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EVALUATION OF MOBILE APPLICATIONS IN THE TEACHING OF GEOMETRY

Abstract: Today’s world implies more and more frequent use of smartphones and their applications in every place and at every moment. In this paper, we will first talk about mobile educational applications in general, and then we will present various research related to the evaluation of mobile educational applications in the teaching of geometry (*Bos*, *Dick*, *Larkin*). Analyzing the relevant literature, the conclusion is drawn that the evaluation of mobile educational applications is important for learning if geometrical content can be successfully carried out according to three aspects: pedagogical, mathematical and cognitive. The pedagogical aspect implies the effectiveness of the application to assist in learning; the mathematical aspect of mobile educational applications is very often not fully satisfied because the incorrect use of mathematical language is noticeable, as well as the incorrect classification of shapes and objects; the cognitive aspect determines to what extent the application affects the development of students’ thought processes. According to previous research, mobile educational applications such as *Co-ordinate Geometry*, *Transformations* and *Attribute Blocks* were rated highly in all mentioned aspects of the evaluation.

Keywords: mobile educational applications, evaluation, mathematics teaching, geometric content.

INTRODUCTION

The times we live in present numerous challenges in terms of the use of digital technologies by both adults and younger populations. Digital technologies have become a key link in education but also in other areas of work. Today, young people spend most of their free time using computers, tablets, mobile phones and television, which increasingly affects the transition from the traditional dimension of education to a system of modernized education based precisely on the use of digital technologies. We will not leave out the fact that ”the role of digital technologies in the understanding of studied phenomena is not to replace natural and/ or social reality and active learning of teaching content. Technology is an addition that gives a new dimension to learning and teaching“ (OECD, according to: Ristić,

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Blagdanić 2017: 4). Namely, digital competences are one of the eight key ones in lifelong education prescribed by the European Union in order to respond to the constant progress and development of society (The European Parliament and the Council of the European Union 2006). "Digital competence refers to the ability to safely and critically use information and communication technology (ICT) for work, in personal and social life, as well as in communication. Its key elements are basic ICT skills and abilities: the use of computers for finding, evaluating, storing, creating, displaying and exchanging information, as well as developing collaborative networks via the Internet" (Ristić, Blagdanić 2017: 3). The functioning of today's society is unthinkable without the use of mobile phones, especially when it comes to young people. Mobile technologies represent portable devices that consist of hardware (physical parts) and software (operating systems and mobile applications) and enable communication through network services (Jarvenpaa, Lang 2005). Mobile technologies are also highly favored in the teaching process, because they provide a wide range of necessary information that makes the entire teaching process more qualitative and functional (Larkin 2014; Clement 2019; Juandi et al 2021). In this paper our focus will be specifically directed to the evaluation of mobile educational applications (APP) in teaching mathematics with special reference to their application when studying geometric content.

BRIEFLY ABOUT MOBILE APPLICATIONS

In order to explain the concept of "mobile educational applications", we will first explain what "mobile learning" means. Mobile learning is about sharing information through mobile technologies. It is a subtype of electronic learning where communication takes place through mobile phones instead of using a computer (Nordin, Embi, Yunus 2010). With the help of mobile learning, it is very easy to get necessary information through, for example, online dictionaries, various social media sites, voice search, etc. Mobile devices make this possible with the help of their touch screens, easy access to Internet browsers, and the use of microphones and cameras (Haag, Berking 2019). By using mobile phones, along with all the possibilities they provide, it is very easy to access certain mobile applications that aim to improve and create quality, functional knowledge. Research conducted in Australia and China confirmed the positive effects of using mobile phones in class and showed that students are far more motivated and interested in participating in the learning process (Zhang 2019). Mobile applications are software designed to provide a variety of uses on both mobile phones and tablets (Clement 2019). Mobile educational applications have been recognized as some of the most important innovations that have influenced teaching and learning, so there is an increased research interest on the introduction and implementation of mobile learning in the context of formal education (Panteli, Panaoura 2020). The rapid development of science and technology has been accompanied by the development of mobile educational applications that are mostly free and very easy to use and install. The use of mobile educational applications allows students to engage in problem-solving based learning activities, to work on tasks that are goal-oriented and to develop their own understanding through active involvement and sense-making (Charles-Owaba, Ahiakwo 2021). That mobile educational applications improve and enrich student's knowledge is also confirmed by the analysis of the mobile application called *Financial Maths* App, which was designed so that the student independently accesses the mathematical content, where the application explains each step in detail and motivates the student to think critically and creatively while solving problems that have real contexts. This application offers the possibility to engage with different concepts that lead to the solution of the problem. The application proved to be very acceptable to both teachers and students, offering the possibility of further development (Jordaan, Laubscher, Blignaut 2017).

