Design of a Computer Game that Has a Positive Effect on Motivation and Learning Outcomes in Mathematics Teaching

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ABSTRACT

This article proposes a set of design criteria for creating effective mathematical computer games that can meet the needs of all participants in the teaching process. It emphasizes the importance of designing computer games that achieve the educational goal, have clear rules, develop cognitive abilities, and are adapted to the students' age and abilities. The article also highlights the benefits of using well-designed mathematical computer games in education, including faster acquisition of knowledge, skills, and abilities in an interesting and acceptable way, leading to a more creative and modern teaching process. However, the study acknowledges some limitations, such as not considering the views of all stakeholders, not evaluating the effectiveness of specific games, and not exploring potential negative impacts of prolonged use of computer games on students' health and well-being. The proposed set of criteria provides a useful framework for designing educational games, but future research should explore the perspectives of a wider range of participants, evaluate the effectiveness of different games, and investigate the potential negative impacts of prolonged use.

Keywords: education; game-based learning

1. INTRODUCTION

This article will present the design of a mathematical computer game that was created based on previous research, as well as research that was conducted with the aim of determining the best possible approach to teaching with regard to the use of computer games in teaching mathematics (Bado, 2022, Baytak & Land, 2010, Hummel et al., 2017, Overmars, 2007). Based on everything, the criteria for a computer game that will have a positive effect on learning outcomes and motivation are defined. The actual implementation of the research is explained briefly because this text deals only with recommendations for better game design.

The research represents a significant contribution to the improvement of mathematics teaching methodology in primary and secondary schools using information and communication technology and results in recommendations for improving the quality of teaching and better achieving the goals and tasks of the educational process. A model was created to assess the didactic and technical validity of the computer game and a proposal for the design of the computer game. First of all, it is important to note that it has been established that the best results are achieved in a mixed form of teaching (Divjak & Tomić, 2011), so this is also important when designing a computer game. According to previous research and experience of professional work, it is necessary to investigate the mentioned area. The scientific contribution of the research is manifested in new knowledge and the design of an educational mathematical computer game.

2. METHODS

On the basis of the conducted research, it is possible to claim that the use of mathematical computer games in teaching mathematics contributes to a more efficient and faster realization of educational goals at all levels of education. The use of mathematical computer games, based on learning theory, in the teaching of mathematics among students of different chronological

ages affects the development of their logical abilities expressed through the objectives of mathematics as the art of solving mathematical problems and through mathematics tasks that aim to train students for abstract thinking, logical reasoning and precise formulation of phenomena.

The use of mathematical computer games in classes contributes to building a positive attitude of students of different chronological ages towards mathematics as a subject that students perceive as difficult, contributes to their greater motivation and easier, faster and more permanent acquisition of knowledge compared to classes without the use of mathematical computer games.

The research work (Tomić, 2011) empirically proved that the application of mathematical computer games in the teaching of mathematics has a positive effect on the learning outcomes of students of all age groups. Chronological age did not prove to be a significant factor for the impact of computer games on learning outcomes, so, therefore, there is no difference in the learning outcomes of younger students compared to students of older chronological age. The influence of computer games has been confirmed regardless of chronological age. All this was confirmed by researching three groups of students with regard to age: students of the 4th grade of elementary school (students of younger school age, average chronological age of 10 years), students of 8th grade of elementary school (students of older school age, average chronological age of 14 years) and 4th grade high school students (average chronological age of 18).

The research proved that the use of mathematical computer games has the same effect on both sexes, which was confirmed by all other previous studies. There is no statistically significant difference in learning outcomes between boys and girls after using a mathematical computer game in class.

A blended approach to learning with the help of computer games gives better results in terms of achieving better learning outcomes than strategies that are taught only traditionally or only using games. This approach to learning mathematics using mathematical computer games proved to be the best teaching strategy. Teaching that includes only mathematical computer games or only the traditional approach produced equal results (weaker compared to the mixed approach). This indicates the need for interventions in the traditional approach to teaching mathematics.

Thus, the conducted empirical research has confirmed that the application of mathematical computer games in the teaching of mathematics has a positive effect on the learning outcomes of students of all age groups. The differences between the results after the final test were not statistically significant. In other words, the progress achieved by all age groups after playing mathematical computer games was equal. Accordingly, there is no statistically significant difference between age groups after playing age-appropriate mathematical computer games that meet the criteria of a good educational computer game.

