Enhancing STEAM Education with AR: A Primary Education Teacher Training Study

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Abstract: This research delves into the influence of Augmented Reality (AR) on Science, Technology, Engineering, Arts, and Mathematics (STEAM) education within the domain of primary school teacher training at the university level. The core aim is to augment digital literacy within the primary education framework through inquiry-based teaching methods. This investigation was organized among students enrolled in the Faculty of Education, Comenius University in Bratislava. The empirical research is devoted to the contribution of AR technologies to the enhancement of STEAM education and its implications for future primary education teachers. Utilizing a qualitative research methodology, the study facilitated small-group project work among students, complemented by focus groups and interviews to garner comprehensive insights into their experiences and perceptions. The findings of this study illuminate the significant role of AR applications for enriching STEAM education, manifesting in motivation of future teachers and the advancement of specific STEAM competencies. The results indicate the advantage of the integration of AR technologies in educational settings as a tool for supporting digital, technical, and artistic skills among students. The research results are possible to use in the innovation of teacher training primary education study program. An interdisciplinary approach towards STEAM education can help future teachers to navigate and to understand a technologically driven world effectively. Furthermore, the study offers actionable recommendations for practicing primary school educators on the implementation of AR-based pedagogical strategies to enrich the learning experience. By doing so, it aims to bridge the gap between traditional educational methodologies and the demands of contemporary digital literacy, ultimately fostering a more engaging and effective learning environment for future generations. The research results will be implemented into the STEAM oriented subjects into the primary school teacher training at the university level and in the lifelong learning of the in-service primary school teachers from educational practise.

Keywords: Augmented reality in education, AR ruler application, Primary education, STEAM education, Teacher training

1. Introduction

The main aim of this study was to investigate the link between STEAM education using augmented reality and the development of digital, technological, and mathematical competencies. The research was conducted as action research with students of the Faculty of Education who are future primary school teachers. Participants were enrolled in mathematics, geometry, and technology-focused courses that covered certain components of STEAM education. Another research aim was to strengthen students' digital competences within the innovated primary school curriculum, which expect the usage of ICT tools in STEAM education and development of digital competences of primary education pupils.

During the courses, students were introduced to the use of augmented reality applications in pre-primary and primary education, including popular applications such as Quiver and Animals D4. Based on this knowledge, students were tasked with designing and implementing a project for pupils aged 6 to 11 years old. The project focused on STEAM learning outside of the classroom, mainly through field activities in the school or in the students' local area.

In terms of mathematics, the project emphasized concepts such as geometry, estimating distances, lengths and possibly areas, along with other related mathematical principles. Students were instructed to record their estimates of building dimensions and then use augmented reality applications to obtain measurements that they could compare to actual values. In addition, they were encouraged to investigate various mathematical aspects of the buildings or objects under investigation, such as symmetry and geometric shapes.

Art education also played a key role in the project. Students were expected to engage in discussions and guesses concerning the artistic qualities and architectural styles of the buildings or monuments they encountered. These estimates were then to be compared with information available on the internet, allowing students to gain a deeper understanding of the artistic aspects associated with the buildings in question.

In the project, students used mathematical competences such as calculating the content, volume and reduction of solids. The students calculate surfaces and volumes of different kinds of buildings. They also used technical parameters to correctly represent models of buildings, thus linking mathematics and technology knowledge. The students also developed technical competences by constructing mentioned models.

The integration of technology was achieved through searching for interesting facts about the buildings or objects, including details about the building materials used and significant historical events related to the buildings. In addition, the project considered the possibility of incorporating virtual tours of selected buildings, further enhancing the technological component of the project.

Geometry and measurement are pivotal in the mathematics curriculum of primary schools, fostering students' mathematical reasoning, spatial intuition, and real-world imagination. Estimation, deeply intertwined with number sense and measurement, is of paramount importance as a mathematical skill (Lucas & Son, 2013).

Performance standards for mathematics education emphasize the development of students' ability to estimate the lengths of line segments, shorter lengths in centimetres (or millimetres), and longer lengths in meters. Thus, mastering estimation becomes crucial in an educational context, serving as an indispensable skill for daily life and decision-making. Siegler and Booth (2004) underscore the importance of estimation in practical scenarios, such as predicting travel time, gauging object weight, and measuring distances, highlighting the necessity for reasonably accurate estimation skills.