EVALUATION OF MOBILE EDUCATIONAL APPLICATIONS IN ELEMENTARY GEOMETRY TEACHING

As the use of mathematical applications in classrooms becomes more frequent, research into their effectiveness is necessary to discover the best way to use them. This is especially true for geometry applications where accurate and dynamic representations are crucial in enhancing mathematics learning. Early findings indicate that most apps are limited in their ability to help students develop an understanding of geometric concepts. In this section of the paper, we will deal with the evaluation of educational software in order to examine qualitative evaluations of geometric applications based on pedagogical, mathematical and cognitive aspects.

Early research findings indicate that most graded geometry apps do little to help students develop understanding of geometric concepts and that accuracy in representations is not evident. Although research has been conducted on the mathematical effectiveness of applications (Attard, Curry 2012; Larkin 2013; Moyer-Packenham et al. 2015; Panteli, Panaoura 2020), there has not been much research on their usefulness in developing geometric concepts, but rather their basic descriptions. An initial review of applications (Larkin 2013) found few applications that are specifically geometric. However, the application market has progressed, that is, a lot of geometric applications have been made. According to data from 2015, there were about 150,000 educational applications in the *iTunes* store (148AppsBiz 2015). According to the latest data, there are over 520,000 educational applications (Pocketgamer.biz 2022).

Larkin's review of 53 geometry applications, published in the journal *Australian Primary Mathematics Classroom*, confirmed the findings of previous research on number and algebra applications. Namely, finding an adequate geometric application that is useful in elementary mathematics teaching is a difficult task, in terms of the time it takes and the poor quality of the applications that are available for download (Larkin 2014). During the search for mathematical applications, the following terms were used: geometry elementary education; geometry junior education; geometry primary education.

Dick criticized applications from a mathematical, pedagogical and cognitive perspective (Dick 2008). Dick suggests that students are most likely to describe the pedagogical value in terms of how it enabled them to interact with mathematics (for example, ”I made this triangle“, not just as a description of procedures to use, e.g., ”I adjusted the settings“). Therefore, in order for an application to be an effective tool, it must support any student action that will lead to a conceptual understanding of the underlying mathematical principle.

Dick suggests that pedagogical aspects relate to the effectiveness of digital tools to support learning and include ”the extent to which teachers and students believe that digital teaching tools enable students to engage with mathematics in ways that are appropriate to the nature of mathematical learning“ (Zbiek, Heid, Blume, Dick 2007). The effectiveness of digital teaching tools in terms of the pedagogical aspect must support the way in which students initially develop conceptual knowledge and later procedural and declarative knowledge. For example, the *Co-ordinate Geometry* app develops application-based learning by having students learn new concepts, apply these concepts, and then test their knowledge of what they have learned through a quiz (Larkin 2016).

Another aspect that is considered is the mathematical aspect. The mathematical aspect is present when the student's activity is ”probable, concrete and related to how mathematics is a functional part of life“ (Bos 2009: 171). It is defined as ”the devotion of digital teaching aids in showing mathematical properties, conventions and behavior as would be understood or expected by the mathematical community“ (Zbiek, Heid, Blume, Dick 2007: 1173). Dick warns that the desire to adapt the application to students and teachers can sometimes be contrary to correct mathematical structures (Dick 2008). Problems of the mathematical aspect (Larkin 2013) are generally related to the incorrect use of mathematical language or the classification of shapes and objects (e.g. checkers instead of rhombuses, squares are not considered quadrilaterals, triangles are not classified as polygons, and the lack of connection between mathematics and the real environment, with minor exception of the applications *Geometry 4 Kids* and *Simitri*).