All of the above made it possible to create criteria for the design of a computer game that has a positive effect on motivation and learning outcomes in mathematics classes, combining different methods and media in a blended form of teaching that allows students to learn in the way that suits them best, using different learning styles, while avoiding monotony in teaching and learning. In this way, according to (Bersin, J., 2004) along with the understanding and application of learned facts, it is possible to systematize knowledge and its durability, which is also the approach to teaching in the modern education system.

3. RESULTS

(Divjak & Tomić, 2011) point out that information technologies are an integral part of modern society, which bases its progress on the fact that knowledge is one of the goals of education. In addition to acquiring knowledge, skills and routines, the goal of education is to create a complete person who can make rational and timely decisions, react deliberately in new

situations and be trained for lifelong learning. Information is the basis of modern society, and the goal of the media is to convey information or messages. Communication can take place in different ways: speech, signs, codified behavior and can be direct or through the media. The distinct communication-technological connection of today's society is also the reason for its global connection through the media and information networks. It is also interesting how most of the communication is done through visual media. We decide about the form and content of things, mostly, based on their appearance, starting from the observation of visual forms towards their understanding. We often experience reality through the media - photography, television, film and video, and new media are becoming increasingly popular: the Internet, computer games, virtual worlds, multimedia CD-ROMs, web, blog, e-mail, interactive television and mobile devices. In today's world, in which the use of new information and communication technologies, and therefore computers, and playing computer games has almost become an everyday thing, there is a need for their use for educational purposes, i.e., as an aid in the realization of the goals of upbringing and education. Learning through computer games reveals new ways of designing lessons using information and communication technology and at the same time provides students with the opportunity to acquire the skills and abilities needed for the future. Learning through computer games can be a supplement to classic work in the classroom. Why are computer games important? Through educational programs, children learn in a simple and interesting way, and games make technology fun. Computer games develop cognitive skills, intelligence, problem-solving skills, and a sense of competence and self-confidence. Games also have a positive impact on hand-eye coordination, fine motor skills and spatial skills. Talking about computer games in elementary and high school classes, it is necessary to refer to the design of the computer game. How important it is for a good computer game for educational purposes and what it should contain will be discussed in this text based on the findings of previous research conducted in the world, as well as this research work. Although there is no standard classification of computer games, according to (Gros, 2007) computer games can be divided into the following types:

• action games (platforms) – reaction games,

• adventures – the player solves a certain number of tests with the aim of passing through the virtual world,

• fighting games – games that involve fighting against computer-controlled characters or those controlled by another player,

• role-playing games - the player assumes the role of another person or being,

• simulations - the player must achieve a specific goal in a simplified representation of reality,

• sports games - sports as the basis of these games,

• strategies - games with a historical or imagined situation and expect the player to choose the best strategy to achieve the given goal.

All the mentioned types of games were used in various researches in the educational process, through which they were determined, along with the sociological aspect of the game (the influence of computer games on the development of social skills, especially togetherness) and the effects of learning and the realization of educational goals.

What is meant by good computer game design? Opinions differ. We will list the results of previous research in the world and the important criteria for a good mathematical computer game, which we came up with through our own research.

They claim that serious computer game design is an art (Jantke & Hume, 2015) and add that it is important to understand digital role-playing based on theories of social psychology. The results of the research carried out by (Suryono & Subriadi, 2016) show that it is very important to know what is the deeper influence on the attitudes of the players that is changed

by playing the game. This is very important when explaining the motivation of students to play a computer game.

(Shafie et al.., 2010) point out that the following criteria are necessary for the quality design of an educational computer game:

• every educational computer game must have specific and clear educational goals,

• a computer educational game, at its beginning, should have clear and comprehensible instructions so that students understand what is expected of them and better manage themselves in different scenarios of the game,

• the importance of including different levels of the game, ranked by difficulty (for example, if there are 6 levels in the game, to progress in the game it is enough to complete the first 3 levels. In this way, it is possible for students of different abilities to progress through the levels depending on their abilities, while that makes them feel successful),

• discreet sound that does not interfere with concentration and the goal of the game, which is primarily the acquisition of certain knowledge or the development of certain skills.

The paper (Midura et al., 2015) presents a design framework aimed at creating more accessible games for better learning outcomes. It is important to start the design process by stating the objectives for the unit or lesson for which the game is being designed. The next step is to design in-game tasks, learning experiences that will give players the opportunity to explore the topic and practice. And finally, it is necessary to create a model of proof of learning results. These steps cannot be executed sequentially but must be re-examined.

