Types of graphic interface design and their role in learning via mathematical applets at the elementary school

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The research goal was to test the suitability of the character of the graphic design on the student's achievements while engaging with mathematical applets for elementary grades. This quantitative research compares two pairs of mathematical applets, which differ only by the type of graphic design; in the extent of detail and the amount of distraction, while the mathematical problems are identical. The first applet has animated graphics based on designs by Matific, a repository of mathematical applets. The second applet was designed specifically for this research in a schematic and visually simple version of the same activities. Students in the schematic graphics group made fewer mistakes and needed less time to complete the activity than students in the animated graphics group. In addition, students with lower mathematic ability succeeded better in the schematic group. No differences between the two groups were observed regarding the level of students' enjoyment.

Keywords: Educational design, graphic design, schematic graphics, cognitive load, mathematical applets.

Introduction

Gamification is an effective learning strategy in mathematics education at the elementary level. Moreover, a clever integration of educational computer games during the learning process contributes to the student's learning, and provides positive experiences (Wouters & Van Oostendorp, 2013). During integration of mathematical computer games both cognitive processes and motivational implications on the learning are taken into account.

The cognitive load theory and the dual-coding theory (Kalyuga, Chandler, & Sweller, 2000) depicts the learning process as two independent learning channels, a visual and a textual channel. The decoding of each channel is processed separately in our minds, and only then can be processed together to create a unified meaning alongside prior knowledge. The decoding and processing procedures strain the working memory, which has a limited load capability (Cook, 2006). The split between the two channels can ease the learning process if the two channels are supplementary. However, an ineffective split may cause additional load on the working memory and therefore decrease learning efficiency. Learners who face difficulty with the learning material, and those who have less prior knowledge, are more likely to be "sensitive" to the dual channel split. Prior studies have shown that such learners are less capable of utilizing visual content that accompanies textual content (Tsai et al., 2016; Mason, Tornatora, & Pluchino, 2013).

Aside from the cognitive aspect, another perspective on the effectiveness of learning by computer games, is through the motivational influence it may have on the learner. Enjoying the learning activity may lead the learner to identify with the learning goals and values (de Lope et al., 2017; Chang, Evans, Kim, Norton, & Samur, 2015; Sedighian & Sedighian, 1996). Graphic design which is consistent with the learner's interests can help the learner relate to the game. Relatedness, as used by Ryan & Deci (2000), is crucial for achieving intrinsic motivation.

Many studies compare computer games to traditional teaching and identify three advantages of digital technologies: increase entertainment, enhancing motivation of the students, and augmenting their ability to feel involved and active in a learning environment that is individually fitted to their needs (Wouters & Van Oostendorp, 2013; Giannakos, 2013; Chang et al., 2015; de Lope et al., 2017). However, there is a lack of research comparing learning from different computer games. A gap exists between developers, who are not familiar with the design domain, and designers who are not proficient in the educational and pedagogic area of expertise. This gap causes the challenge of creating digital educational materials consistent with theoretical knowledge in the field (de Lope et al., 2017). Learning applets can be compared with many different parameters. This research focuses on one issue: how to design the interface. Specifically, should one use schematic or animated graphics. This research provides a partial and specific response to the lack of empirical work in this area.

The study

The present research stems from a broader study which examines possibilities of better utilizing web-based games in the mathematics classroom, given the practical need for a framework for teachers' choice of mathematical applets, and their integration within the sequence of lessons. Informed by the cognitive load theory and the dual-coding theory, the goal of the presented research is to test the suitability of the character of the graphic design on the student's achievements, in mathematical applets for elementary grades. Three research questions have been studied: (a) How does the learning process differ in learning from animated graphics versus schematic graphics? (b) In what ways are these differences affected by students' proficiency in mathematics? (c) What are the differences in students' enjoyment between graphic designs? Due to space limitation, in this paper we present only the findings relating to the working time and the level of accuracy of the answers (for more details See Ben-Haim, 2018).