The notion of cognition is crucial in geometry applications. The digital nature of the ”app object“ (Larkin 2013) potentially leads to a high level of cognitive development; for example, 3D objects can be disassembled and reassembled, and this can strengthen the connection between 3D objects and their 2D representations (e.g. mesh cube). The cognitive aspect implies acting on the rational side of the child's personality, strengthening knowledge, the need for learning, teaching and understanding the process of education (Suzić 2001). According to Bos, it is the degree to which the application helps the development of thought processes in students (Bos 2009).

According to Zbiek et al., the cognitive aspect refers to ”the ability of digital tools to reflect student's thought processes” (Zbiek, Heid, Blume, Dick 2007). In her research (Bos 2009), Bos categorized software according to the low, medium and high level of presence of these three aspects. In each dimension, it uses numerical values to represent the degree to which these three aspects are present. In order to make comparisons between the three aspects, numerical values are given from 1 (low level) to 10 (very high level) for each of the three aspects.

Table 1. Aspects in applications by level according to Bos (Bos 2009)

Aspects	Low level (1–3)	Medium level (4–7)	High level (8–10)
Pedagogical Aspect The extent to which the application can be used to support learning	It is hard to work on the app. Access to the application is difficult. The application is not suitable for mathematical content.	Using the app is not intuitive at first, but it becomes with practice. The presented mathematical contents are suitable but can be developed without the application.	Handling the application is intuitive and encourages user participation. Little or no training or instruction is required.
Mathematical Aspect The extent to which an application reflects mathematical properties, conventions, and behaviors	Mathematical contents are not sufficiently developed or are too complex. Not enough templates. There is no connection between mathematics and the real environment.	The application of mathematical content is unclear. The creation of a pattern is obvious, but it cannot be predicted or is unclear. There is a certain connection between mathematics and the real world.	The developed mathematical content is accurate and age appropriate. Patterns are accurate and predictable. Clear connection of mathematics with the real environment.
Cognitive aspect The degree to which the application helps develop the student's thought processes	There are no opportunities to explore or test assumptions. Static or inaccurate displays. Templates are not related to concept development.	Limited opportunities to explore or test assumptions. Minor glitches with the renderings, but still make sense. Limited connection between templates and concept development.	The app encourages exploration and testing assumptions. The displays are accurate and easy to navigate. Templates clearly help concept development.

In his research evaluating 53 geometric applications, Larkin used Bos's (Bos 2009) framework for evaluating educational software. The geometric application *Transformations* is an example of the fact that the design of the application requires additional help from an adult when using it, especially in the quiz part, but also to encourage the learning of mathematical content. The app is good in the research part but too complex in the quiz part. The app develops concepts very clearly – much more effectively than paper and pencil would. Mathematical content is correct, age-appropriate and accurate. There are no connections between mathematical examples and the real world. Research is encouraged and contributes to conceptual development.

The next application whose review we considered in this part is related to geometric shapes (*3D GeometryBasica*). The application includes eight 3D objects. The only action that can be performed is zooming in or out to make the object larger or smaller. Each subject has a mathematical description and symbols and formulas for calculating area and volume. Reviewer comments say that using the app is intuitive, mostly due to its limited options, but that the content is accurate. From a conceptual development perspective, the application contains complex formulas for calculating surface area and volume, but no relationship is established between the surface area and volume of objects or between the surface areas and volumes of different objects. The application does not have examples of the connection of mathematics with the real environment. The app has very limited utility and does not do anything that other manipulatives or even pen and paper cannot already do.

Next, the *Shape Rotate* app was rated low because instead of students specifying how to draw specific angles, the app allows them to enter a numerical value, and then the app draws the angle for them. Given that many applications are made by non-educators, poor mathematical structuring of future applications is likely to continue (Larkin 2016).

The most popular area is geometric shapes and this may be because these applications are easy to make from a technical perspective. Although they are the most common, most of these shape apps are very basic and only involve naming shapes and very simple matching exercises. Many of these activities can be done more easily using the right objects. Apps related to angles and 1D geometry were frequent, but this is due to the large number of quiz apps, not the availability of a large number of apps that develop an understanding of 1D and angles.