(Moreno-Ger et al.., 2008) believe that the design of an educational computer game is important:

• choose a game genre suitable for the content,

• create a visual appearance of the game adapted to the specifics of the teaching content and the age of the children,

• take care of the good integration of the game with the online environment since it is the environment that is the basis of most educational games. Most computer games are integrated in an online environment. However, if teachers create the game themselves, it is advisable to place it in an LMS system and thus monitor the effects of the computer game on the participants of the educational process.

A computer game must be designed to increase the results of learning outcomes with special emphasis on increasing cognitive abilities, school achievement, cooperative work and motivation, and the engaging appeal of the game. They pointed to all of the above in their research (Orr & McGuinness., 2018).

In his research (Bado, 2022) he reviews the literature on computer games, primarily analyzing the design of computer games. In doing so, he states the importance of the theoretical basis of computer game design, design elements that lead to successful learning, and learning outcomes by playing a computer game. Furthermore, the author considers the following important elements of educational computer game design: clear game goals, well-defined game rules, narrative context, appropriate rewards and interactivity. All these elements are necessary in order for the game to stimulate the achievement of the desired learning outcomes, that is, the educational goals of each lesson in which the computer game was used.

Creating an educational computer game includes a large number of aspects according to (Overmars, 2007). The way of playing the game must be well defined, a well-told story, plastic characters, well-created all levels of the game, interaction and quality management of computer controls are important. According to the author, the basis of a mathematical computer game is the rules that define the game. Thus, the primary aspect in designing a mathematical computer game is to define a set of consistent, well-defined and meaningful rules. Therefore, a person who designs a mathematical computer game requires creativity, but also the possession of mathematical knowledge and skills. Furthermore, it is important that the computer game

contains events that occur with a certain probability (e.g., creating a special/bonus level) in such a way that the game designer selects the probable events, thus making the game play more interesting. (Overmars, 2007) also points out that before the commercial use of a computer game, it is necessary to conduct a usability test, because this is the only way to prove whether the game meets the players' requirements.

And (Gros, 2007) lists the elements that should be taken into account when designing an educational computer game:

• learning content,

• transfer of learning experience,

• learning complexity,

• individual differences - there are large differences in abilities and interests among students, therefore the author notes that, until now, insufficient research has taken the above into account,

• organizational aspect – it is important to find a way to integrate the computer game into the teaching process, keeping in mind the time. Namely, - playing games, in general, requires many hours of playing, so he suggests continuing the game outside of school, i.e., at home,

• the role of the teacher - a teacher with little experience in playing computer games feels insecure and needs significant support during the process of using the computer game for educational purposes.

(Schaefer & Warren, 2004) in their research paper suggest a good structure of an educational computer game:

• modeling - choosing the type of geometry during the game, the functionality of the geometry during the game and the way in which the geometry will be manipulated in the game,

• rendering – there are two choices for 3D games, OpenGL and DirectX,

• animation – determination of movement by animation and other animation elements,

• networking - it is necessary to foresee the possibility of playing an educational computer game in a network, although the game should primarily function as a stand-alone,

• other components - which are not really necessary, and depend on the type of game and previous elements such as: the appearance and content of the menu, the way of configuring different game settings, music, sound effects, etc.

Furthermore, the authors propose a graphic design of the game, which must contain:

• computer game level design,

• character design,

• subject design,

• other graphic elements - photos, video clips, etc.

They also point out the importance of adapting the design of the computer game to students of different abilities and adapting the time duration of the computer game within the teaching process.

Similar to its predecessors (Ellington, 1987), also indicates the elements that computer game design should take into account:

• selection of computer game content,

• choice of game format (e.g., simple card game, adventure, etc.),

• choice of computer game structure (linear, branched, circular, interactive, etc.),

• choose how to use the structure in each of the format types.

The author further points out that the game should be implemented in the teaching process through three phases that include: prototype production, field testing and prototype revision.

Through research, using the AHP method, we determined the design criteria that are important to teachers, computer scientists and students when choosing a mathematical computer game. They were offered the following criteria created in the brainstorming process

(in which teachers of mathematics and computer science participated) and based on previous research:

• interface (user interface and game content comprehensible and appropriate for the age/user),

• educational framework (compatibility of the game with the existing educational framework),

• goal (clear goals and rules of the game),

• development of abilities (support for the development of cognitive abilities and intelligence),

• development of creativity (support for the development of creativity and competitive spirit),

• multimedia (information presented or saved in a combination of text, graphics, sound, animation and video combined via a computer),

• interactivity.