Methodology

This research defined two types of graphics: "animated graphics" and "schematic graphics", which differ in the extent of detail and the amount of distraction (Figure 1). This quantitative research compares two mathematical applets. The two applets differ only by the type of graphic design, while the mathematical problems are identical. The first applet has animated graphics based on designs by Matific, a collection of educational math applets which is in use by many schools in Israel. The second applet was designed specifically for this research in a schematic and visually simple version of the same activities.

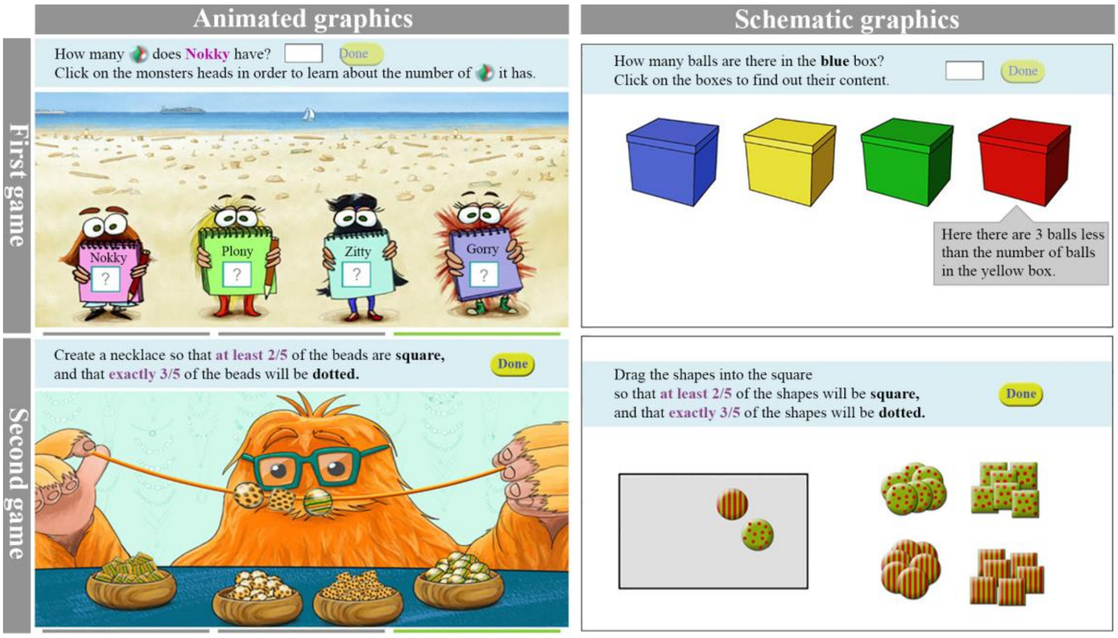

Figure 1: Screenshots of two applets from the two types of graphics

(translated into English - originally in Hebrew)

287 fifth and sixth grade students (50.9% males, 49.1% females) from three elementary state schools in the center of Israel participated in the activity to collect data for this research. All the children were randomly divided into two equal groups: animated graphics group vs. schematic graphics group. The schematic group employed simple and abstract graphics, based on geometric shapes and solid colors (with no shading or hues). In contrast, the animated group employed more complex and colorful graphics, including simple animation. In the animated graphics there is the appearance of depth and space. The elements are figurative and include expressive characters creating an accompanying narrative.

This research monitored students' activity during their play, which enabled the identification of different levels of success between the two groups, differences in working times, and comparison of the students' reports of their degree of enjoyment from the activity. We examined the differences in the learning processes in the two groups. In addition, the students from both groups were divided into two levels based on their proficiency in mathematics. The differences between the groups in performance throughout the activity were compared using statistical tests (t-tests, ANOVA and chi-square) to identify statistically significant differences. Privacy of the children was protected in this research. The schools' names were replaced by numbers, and students' names were not mentioned.

