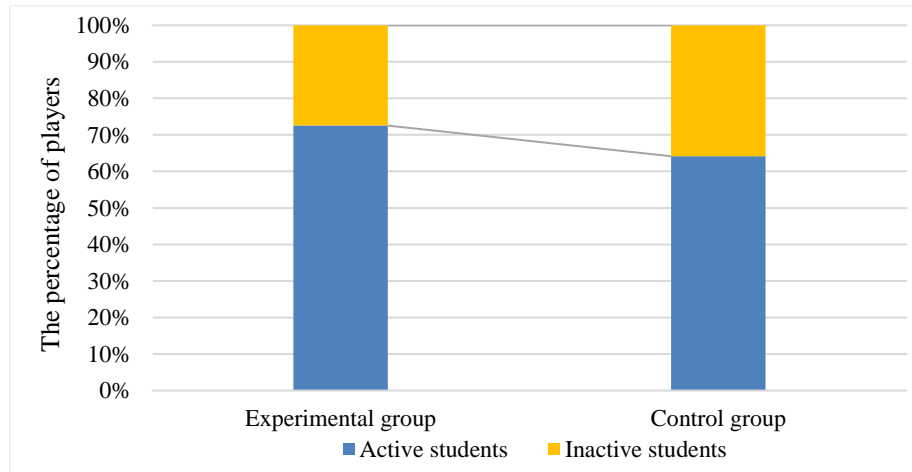
Fig. 4. The distribution of active and inactive students within
the control and experimental groups

The differences in student behaviour between the groups, which are reflected through the use of motivational elements related to keeping track of progress, comparing scores and the number of games played, are given in Table 3.

Table 3. The differences between the control and experimental groups in the use of
motivational elements in the game "Zagonetke mudrog lisca"

Group	Trophies and medals	Top 20	Progress	Game played	Average session
Control	-	601	97	909	11.46
Experimental	448	382	114	1938	10.14

There is no statistically significant difference between the control and experimental groups neither in the average number of games played in succession (average session) nor in keeping track of their own progress.

There is also no difference in the results regarding the trophies and medals won, for which the records were saved for both groups, although the control group had no knowledge of their existence and only the experimental group had access to the trophies and medals report.

The average number of trophies and medals won with regard to the number of games played is shown in Table 4.

Table 4. Trophies and medals won by the control and experimental groups
in the game "Zagonetke mudrog lisca"

Group	Trophy	Gold medal	Silver medal	Bronze medal
control	0.32	0.20	0.09	0.12
experimental	0.32	0.07	0.10	0.19

With regard to the total number of trophies and medals won, the experimental group has somewhat lower average results compared to the control group, due to a higher difference in gold medals won in favour of the control group. That might be a consequence of having enhanced graphics and also messages which, although encourage playing, might act as distractors.

The difference in keeping track of the Top 20 results between the two groups is statistically significant ($\chi 2 = 4.8555$, $p < 0.05$). The experimental group less often looks at the Top 20 list because of the additional motivational element which gives them way to compete in terms of the number of trophies and medals won. Therefore, they more often use that option than the former one.

According to the chi-square test, there is a statistically significant difference between the groups in terms of the number of games played ($\chi 2 = 8.0661$, $p < 0.01$). The experimental group plays the game more than twice as often.

The distribution of the average number of games played by each group is given in Fig. 5 (experimental: 52.41; control: 26.74).
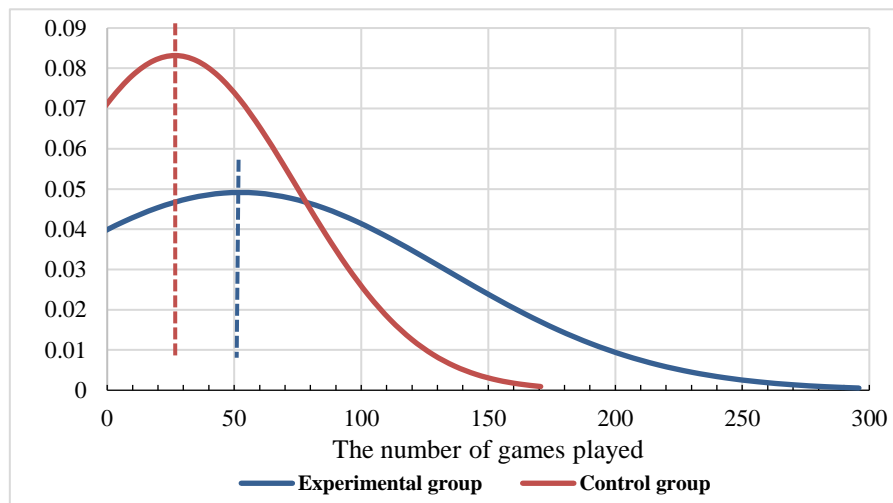

Fig. 5. The distribution of the average number of games played by the control and experimental groups in the game "Zagonetke mudrog lisca"

By analysing the results of the statistical tests, a positive influence of including additional motivational elements can be observed in terms of higher frequency of playing in favour of the version which includes additional graphical elements needed to indulge in roles, messages of support and more competitive elements. The null-hypothesis is, therefore, rejected and the working hypothesis that there is a difference between the control and experimental groups in the number of the games played is accepted in the scenario in which the experimental group plays the version which includes additional graphical elements needed to indulge in roles, messages of support, and uses more competitive elements. In simple words, the use of additional

motivational elements in educational computer games for learning Mathematics has a positive effect on the frequency of playing.

6 Conclusion and Future Work

When problem solving tasks are integrated in computer games, the learning becomes much more fun for students. The developed model can be continuously used to improve learning. As a method, it represents assessment for learning. Besides, it gives on-demand feedback on their progress in knowledge acquisition and their progress in relation to other students, i.e. by selecting the option Show my progress. The students can gain insight into their achievements from both, the Top 20 list and the number of trophies and medals won. Therefore, the model can also be used as a method of assessment as learning.

The results presented in this paper signal at the importance of adding competitive elements to act as a motivation and thus positively affect the frequency of game usage, i.e. repeated playing. Intrinsic motivation can also be affected by integrating some other motivational elements such as graphical elements or messages of encouragement.

In order to detect which of the elements individually or which combination of elements has the greatest influence on the student motivation for playing the game, several experimental groups would have to be formed. Moreover, elements which might distract users and thus have a negative influence should be analysed separately.

7 Acknowledgement

8 References

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