The aforementioned research showed that the most important criterion for teachers when designing a mathematical computer game is its compatibility with the existing educational framework. Namely, it should primarily be in accordance with the teaching contents, following the realization of educational outcomes. The second criterion, in order of importance, includes clear goals and rules of the computer game. The next criterion that they consider important is the development of abilities, that is, that the computer game develops students' cognitive abilities and intelligence, and then that it affects the development of their creativity. After the mentioned criteria that teachers consider the most important for good design, they attach somewhat less importance to multimedia content in a computer game, as well as to a user-friendly interface and interactivity.

For students and computer scientists, unlike teachers, the criterion of multimedia in a mathematical computer game is in second place, together with the criterion of the clarity of the goal and the rules of the game. And for them, the most important criterion is the compatibility of the game with the existing educational framework. After that, it is important for them that the game contributes to the development of cognitive abilities and intelligence, as well as to the development of creativity, and that the interface is user-friendly. According to them, interactivity is the least important criterion for a good mathematical computer game.

It is an interesting fact that students and computer scientists attach great importance to multimedia content. Multimedia usually means combining text, sound and video. Today's development of online technologies provides multimedia with unlimited possibilities. The internet is characterized by the use of text, sound, images, interactive elements and animation. The content compiled in this way provides rich presentation possibilities using advanced technological solutions, which is, in a way, in line with the area of interest of computer scientists, but also of students who are typical representatives of new generations who like to learn by combining text, sound, image, interactive elements and animation.

Regarding multimedia, (Bidarra & Martins, 2010) presented a prototype of an educational multimedia system called Geodromo. The basis of their project was the creation of a multimedia simulator and an online puzzle game with the aim of improving the learning process. When designing, they focused special attention on the cognitive and affective side of the instructions. In this challenging process, both for technicians and designers, they became aware of the fact how important it is to take care of the design elements of a computer game (in this case, multimedia) and align them with the goals of the game (in this case, to affect the quality of learning).

Educational theories surrounding the use of computer games in teaching are constantly evolving. They primarily concentrate on the design and effects of educational games on motivation and learning. According to (Warren et al., 2008), playing educational computer

games, but also designing computer games itself, achieves the realization of the educational goals stated in the teaching curriculum. The aforementioned authors state that educational games such as Math Blaster or Reader Rabbit (so-called drill and practice games) are based on the constant possibility of repetition and practice with almost simultaneous feedback on the acquisition of the content. At the same time, they recall the research conducted by Lee et al. in 2004, in which they proved that a game designed in this way (drill and practice) helps children practice and solve mathematical facts and problems and increases their speed and accuracy.

The results of the research conducted by (Baytak & Land, 2010) show the advantages of creating, i.e., designing, an educational computer game by students. The advantages are reflected in the following:

• designing an educational game allows pupils/students to present their understanding of some content in a concrete and meaningful way,

• game design leads to greater engagement of participants and strengthens the sense of community in the class,

• strong motivation of students for work and learning, which proves their constant engagement

• encourages diversity of ideas,

• students learn to ask for and provide help.

(Leng et al., 2010) also highlight the benefits of designing a computer game by students by pointing out the extra help students have at their disposal using some of the following programming tools: Game Maker, Torque Game Builder, Golden T Game Engine, The Game Creators, and 3D Game Studio. At the same time, it is important to emphasize that creating computer games is a new experience for students and they need certain prior knowledge, i.e., knowledge of working in such an environment. Research conducted by (Leng et al.., 2010) in a secondary school in Malaysia shows that Game maker is the most suitable tool for developing own of educational games because it provides a simple environment for game creation. Students successfully created computer games with this tool without special programming skills.

Regardless of all the mentioned advantages of using computer games in teaching and despite the fact that a large number of teachers believe that computer games have great educational potential, many teachers still have a negative attitude towards them. Therefore, (Demirbilek & Tamer, S, 2010) investigated the reasons for such attitudes in their work. According to the aforementioned research, the reasons for some teachers' concerns about the use of educational computer games in mathematics classes are as follows:

• the opinion that computer games have limited educational potential and the fear of an inadequate atmosphere in the classroom while playing a computer game,

• inadequate equipment in classrooms (which primarily refers to hardware),

• not enough mathematical computer games in the mother tongue,

• computer math games do not uniformly cover every area of mathematics,

• playing computer games requires a lot of time, and there is a fear that it will not be possible to process the given curriculum in the allotted time.