Visualizing plane and spatial geometric figures during primary-level mathematical lessons can bolster students' measurement sense, closely tied to estimation abilities. Using concrete materials in the classroom has proven to enhance understanding of mathematical concepts related to geometric figures (Gilliland, 2002). Modern technological tools, like augmented reality applications, enrich visualization, further elevating the learning experience.

Merging contemporary technology with innovative teaching methods can effectively nurture geometric literacy, including the skill of length estimation. In our research, we adopted the project method tailored for prospective primary teachers.

Project-based learning (PBL) is a student-centric teaching approach emphasizing inquiry, collaboration, and real-world application. It engages students in addressing authentic problems or questions, fostering deeper comprehension and skill enhancement (Buck Institute for Education, 2018). Nevertheless, PBL's potential in enriching learning and equipping students for contemporary challenges renders it an invaluable educational approach. The concept of STEAM (Science, Technology, Engineering, Art, Mathematics) education is based on constructivist pedagogical principles and emphasizes teamwork, collaboration, and discovery; therefore, it shares many commonalities with PBL (compare with Wahdaniyah et al., 2023).

In our approach, we integrated a project-based method with STEAM content for training future educators, incorporating augmented reality applications to amplify measurement tasks. Adhering to STEAM principles, our action research aimed to deepen students' geometric understanding and refine their estimation skills. By leveraging augmented reality, we sought to create an immersive learning environment, arming future educators with tools to enhance geometric literacy in their students.

2. Literature review and Theoretical Background

2.1 STEAM Education for the Pre-Service Teachers

The STEAM concept, which stands for Science, Technology, Engineering, Arts, and Mathematics, is integrated into various learning areas of the Curriculum for primary education.

Innovations in science and engineering are expected to be the primary economic drivers and job creators. As technology replaces certain jobs, understanding math becomes essential for science, which subsequently drives technology. Engineers are crucial for production, and design ensures products are both functional and aesthetically pleasing. As a result, an increasing number of jobs will require STEAM knowledge. Integrating STEAM subjects can enhance learning quality, foster creativity, and motivate work. However, 21st-century educators must consistently update their skills to effectively teach emerging technologies. While their responsibilities may increase, the quality of teaching remains dependent on their commitment to content. Education should be adaptable, laying a foundation for rapid advancements and self-adaptation to technological shifts. Researchers indicates a need for more professional development for teachers in modern STEAM technology integration. (Gajić & Cekić-Jovanović, 2022).

In primary education, STEAM incorporates tasks and environments that merge knowledge from various fields, such as art, architecture, culture, and history, into mathematics instruction. This approach aims to enhance reasoning and problem-solving abilities among students, using their mathematical knowledge at their level. Students can observe buildings of different architectural styles, helping them identify connections between various disciplines of study, including mathematics, culture, and history. Through tasks, procedures, and educational activities, students can integrate primary mathematical knowledge with architectural elements found in their surroundings or places they visit. During walks or excursions with their teacher, students can gather data related to specific buildings representing different architectural styles. By designing STEAM activities that connect culture, history, and architecture to mathematical learning, the objective is to foster modelling skills, imagination, and problem-solving abilities while developing students' specific mathematical expertise, such as measuring and estimating lengths (as seen in El Bedewy et al., 2021).

The ArchiSTEAM approach in architecture education extends beyond the traditional teaching of STEAM disciplines. It incorporates collaborative learning methods that seamlessly blend these subjects. This approach aims to bolster students' 21st-century skills, fostering creativity, innovation, and improved learning outcomes. The STEAM methodology promotes a harmonious integration of disciplines and provides a teaching framework that empowers instructors from diverse fields to cultivate a progressive learning environment.

Integrating STEAM education with augmented reality (AR) applications offers an innovative approach to educating the alpha generation's pupils. Born after 2010, these pupils have grown up with technology as an intrinsic part of their lives. By merging STEAM principles with AR, we tap into their natural affinity with technology to create engaging and immersive learning experiences. This approach recognizes the alpha generation's inherent fluency with technology, enabling us to harness its potential to enhance their educational journey and cultivate their curiosity, creativity, and critical thinking skills.

Teachers in STEAM fields often face challenges such as costly or inadequate labs, equipment malfunctions, and difficulties replicating experiments (Godoy, 2021). AR provides solutions by being cost-effective, bridging the physical and virtual worlds, and enhancing students' comprehension (Restivo et al., 2014; Hsu et al., 2017). Ajit et al. (2021) reviewed literature on AR in STEAM and found it enhances conceptual understanding, learning outcomes, teamwork, and student engagement. A significant advantage of AR is its potential to increase students' interest and motivation in STEAM. As educators seek innovative engagement methods, research suggests AR tools can address motivation concerns (Mystakidis et al., 2022; Schmidthaler et al., 2023).