Findings

Differences in the learning process between the two groups

The research results show evidence that students in the schematic graphics group made fewer mistakes than students in the animated graphics group. Figure 2 shows the percentage of students who answered correctly on the first, second or third attempt (light blue and light orange refer to the percentage of students that answered correctly on the first attempt). As can be seen, for all three questions included in the applet, the schematic group (blue) answered with fewer attempts (meaning fewer mistakes) than the animated group (orange). The differences between the groups are greater in the first and third questions, which were more difficult than the second. Further results show that the schematic group needed less time to complete the activity. Notably, these differences between the groups were observed on the first game of the applet, but not the second.

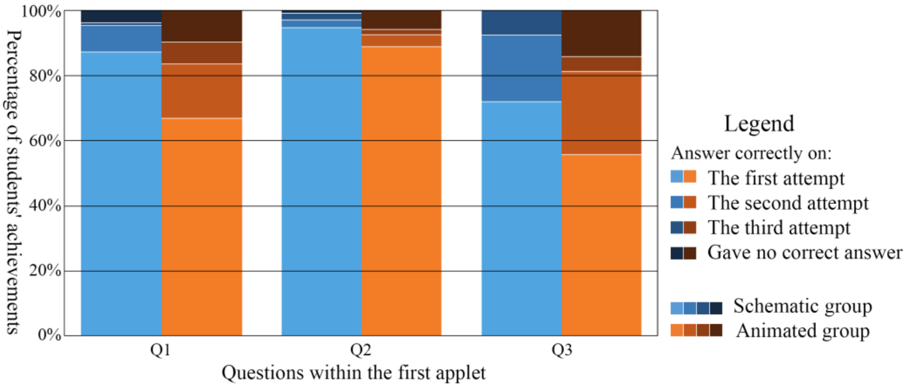

Figure 2: Percentage of students according to success in answering during the applet

Differences between the two groups and the students' proficiency in mathematics

The difference between the two graphic groups is even greater among the students with weaker math achievements (Figure 3). Students with lower mathematic ability succeeded better in the schematic than in the animated graphic group.

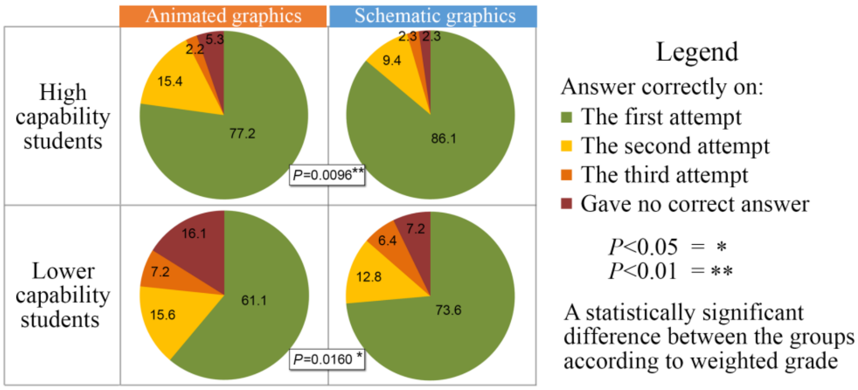

Figure 3: Percentage of attempts to answer during the first applet, comparison of groups and of students' proficiency

Further results arise from two measures by which the students are classified as having low- or high-scores in mathematics: according to the student's school's performance, or according to the student's answer to a final question which was identical in the two groups. Some differences were found, though not always consistently, in distinguishing between low- and high-performing students. In some cases, the animated group was more challenging to low-performing students than to high-performing students. Also, low-performing students in the animated group, required significantly more time than other students.

Differences in students' enjoyment between graphic designs

Contrary to expectations, no differences were observed regarding the level of enjoyment that students reported at the end of the activity with the applet. Students from both graphic groups, and from both performance levels reported similarly on how much they liked the applets. These findings show no advantage for the animated graphics design with regards to satisfaction.