4. DISCUSSION

The results of this research suggest to professional manufacturers of computer games that it is necessary to include teachers in the process of creating a computer mathematical game because, only in this way, their attitude towards the role of mathematical computer games in the teaching process would change, but also contribute to the development of those design criteria that are important in the educational process itself.

Therefore, a good design of mathematical computer games is reflected in the unity of purpose, functionality and economy of the teaching process. It is necessary to include playing

computer games in the teaching process because they contribute to the faster achievement of educational goals. This is supported by the fact that information is easier to remember if it is received through several senses (e.g., information received through the sense of sight is remembered better than information received through the sense of hearing, since more than a third of the cerebral cortex deals with visual information processing). Images and movies embedded in the presentation enable memorization of the presented information incomparably better than when the information is interpreted only in textual form. At the same time, information received through different senses (sight, touch, motor) reaches students in several ways, and the possibility of remembering the content is far greater than if the information is received only through one sense, i.e., in one way. The design of a mathematical computer game should include criteria that are important to all participants in the teaching process, and therefore their views should be taken into account when creating mathematical computer games. At the same time, most researches agree that computer games, above all, must achieve the given educational goal (respect the educational framework) and that the rules and goals of the game itself must be precise and clear. Furthermore, the educational computer game must develop the intellectual, psychomotor and creative abilities of the students. Design criteria such as interface, multimedia and interactivity should be aimed at achieving the given educational goals. It is also important that the design of the computer game is adapted to the students according to their chronological age and their abilities, and that it takes into account its duration within the teaching process. There are multiple benefits in the use of well-designed mathematical computer games in classes because, along with the use of modern information and communication technology, students are given the opportunity to acquire knowledge, skills and abilities more quickly in a way that is acceptable, motivating and interesting to them, all for the purpose of achieving goals upbringing and education.

We can summarize all of the above in the Table of criteria that are necessary for us and whose importance is defined by the order of listing. Likewise, the importance of the criteria was defined by the reflection of a team of experts in the field of mathematics and information sciences, teachers in primary and secondary schools, as well as pupils in primary and secondary schools. Furthermore, each of the criteria is explained in the overview of previous works as an important criterion for a good computer game (see Table 1).

Table 1 Educational computer game design - criteria proposal

Compatibility of the game with the existing educational framework	(Ellington, 1987) indicates that the choice of computer game content is an important element in the creation of a computer game. If it is educational, the content must be adapted to the educational framework. (Roach, 2003) consider an important criterion of a good mathematical computer game to be comprehensible content of the game that is in accordance with the existing educational framework, i.e., with the goals and tasks of the educational process. Furthermore, (Moreno, 2002) in his work presents cognitive theories of learning using multimedia and emphasizes the need to take into account the cognitive and individual needs of students when using multimedia in the teaching process. Fifth and sixth grade elementary school students learned to add and subtract whole numbers using a multimedia interactive game that was made according to the existing educational framework. The results showed that the computer game helped reduce the cognitive load, especially for students with a lower level of prior knowledge and less experience in using computer technologies. (Karakus et al., 2008) conducted research in which they sought to find out what high school students think about playing computer games in mathematics classes and what their expectations are from