Less than half of all evaluated apps (26 out of 53) failed to get a six in any of the three aspects (does not support pedagogy, is not mathematically correct and is cognitively inactive). The mean score of 53 applications (12.9/30) did not reach a passing grade. In short, mathematical, pedagogical and cognitive aspects are poorly represented (Larkin 2016). Also, applications that received a score of 6 or higher scored well in terms of the pedagogical aspect but not so well in terms of the mathematical and cognitive aspects. However, many applications met only one pedagogical criterion: they are easy to use without instructions. Given that applications are made by people who are not mathematicians, it is not surprising that this aspect is the most prevalent in applications. Other applications partially meet the criteria of developing ideas and concepts about basic geometric figures in an appropriate way, without having to do anything more than what could easily be displayed on an interactive whiteboard or using some other teaching aids. Although some of the apps scored highly in one of the aspects, they did not score highly in other aspects because they had a weak connection between geometry and the real environment as experienced by children and were ultimately inconsistent in terms of higher levels of abstraction (e.g. squares are not classified as quadrilaterals or triangles are not included in polygons). In mathematics, concepts are much more abstract than those in everyday life, and learning itself has the characteristics of more abstraction. More abstract means more distant from perceptions and concrete impressions. For example, square < rectangle < quadrilateral < polygon (Đokić 2007). Table 2 summarizes the seven applications that were rated six or higher in all three aspects.

Table 2. Applications that were rated with a score of six or higher in all three aspects (Larkin 2016)

Name of the application	Pedagogical Aspect /10	Mathematical Aspect /10	Cognitive aspect /10	Total score /30
Co-ordinate Geometry	9	8	9	26
Transformations	9	8	9	26
Attribute Blocks	8	8	8	24
Shapes–3D Geometry	9	6	8	23
Shapes and Colours	7	6	7	20
Pattern Shapes	8	6	6	20
Isometry Manipulative	7	6	6	19

It should be noted that only one application, *Simitri* (Simitri 4, 9, 8), received a very low rating from the pedagogical aspect and high ratings from the mathematical and cognitive aspects. Therefore, students should not use the app alone, without supervision. Except in the case of the top three apps, teachers must determine the exact purpose of using the app and then look at the content covered as well as the ratings of all aspects to find an appropriate one that supports students' mathematical learning.

The application *Geometry Montessori* (Geometry Montessori 9, 6, 5) is rated the same or better than the three applications that are among the top seven, but it is relatively poor when looking at the cognitive aspect. The application *Geometry Montessori* would be appropriate to use for the review of the material because it received a rating of 9 from the pedagogical aspect but not for developing the mathematical or cognitive aspect.

For example, the *Pattern Shapes* app made Larkin's list because it scored at least a six in each of the categories. The app is really useful in a pedagogical sense (score 8), but it does not support connecting examples from everyday life. This pattern of quality in one area and weakness in one or both of the remaining two is also present in other applications, which means that teachers need to do significant prior planning if they want the application to be useful and not potentially harmful to some forms of mathematical knowledge.

Ristić and Blagdanić (2017) present a broader proposal when it comes to the evaluation of mobile applications, and it is about analyzing applications from a point of view that includes six criteria: (1) scientific and professional criteria; (2) pedagogical-psychological and didactic-methodical criteria; (3) ethical criteria; (4) language criterion; (5) technological and graphic criterion and (6) security criterion.

In the following text, we will briefly explain what each of these criteria entails. First, the scientific-professional criterion implies that the application must enable the achievement of the goals and objectives of the subject, the contents must be provided by the curriculum, and the application must be harmonized with the methodology. Pedagogical-psychological and didactic-methodical criteria imply that the application must be suitable for the age of the students, encourage students to be active and engage in cooperative learning, develop independence and initiative in learning, encourage different forms of learning, ensure interactivity and feedback, etc. Ethical criteria include encouraging tolerance and respect for diversity, promoting non-violence, and respect for inclusion and gender equality. The language criterion includes respect for the language norms of the native language or a national minority or a foreign language; the language and sentences must be adapted to the age of the students, as well as the professional terminology used. The technical and graphic criterion refers to compliance with technological W3C standards; the application must have clear and simple navigation and instructions that facilitate use for both students and parents and teachers, and graphic and multimedia elements must be of high quality, clear, content-related and accompanied by a title or explanation. The security criterion implies the safe transfer of data from and to users, and students must not be led to activities that could put them in danger.