Discussion

The findings of this research show differences between the two graphic groups. Students in the schematic graphics group made fewer mistakes and needed less time to complete the activity than students in the animated graphic group. In addition, students with lower mathematic ability succeeded better in the schematic group. These findings consistent with the literature on cognitive load theory and on the dual-coding theory (Kalyuga, Chandler & Sweller, 2000). In some cases, the animated group was more challenging to low-performing students than to high-performing students. Also, low-performing students in the animated group, required significantly more time than other students. These results are consistent with professional literature claiming that low-performing students and students with lower prior knowledge, encounter difficulties integrating visual and verbal inputs (Cook, 2006; Mason, Tornatora, & Pluchino, 2013). This means that graphic design of mathematical applets must be adapted to the mathematical knowledge of the learners. Students may find the activity harder when the graphic design is complex, if the activity generates significant cognitive load on the working memory. These findings lead to the conclusion that complex graphics may cause inhibitive cognitive load depending on the learning situation and on the student’s performance. Notably, no differences between the two groups were observed regarding the level of students’ enjoyment.

The advantage of gamification in the learning process is in its ability to hide the real necessity to learn mathematics (that is remote to the child), and present a goal that the learner can understand and relate to, which also leads the learner to achieve the real goal of learning mathematics (Sedighian & Sedighian, 1996). Gamification may lead to learning via inner motivation, out of interest and curiosity with a clear goal in mind. The design of learning materials should speak in a familiar tone and be relevant to the learner’s world (Hui, 2009).

The common misconception regarding digital learning is to think of technology as if it were "chocolate covered broccoli" (Bruckman, 1999, p.75). The advantage of digital gamification is not simply as a means of up grading conventional learning through external motivation (Habgood & Ainsworth, 2011). In order to truly leverage digital integration, the applet must be embedded in the learning process, and must stimulate an active intellectual activity (Sedig, 2008). The visual graphics of mathematical applets must act as the starting point for understanding the problem in a given exercise, leading the learner to insight and solutions (Van Garderen & Montague, 2003). To do this, the graphics must integrate between the game-play of the applet, its plot and the learning content (Wouters & Van Oostendorp, 2013).

The philosopher Marshall McLuhan saw the medium as the source of change in society and coined the phrase "the medium is the message" (McLuhan & Fiore, 1967). In his view, it is not the content transmitted through the medium, rather than the medium itself that comprises the meaning, it is the medium itself that significantly influences the society. In our opinion, this insight echoes in the context of integrating applet-games into the classroom. Applets excite the learner simply by the use of the screen, rather than by the displayed content. It is our belief that as educators, we must not "take a step back" when the computer enters the classroom. Rather, we must insist on taking an active role directing and navigating the digitally enhanced learning process.

This research was performed with the attempt to maintain objectivity as much as possible, in the collection and analysis of the data. However, there are some limitations in this research. From practical considerations, the studied population was limited, and comparison between the groups was based on only two applets among a large pool of applets. Hence the studied population is not representative of Israeli students, and the activities are not representative of general mathematical learning games, nor of Matific applets in particular. It should be noted that, from among the three schools, only students from school 1 were not familiar with Matific before data was collected. While this research advances the understanding of development and design of digital learning interfaces in math education, further research is needed to extend these preliminary insights, to enhance the benefits of digital learning, and to sharpen teachers' guidelines for implementation.

Conclusion

The results of this research assist us in formulating indicators for teachers, that will enable them to address both personal/experiential aspects of the learner, as well as cognitive aspects. In light of this research, three guidelines have been deduced which could assist developers, designers and teachers to reach a more effective integration of mathematical applets in the elementary school environment: (1) Different graphic designs are suitable for different audiences and for different learning situations. Complex and animated design can cause difficulties if the learning situation is challenging; (2) A schematic graphic design, with few unnecessary details, is more appropriate for applets that tend to have a high cognitive load on the learner; (3) The design must consist of a narrative that connects between the interests of the learner and the content of the learning material. Figure 4 presents the conceptual chart flow that enables practical application of the research findings.