	playing such games. 1223 secondary vocational school students from 8 different schools that were distributed in 6 cities participated in the research. They determined that the respondents believe that computer games can be used in mathematics classes primarily to improve their mental abilities and that they consider the game's compatibility with the existing educational framework to be very important. A similar study was conducted in 2017 in Pakistan. (Khan et al., 2017) show the importance of matching the game with the educational framework. This same criterion is considered important by many other researchers in the previously mentioned research (Azamovna, 2022; Huang Wen-Hao et al., 2010; Wang & Zheng, 2021). (Miller & Kocurek, 2017) point out in their research that the most important criterion for the design of an educational game is adaptation to the content with the integration of theoretical frameworks from the field of learning science, all with the existing educational framework.
Multimedia contents	(Schaefer & Warren, 2004) suggest in their research work that a well-structured educational computer game must also contain well-developed multimedia elements. Multimedia elements (motivational elements that support the flow of the game: animations, music, special effects) were also highlighted in the brainstorming process as an important criterion of a good mathematical computer game. In this regard, the visual appearance of the game is also important, which should contain different colors and interesting details (which varies from person to person). (Gee, 2003) emphasizes the importance of good multimedia content in his research. Also, (Vankúš, 2021) claims that mathematical computer games should contain fun elements (graphics, sound, story, characters and humor) in order to achieve their goal. Namely, properly directing attention to important visual parts in a multimedia environment (Fonseca & Câmara, 2020) helps students learn and remember. Clarity and natural animation, quality multimedia content, as an important element of a good educational game, is highlighted by (He, 2017) and claims that clarity is important because it facilitates understanding of the environment or context and reduces confusion or frustration.
Clear goals and rules of the game	According to (Warren et al., 2008), playing educational computer games, but also designing computer games itself, achieves the realization of the educational goals stated in the teaching curriculum. Through the brainstorming process, it was determined that the game must have clear and comprehensible instructions and contain additional information (in the form of explanations) appropriate for the age for which it is intended. It was pointed out that this criterion is extremely important for games intended for younger children. At the same time, it is important what we want to achieve with the game - therefore, the goals and achievements of the game should be clearly defined. Research also agrees with this opinion, proving that it is extremely important that a mathematical computer game has a clearly expressed goal or goals (Hurd & Jennings, 2009; Malone & Lepper, 1987). (Yu et al., 2021) in their work examine the attitudes of elementary school students who played a mathematical computer game that contained clear and comprehensible goals and clear game rules. They determined a significant relationship between the attitude towards mathematics and the attitude towards a mathematical

	computer game and concluded that a computer game that contains clear goals and rules of the game has a positive effect on students, developing their positive attitude towards learning mathematics. The result of the research conducted by (Marchetti & Valente, 2015) proves that the use of educational computer games in teaching can improve the teaching process and achieve educational goals more easily, provided that these goals are clearly defined in advance.
Support for the development of cognitive abilities and intelligence	(Bidarra & Martins, 2010) presented a prototype of an educational multimedia system and an online puzzle game with the aim of improving the learning process. When designing, they focused special attention on the cognitive and affective side of the instructions. Many studies have shown that the game must be created to support the development of students' cognitive abilities and intelligence. (Sedig, 2007) in his research, in which elementary school students participated, shows how playing a game facilitates children's understanding and at the same time makes learning more fun. Through research, it has also been proven that such a way of learning using computer games is purposeful and effective. Furthermore, the research showed that, especially in geometry, there is a great possibility of using mathematical computer games for the purpose of increasing motivation and achieving better educational achievements, increasing the cognitive abilities and intelligence of students. The research (Ke & Grabowski, 2007) proved that playing a computer game supports the development of cognitive abilities in elementary school students. The research included 125 students divided into collaborative groups, and they had a competitive nature. In addition, the results of this research showed that playing a mathematical computer game is more effective than traditional math exercises, both in increasing student results in knowledge tests and motivation for learning, but also that it affects the formation of a positive attitude of students towards mathematics. The importance of supporting the development of cognitive abilities is emphasized by (Orr & McGuinness, 2018) in their work in which they examine what exactly learning is in learning using computer games.
Support for the development of creativity and competitive spirit	The competitive spirit is highlighted in the brainstorming process as an important criterion of a good mathematical computer game. And according to (Malone & Lepper, 1987) a good mathematical computer game must stimulate a sense of competition in students. (Huang Wen-Hao et al., 2010) indicate that learning based on mathematical computer games has become increasingly important in recent years, first of all, in the motivation and better knowledge of students, but also in the development of personality characteristics such as curiosity, determination and creativity. Likewise, (Shaffer, 2006) proves that students, apart from learning mathematics, can use the experiences gained through playing a computer game in everyday situations, that is, they can more easily solve the problems they encounter in their everyday life, which increases their creativity. In the research conducted by (Ke & Grabowski, 2007) a mathematical computer game was used that had a competitive character. It has been proven that playing such a computer game has a positive effect on the motivation, attitudes and learning of mathematics among elementary school students, which demonstrates the advantages of a mathematical computer game that awakens a competitive spirit among