2.2 Estimation and Measurement

Estimation and measurement of length are specific spatial skills. According to Wai et al. (2009) and Sorby et al. (2022), there's strong correlational evidence linking spatial skills to success in STEAM education across different educational levels. Other studies have found connections between spatial skills and creativity, technical innovation (see Kell, 2013), and success in computer programming (compare with Jones, Burnett, 2008).

Spatial ability plays a significant role in mathematics and STEAM subjects. Gunderson et al. (2012) suggest that spatial skills play a crucial role in developing numerical reasoning, aiding primary level pupils in creating a spatially meaningful numerical representation. This includes the linear number line and number operations. Young et al. (2018) explain that spatial and mathematical skills are closely connected to development in STEAM subjects in the educational process. They are enhanced by concrete 3-D manipulative activities, making the estimation and measurement of space figures and objects beneficial for this development.

Mathematical concepts like symmetries, algorithms, patterns, and shapes can be observed in various architectural constructions globally (compare with Ajmera, 2020 and Wilson, 2021). According to Thui and Thi (2022), typologies and their relationship to geometries are considered significant features in architecture. For example, the use of the golden ratio or geometric shape patterns is prevalent in architecture, cultural heritage, and human history. This suggests that many iconic structures, such as the Eiffel Tower in France or the Taj Mahal in India, are built based on mathematical and STEAM contents and skills (see Dana-Picard et al., 2021).

Tom Caudell, while working at Boeing in 1990, coined the term "Augmented Reality" (AR) to describe the integration of virtual images into the real world, augmenting reality with virtual elements. This integration is facilitated through Information and Communication Technologies (ICT) using mobile devices equipped with cameras, such as computers, tablets, or smartphones with iOS or Android operating systems, which provide access to AR content. AR development also promotes higher learning autonomy, the use of mobile-learning support systems, and encourages exploration of ICT among students, fostering collaboration, innovation, and

creativity. AR applications enable the integration and interaction between the real and virtual worlds, offering great versatility and creativity in their applications (Coimbra et al., 2015).

The primary objective of an AR system is to enhance users' perception and interaction with the real world by supplementing it with 3D virtual objects that appear to coexist in the same space. While recent studies have expanded the definition of AR beyond this scope, in line with the original survey, we identify three key properties that AR systems share: blending of real and virtual elements in a real environment, real-time interactive features, and registration in 3D (Azuma et al., 2001).

3. Augmented Reality Applications in Mathematics Education

According to Arusoaie et al. (2010), augmented reality (AR) is a variation of Virtual Reality. While Virtual Reality creates a synthetic environment such that the user cannot see the real world around him, AR allows the user to see the real world, but with virtual objects superimposed onto the real-world surroundings. Therefore, AR supplements reality; it doesn't completely replace it. AR can be thought of as the "middle ground" between Virtual Reality and the real world.

In recent times, augmented reality (AR) applications with built-in measurement tools have gained significant popularity. These tools enable users to measure various quantities, including length, area, volume, and angles. They have proven useful not only in everyday tasks but also in the fields of mathematics and physics education. While developers acknowledge that the measurement accuracy is not perfect at present, they are actively working to improve it.

Berger-Halad and Ferko offer an in-depth systematic overview of Virtual, Augmented, and Mixed Reality concepts, along with their evolution and potential in education (Berger-Haladová & Ferko, 2019). Bohdal (2019) and Bohdal (2020) delve into the intricate details and progression of Virtual and Augmented Reality devices.

4. Survey and Context of this Study

In the subsequent section of this paper, we will describe the research conducted with future primary education teachers at the Faculty of Education of Comenius University in Bratislava. In Slovak conditions, primary education teacher training is a master's program, which follows the bachelor's study of the pre-primary education teacher training program. The research activities carried out with these students focus on outdoor STEAM activities appropriate for the primary level.

The study was carried out during the 2022/2023 academic year, involving both full-time and part-time students from the Faculty of Education at Comenius University in Bratislava. The participants for the research were made up of 81 students who are preparing to become primary education teachers. These students came from four different courses devoted to mathematics and technical education. The students self-organized into 37 smaller working groups for the purpose of the research.