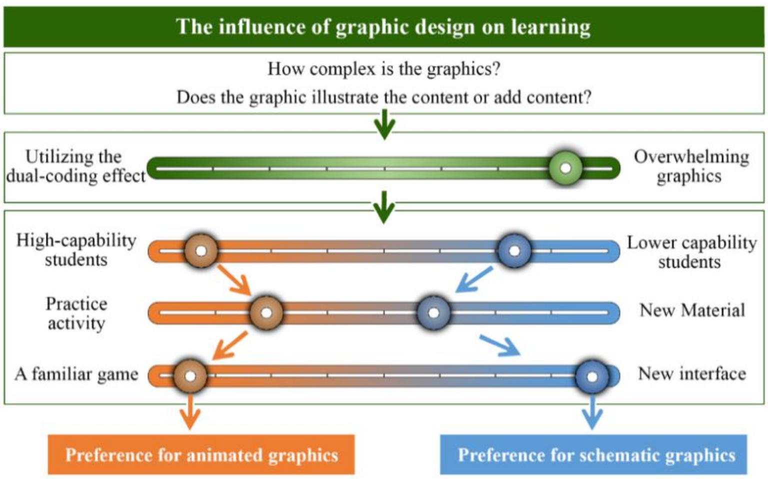

Figure 4: A conceptual chart for selecting graphics according to the characteristics of the students

As shown in figure 4, the teacher must first identify the characteristics of the existing graphics in the applet in question. Two parameters need to be taken into account: (1) complexity of the graphics, and (2) to what extent the graphics serve a pedagogical role. Graphic complexity is rich in detail, contains animations, describes facial expressions and may contain a third dimension, similar to the animated group in this study. In contrast, schematic graphics portray minimal detail often represented abstractly. The role of graphics covers a spectrum from pedagogical to motivational. Pedagogical graphics are integrated with the learning content and complete that content by visualizing it. Motivational graphics merely motivate and do not clarify the learning material.

In the second step, the teacher may examine the applets suitability to the target audience. Figure 4 depicts the questions that can be asked in the process and portrays two possible scenarios, each leading to a different outcome with respect to a different type of graphic design. Applets identified as having "overwhelming" graphics should lead to closer attention to the following indicator in overall decision making. The three scroll bars at the bottom of figure 4 express different aspects for the given audience. The right-hand side (blue) indicates difficulties that the learners encounter. The left-hand side (orange) indicates less challenging learning situations. The two scenarios depict clear-cut cases, where the three markers clearly lead to one side or the other. To conclude, schematic graphics is preferable when encountering challenging learning situations.

The research conclusions can assist developers and designers of instructional materials in decision making regarding graphics in relation to learning content. Applets built on a linear continuous sequence of activity can design a gradual increase of the graphic load, so that the learner in the early stages of the applet will gradually adapt to the new interface. As the learner progresses throughout the activities, the graphics may unfold into a more complex environment, without having a negative effect on the learner due to the familiarity with the interface. Another rule of thumb regards applets addressing the learning stages of instruction in which the graphics may maintain simplicity and a schematic abstract approach, as opposed to the stages of practice, assessment, evaluation, or recall in which the graphics may consist of a more complex design. This implies that the design team and the pedagogic team must work together in planning educational applets.

While the animated group presents a more attractive design than the schematic group, the former does not incorporate the learning content within the visual design. This is a common major disadvantage among applets. Developers and designers must manage the split between the applet plot and the learning material in order to truly utilize the advantages of digital gamification. This study provides rules of thumb on considerations regarding future development and design of mathematical applets.

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