	students. On the trail of these studies, there is also a study that dealt with playing games oriented to career choice conducted by (Hummel et al., 2017) and showed that is a kind of competition (when choosing a career) by playing a computer game has had good effects.
User interface and game content understandable and appropriate for the age (of the user)	This criterion was highlighted in the brainstorming process in terms of the importance of a good graphic interface that should be intuitive and suitable for the user. Namely, the participants of the brainstorming pointed out that the appearance of the graphic interface should be appropriate and interesting for children, i.e., a certain age of students, and that students must be able to navigate the menus in the game. This is also the opinion of (Gee, 2003), who claims that a good mathematical game must be appropriate for the child's age. (Vankúš, 2021) emphasized that mathematical computer games should present concepts in a simple and comprehensible way, and that they should have a good user interface for manipulating concepts and objects, as well as quality navigational structures and sequences of activities. According to (Rosas et al., 2003) a well-designed mathematical computer game must have a well-designed and clear user interface and content the game must be clear and comprehensible, because that is the only way it can serve as a motivating factor for students to learn mathematics. Games should be created in such a way that the appearance of the user interface supports the achievement of the educational goals of mathematics in primary and secondary schools (depending on the age for which the game is intended), and especially for learning the basics of mathematics. The user interface and its importance are also dealt with by (Chang et al., 2017) where they use a modular object-oriented dynamic learning environment, and virtualization technology was used for building a private cloud. Furthermore, games and related modules are developed on GoogleApp Engine to improve the performance of the cloud learning system. And a game-based learning approach was adopted to stimulate students' curiosity, resulting in active learning and improved learning outcomes. The already mentioned (Miller & Kocurek, 2017) point out the special importance of game content, which must be age-appropriate, especially for younger children, where they suggest the development of diverse content, but also emphasize how necessary to create a balance between playing and learning in the real world.
Interactivity	According to (Overmars, 2007) the way of playing the game must be well defined, it is important to have a well-told story, plastic characters, well-created all levels of the game, and especially interaction and quality management of computer controls. Interactivity is the first thing mentioned in the brainstorming process. It was stated that it is very important for the player, i.e., the student, to receive feedback by playing a mathematical computer game. Many studies highlight the advantages of interactivity in computer games. The already mentioned (Vankúš, 2021) emphasizes the importance of feedback and indicates the importance of rewarding when playing it. (Moreno, 2002) used multimedia interactive games in his work that visually and symbolically depicted arithmetic procedures. The results showed that a computer game with interactive elements helped reduce cognitive load.

5. CONCLUSION

As a good design of mathematical computer games is reflected in the unity of purpose, functionality and economy of the teaching process, it should include criteria that are important to all participants in the teaching process and, therefore, their views should be taken into account when creating mathematical computer games. In doing so, as an aid in the selection of criteria, brainstorming was used in group decision-making, which creates a table of criteria, and the order of importance of the criteria is determined later using the AHP method for group decision-making. The contribution of the research is, among other things, a proposal for a good design of mathematical computer games. Speaking about the design criteria of a good mathematical computer game, most researches agree that computer games, first of all, must achieve the given educational goal (respect the educational framework) and that the rules and goals of the game must be precise and clear. Furthermore, the educational computer game must develop the intellectual, psychomotor and creative abilities of the students. Design criteria such as interface, multimedia and interactivity should be aimed at achieving the given educational goals. It is also important that the design of the computer game is adapted to the students according to their chronological age and their abilities, and that it takes into account its duration within the teaching process. It is necessary to include playing computer games in the teaching process, since they contribute to the faster and better achievement of educational goals. This is supported by the fact that information is easier to remember if it is received through several senses (for example, information received through the sense of sight is remembered better than information received through the sense of hearing, since more than a third of the cerebral cortex deals with visual information processing). Pictures and movies embedded in the presentation, as well as computer games, enable better memorization of the presented information than when the information is interpreted only in textual form. Information received through different senses (sight, hearing, touch, motor) reaches the student in several ways, which means that the possibility of memorizing the content is much greater than if the information is received only through one sense, i.e., in one way. The benefit of using well-designed mathematical computer games in teaching is reflected in the use of modern information and communication technology, in providing students with the possibility of faster acquisition of knowledge, skills and abilities in an interesting and acceptable way, which achieves the tasks and goals of the teaching process. From all of the above, but also as a result of our research, the following, most important, criteria for the design of a good mathematical computer game were proposed, listed in order of importance:

- compatibility of the game with the existing educational framework,
- multimedia content,
- clear goals and rules of the game,
- support for the development of cognitive abilities and intelligence,
- support for the development of creativity and competitive spirit,
- the user interface and game content are comprehensible and appropriate for the age (of the user),
- interactivity.