4.1 Research Design and Methodology

It was realized an action research project involving future primary school teachers at the Faculty of Education. This study explored how augmented reality in STEAM education affects digital, technological, and mathematical skills of mentioned students. These students participated in math, geometry, and technology courses related to STEAM. The goal was to enhance their digital competencies for primary education, aligning with the school curriculum.

In these courses, students learned to use AR apps like Quiver and Animals D4 for young pupils. They designed a STEAM-based project for 6 to 11-year-olds, focusing on outdoor learning in areas like math, art, and technology. The project involved planning activities for measuring and comparing building sizes and incorporating math principles like geometry and estimation using AR tools. Art was integrated through analysing the artistic and architectural aspects of buildings, comparing these with online information. Technologically, students explored buildings' histories and materials. The project linked mathematical and technological skills by having students calculate and model building dimensions. This research aimed to understand how AR in outdoor STEAM projects develops literacy and competencies in primary education, focusing on its impact on pre-service teachers' perspectives and motivations.

We formulated the following research questions:

- How does the integration of augmented reality applications in STEAM education motivate future educators to foster pupils' individual literacies in primary education?

- What are the perspectives of prospective primary school teachers regarding the potential benefits of using augmented reality applications in STEAM education?

To address these questions, we employed focus groups as a research tool to gather insights and preferences related to our research objectives. We chose qualitative research as our approach because we sought opinions and attitudes that cannot be quantified or easily summarized in numerical data. Qualitative research was most suitable as it allows for a deeper exploration of individual and group perspectives on the subject matter.

The main advantage of qualitative research lies in its ability to facilitate open discussions within a small group, where every participant can express their opinions without getting overshadowed by others (Kostrub, 2022).

Qualitative research is based on collecting comprehensive data without predetermined hypotheses or the need to confirm or refute existing theories. Its purpose is to gather as much information and data as possible to gain a nuanced understanding of the research problem. Through the process of data collection, patterns and themes emerge, leading to tentative conclusions. If sufficient additional data is available, new theories can be developed. Qualitative research involves investigating actions and issues within their natural environment to gain a comprehensive picture of these phenomena based on the data and the specific relationships between the researcher and the research participants (Severini & Kostrub, 2018).

We conducted data collection and evaluation according to the well-known principles of qualitative research. Data collection was conducted through the collection of educational student portfolios.

The research subjects consisted of students from the Faculty of Education at Comenius University, who are prospective primary school teachers for pupils aged 6 to 11 years. The selection of participants was done through purposive sampling. The research was conducted during the summer semester of the academic year 2022/2023. In guided focus groups, students presented their own project proposals and discussed their implementation using various media such as text, images, and videos, focusing on different thematic areas of education.

In our qualitative research, we analysed the students' projects, employed the observation method to assess their project presentations, and qualitatively evaluated the data from the semi-structured interview. Its predetermined thematic framework was devoted to development of digital skills of pupils in proposed activities by students – future primary education teachers. The interview included the following prompts:

- How would your proposed activities foster primary education pupils' digital skills?
- How would your proposed activities support pupils' estimation skills?
- How would your proposed activities expand pupils' technical knowledge, such as understanding building materials and construction methods?

These prompts reflect above mentioned research questions because proposed activities of students-future teachers develop digital literacy and literacies connected with the STEAM oriented teaching in primary level.

4.2 Results and Discussion

The following activity describe the selected realized project of working group, in which there were primary education teacher training students:

Activity Project using AR (excerpt). Source: author's own elaboration.

STEAM area: Mathematics, technology, art, architecture, engineering.

Target group of pupils in the school: 6-11 years.

Activity Objective: Exploring the chapel in the Slovakian village Pusté Úľany.

Didactic resources and aids: AR Ruler app, geometric shapes worksheet, crayons, markers, didactic building blocks.

Time and space of activity: 20 minutes in the classroom, 40 minutes outdoors, 45 minutes in the classroom.

Methodical procedure in teaching:

Pre-active phase: This phase is in the classroom and pupils will try to sketch the building from the front and the side (see Figure 1).

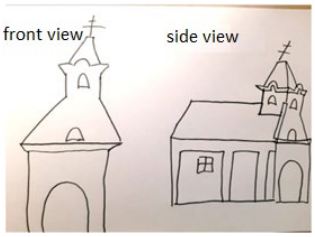

Figure 1: Sketch the chapel by pupils

During the initial stage, the teacher accompanies the pupils in the classroom where they engage in a discussion about a local chapel. Subsequently, the pupils, divided into groups, proceed to draw the chapel from different angles, including the front and the side.