It is widely accepted in the mathematics community that if used thoughtfully, digital tools can enhance mathematics learning (Burns, Hamm 2011; Carbonneau, Marley, Selig 2013; Moyer-Packenham et al. 2015; Larkin 2016; Charles-Owaba, Ahiakwo 2021; Yosiana, Djuandi, Hasanah 2021), but teachers still play a key role in deciding how and when to use apps. More significant reviews of geometry applications will be needed in the future, and Bos's (Bos 2009) software categorization and three aspects of application quality considerations (Dick 2008) may be useful in order to support students' mathematical learning.

CONCLUSION

Since we live in a time where children are using smartphones at an ever earlier age, it is clear that the application of mobile learning is a sign of the future and will be an increasing support for education. The young population is increasingly using smartphones for the purpose of obtaining various information through social networks, mobile applications, etc., and what is particularly important to them is the availability and use of these devices anytime and anywhere. Given that the educational system is increasingly based on digital technologies, the use of mobile phones and applications is therefore completely justified. By using mobile applications, students can get very high-quality and effective knowledge, and in order to achieve that, all those applications must be evaluated from several aspects so that the result of their use is truly effective. In this paper, we have considered the evaluation of mobile educational applications according to different aspects, while highlighting the pedagogical, mathematical and cognitive ones. If the application meets the requirements of the pedagogical aspect, students should first develop conceptual, then procedural and finally declarative knowledge. Within the mathematical aspect, the mathematical content in the application must be accurate and adapted to the age of the students, and the abstract world of mathematics must be related to the real environment. The cognitive aspect involves encouraging and developing thought operations through the use of the application, so all templates in the application must be clear and correct. Therefore, the evaluation of the mobile educational application from the aforementioned aspects can greatly contribute to the creation of quality and lasting knowledge among students. Through this work, we got acquainted with the various advantages and weaknesses of mobile educational applications and the learning of geometric content. Therefore, before using any application that is used in the teaching process, it should always be evaluated. Specifically, when it comes to learning geometric content, the mobile educational applications that are rated very highly from a pedagogical, mathematical and cognitive point of view are *Co-ordinate Geometry*, *Transformations* and *Attribute Blocks*. In some future research, it would be challenging to evaluate these applications according to the criteria (6 criteria) proposed by Ristić and Blagdanić.

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ЕВАЛУАЦИЈА МОБИЛНИХ АПЛИКАЦИЈА У НАСТАВИ ГЕОМЕТРИЈЕ

Резиме: Данашње време подразумева све више и све чешће коришћење паметних телефона и њихових апликација на сваком месту и у сваком тренутку. У овом раду прво ћемо говорити уопштено о мобилним образовним апликацијама, а потом ћемо представити различита истраживања која су у вези са евалуацијом мобилних образовних апликација у настави геометрије (*Bos*, *Dick*, *Larkin*). Анализирајући релевантну литературу изводи се закључак да се вредновање мобилних образовних апликација које су значајне за учење геометријских садржаја успешно може извршити са три аспекта: педагошког, математичког и когнитивног. Педагошки аспект подразумева ефикасност апликације да помогне у учењу, мобилне образовне апликације врло често не задовоље у потпуности математички аспект, јер је приметно погрешно коришћење математичког језика, али и погрешна класификација фигура и тела, док се кроз когнитивни аспект утврђује у којој мери апликација утиче на развој мисаоних процеса ученика. Према досадашњим истраживањима мобилне образовне апликације као што су *Co-ordinate Geometry*, *Transformations* и *Attribute Blocks* оцењене су високим оценама у свим споменутим аспектима евалуације.

Кључне речи: мобилне образовне апликације, евалуација, настава математике, геометријски садржаји.