By using a computer game that does not take into account the mentioned criteria, the negative effects of playing computer games in the teaching process may occur. Other researchers agree with this, stressing the importance of a good choice of educational computer game. The negative effects of playing computer games also occur if the game is not aligned with the goals of the educational process. Furthermore, some games (this refers to games whose primary purpose is not education) can increase aggressiveness in students and develop insensitivity to violence. Likewise, some games can lead to social isolation and individuation, especially after playing for a long time. Also, a longer playing time can lead to health problems related to non-ergonomic working conditions at the computer.

Most of the research agrees that computer games must first of all achieve the given educational goal (respect the existing educational framework) and that they must have precise and clear rules and goals of the game. The mathematical computer game, furthermore, must develop the intellectual, psychomotor and creative abilities of the students. Design criteria such as a user-friendly interface, multimedia and interactivity should be aimed at achieving the given educational goals. It is also important that the design of the computer game is adapted to the students according to their chronological age and their abilities, and that the duration of the game is taken into account within the teaching process itself.

There are multiple benefits in using well-designed mathematical computer games in the classroom. With the use of modern IT and communication technology, students of all ages are given the opportunity to acquire knowledge, skills and abilities more quickly in a way that is acceptable, motivating and interesting to them, and the educational process thus becomes more creative, modern and adapted to the new, IT-literate generations of students.

The design of mathematical computer games is an important aspect of modern education, and this study proposes a set of criteria for creating effective games that meet the needs of all participants in the teaching process. However, there are several limitations to this research that should be acknowledged. Firstly, the study only gathered the opinions of a specific group of participants, and there may be other stakeholders such as parents or educators whose views were not considered. Therefore, future research should explore the perspectives of a wider range of participants to gain a more comprehensive understanding of the effectiveness of mathematical computer games in education. Secondly, the research did not investigate the effectiveness of specific mathematical computer games in achieving educational goals. While the proposed criteria provide a useful framework for designing educational games, it is important to evaluate the effectiveness of specific games in achieving their educational objectives. Therefore, future research should focus on evaluating the effectiveness of different mathematical computer games across different age groups and learning styles. Thirdly, the study did not explore potential negative impacts of the prolonged use of mathematical computer games on students' health and well-being. While there are many benefits to using well-designed educational games, prolonged use of computer games can have negative effects on students' health and well-being. Therefore, future research should investigate the potential negative impacts of prolonged use of mathematical computer games In light of these limitations, there are several areas for future research. Firstly, longitudinal studies should be conducted to evaluate the long-term impact of using mathematical computer games on students' academic performance and motivation. Secondly, the perspectives of other stakeholders such as parents and educators should be explored to gain a more comprehensive understanding of the potential benefits and drawbacks of using mathematical computer games in the classroom. Thirdly, the potential of integrating mathematical computer games with other teaching methods, such as project-based learning, should be evaluated to enhance the learning outcomes. By addressing these limitations and exploring these areas for future research, we can continue to develop effective and engaging educational games that benefit students and educators alike.

This study has several limitations that need to be acknowledged. First, the research gathered opinions only from a specific group of participants, including teachers, computer scientists, and students, without involving other important stakeholders such as parents or a wider range of educators. Future research should include these additional perspectives to gain a more comprehensive understanding of the effectiveness and acceptance of mathematical computer games in education. Second, the study did not evaluate the effectiveness of specific mathematical computer games in achieving educational goals. Although the proposed design criteria offer a useful framework, it is important for future research to empirically assess how different games impact learning outcomes for various age groups and learning styles. Third, potential negative effects of prolonged use of mathematical computer games on students'

health and well-being were not explored. Extended computer game usage can sometimes lead to health issues or social isolation. Therefore, future studies should investigate the possible adverse impacts of long-term use and how to mitigate them. Additionally, future research could benefit from longitudinal studies that examine the long-term effects of mathematical computer games on students' academic performance and motivation. Exploring the integration of computer games with other teaching methods, such as project-based or blended learning, could further enhance learning effectiveness. By addressing these limitations and expanding the scope of inquiry, future research can contribute to the development of more effective, engaging, and balanced educational computer games that benefit both students and educators in diverse learning environments.

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