Interactive phase: This phase is realized outdoor. Based on the suggestions provided by pupils for solving a learning problem and their subsequent practical implementation on an individual basis, the aim is to achieve the predefined goal. Pupils estimate the dimensions of the settlement and record them in a prepared table. Subsequently, they utilize the AR Ruler app for measurement purposes and document the measured values in the table (Figure 2).

Figure 2: Measurement of chapel dimensions by application

Moving on to the second part of the activity, the pupils go on a walk to the chapel, during which they have conversations with both their teacher and their peers. They explore various questions related to the chapel's geometry, such as identifying geometric shapes present on the building and determining if there are any symmetrical shapes. Additionally, the pupils estimate the dimensions of the chapel and employ an augmented reality (AR) app to measure them accurately.

Post-active phase: This phase is realized in the classroom. Pupils work and discuss in groups in the classroom. They drew a map and on it the path from the school to the chapel (see Figure 3).

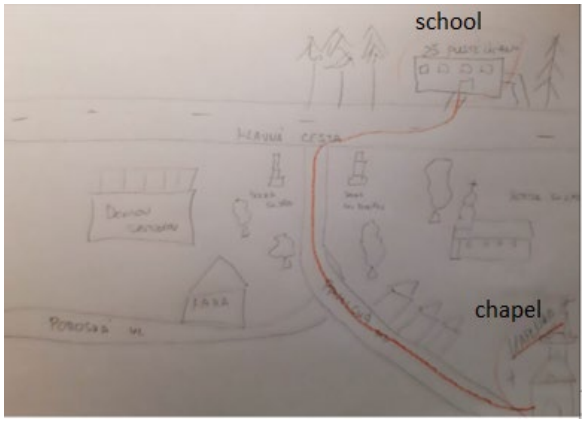

Figure 3: Map made by pupils

In the third part, the pupils return to the classroom. The activity focuses on their orientation in plane and space. They are tasked with drawing a map depicting the route from the school to the chapel. Additionally, using a square grid, they create a floor plan of the chapel. Lastly, they search for geometric shapes that can be found within the structure of the building.

During the semi-structured interviews conducted, we sought teacher training students' opinions on the STEAM outdoor method utilizing augmented reality. The responses we received confirmed a high level of motivation among the students towards this approach. Employing a qualitative methodology, we evaluated the data collected, which consisted of 52 groups of student responses addressing our interview questions. Here are the key findings:

Support for primary education pupils' digital skills: According to most of the aspiring teachers, the use of augmented reality apps can indeed enhance the digital skills of pupils aged 6 to 11. While pupils already have familiarity with various apps on their smartphones, mostly games, some respondents emphasized the importance of learning to use augmented reality apps for measurement, as it would be beneficial for their future.

Support for pupils' estimation skills: Opinions among teacher training students varied in this aspect. While some believed that the activity would greatly aid in developing pupils' ability to estimate the dimensions of buildings, the majority remained neutral, indicating uncertainty about its significant impact on fostering this geometric competence.

Enhancement of pupils' technical knowledge: Regarding the understanding of building materials and construction methods, the majority of teacher training students remained silent or neutral, indicating limited perceived benefits in this particular area for primary school pupils.

5. Conclusions and Implications of the Study

The results of the semi-structured interviews revealed that the STEAM outdoor method using augmented reality shows promise for primary school education. Future teachers expressed positive attitudes towards this approach, emphasizing its motivational and competency-building aspects within the STEAM framework. The results are limited to the sample of teacher training students, who participate in the educational project. The findings can understand in the local condition of the Faculty of Education of the Comenius University in Bratislava. It is the result of the fact, that educational experiment was lead in the qualitative direction. Key findings include:

Support for digital skills: Students believed that augmented reality apps can enhance pupils' digital skills beyond gaming, emphasizing their importance for future applications.

Support for estimation skills: Student opinions varied regarding the impact on developing estimation skills, with some confident in its effectiveness and others uncertain.

Enhancement of technical knowledge: Students were neutral or had no specific views on the method's benefits for improving children's understanding of building materials and construction methods.

This year, the Slovak Ministry of Education is launching a curriculum reform emphasizing pupils' independent thought, action, and decision-making. In line with this reform, our faculty is undertaking a project to innovate the pedagogical approaches for primary education students. The findings from our research, as detailed in this article, could contribute to achieving the objectives of this reform and enhance student experiences with fresh STEAM-related activities.

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