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TECHNOLOGY EXPLORATION OF AUGMENTED REALITY MATHCITYMAP TO INCREASE MATHEMATICAL PROFICIENCY

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Abstract

The aim of this study was to investigate the impact of integrating the discovery learning model with MathCityMap (MCM) media on enhancing students' mathematical proficiency, particularly in the areas of surface area and volume. Employing a quasi-experimental design with a pretest-posttest framework, this research evaluated the effectiveness of these innovative teaching tools across four sessions, including an initial assessment of students' understanding, two instructional sessions utilizing Math City Maps, and a concluding posttest to measure learning outcomes. Data analysis through SPSS revealed statistically significant improvements in students' mathematical proficiency. The findings validate the effectiveness of combining discovery learning with MathCityMap media in improving mathematical understanding and skills, underscoring the significance of innovative teaching and technology in education. This study suggests that a deeper conceptual understanding, alongside accommodating diverse learning styles through the use of technology-enhanced tools, practical applications, and differentiated instruction, can significantly enhance the learning experience. Recommendations for educators include the adoption of such tools and strategies to foster an adaptive, engaging, and concept-focused educational environment, emphasizing the need for further research into the diverse impacts of instructional methods and factors influencing mathematical learning.

Keywords: Augmented reality, Mathcitymap, Mathematical proficiency.

1. Introduction

MathCityMap (MCM) is an innovative educational initiative that leverages mobile technology to enrich mathematics instruction by extending learning beyond conventional classroom environments. Through the establishment of math trails, which are outdoor routes where learners participate in mathematical activities facilitated by the MathCityMap application, students can actively engage with mathematical concepts [1]. This method incorporates augmented reality (AR) elements to offer students a distinctive and interactive educational encounter [2]. AR can help the teaching and learning process [3-5]. The utilization of digital resources such as MathCityMap aids in corroborating outdoor modelling outcomes and amplifying outdoor mathematics education [6].

Studies have shown that MathCityMap is successful in boosting students' problem-solving abilities in mathematics [7]. Its application has been adopted across different educational institutions, ranging from primary to high schools, to enhance academic achievements in geometry and other mathematical topics [8]. Apart from offering clues and verifying solutions, the app fosters self-reliant and cooperative learning approaches among students [9]. This app can help the teaching and learning process, as previous reports did [10-13].

Previous studies have explored the implementation and impact of MathCityMap in educational settings. For instance, research has focused on utilizing MathCityMap in teaching geometry in elementary schools [8]. Additionally, studies have investigated the effectiveness of MathCityMap training for teachers in a hybrid setting [14]. These studies highlight the potential of MathCityMap in enhancing mathematics learning outcomes and teacher training, emphasizing the importance of technology in improving education. However, previous studies on MathCityMap's role in teaching geometry and training teachers underscore its educational potential yet lack exploration of its effectiveness in enhancing understanding of surface area and volume through a discovery learning model. Therefore, this study aims to investigate the impact of combining the discovery learning model with MathCityMap media on enhancing students' mathematical proficiency, aiming to offer insights for improving teaching methods and fostering an engaging, concept-focused educational environment. The novelties of this study are (i) development trail in MathCityMap for geometric concepts, (ii) especially for elementary school, and (iii) lesson plan to increase students' mathematical proficiency.

This research is important because it aims to assess the increase in students' mathematical proficiency using the MathCityMap learning media. With this research, we can find facts about the process of increasing students' mathematical proficiency, and support research in the field of mathematical proficiency. The number of studies regarding mathematical proficiency has continued to decline over the last 5 years (2020 – 2024). Of the 999 articles regarding mathematical proficiency from 2020 to 2024, the number of articles continues to decrease with the number in each year, namely in 2020 as many as 347 articles, in 2020 as many as 271 articles, in 2022 as many as 205 articles, in 2023 as many as 134 articles, in 2023 as many as 134 articles, and 2024 as many as 42 articles [15]. This can be seen from the results of the bibliometric analysis in Fig. 1 which provides in-depth insight into trends, research focus, and research contributions with the keyword "mathematical proficiency".

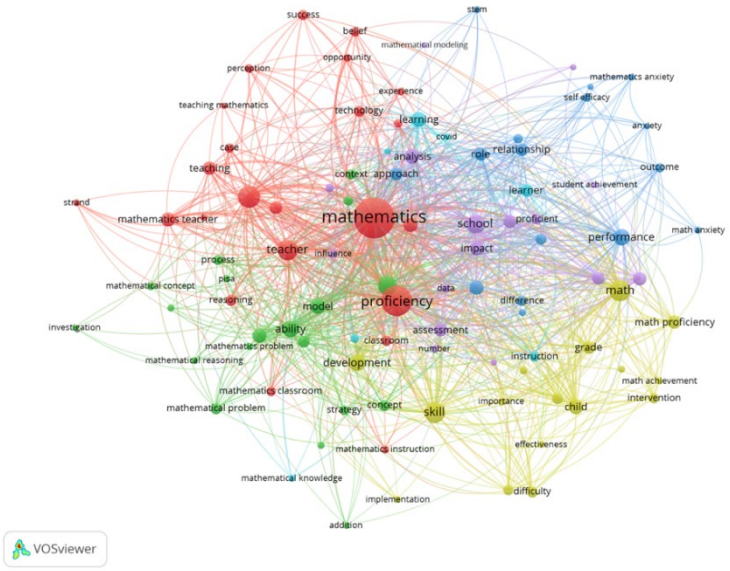

Fig. 1. Network visualization of mathematical proficiency [15].

The network visualization in Fig. 1 shows the terms obtained from the abstract and keywords that correspond to mathematical proficiency. The data collection time was divided into 6 clusters with a total of 97 items and each item had a link, total link strength, and different events. Mathematical proficiency which is used as a keyword is in cluster 1 which is illustrated in Fig. 2.

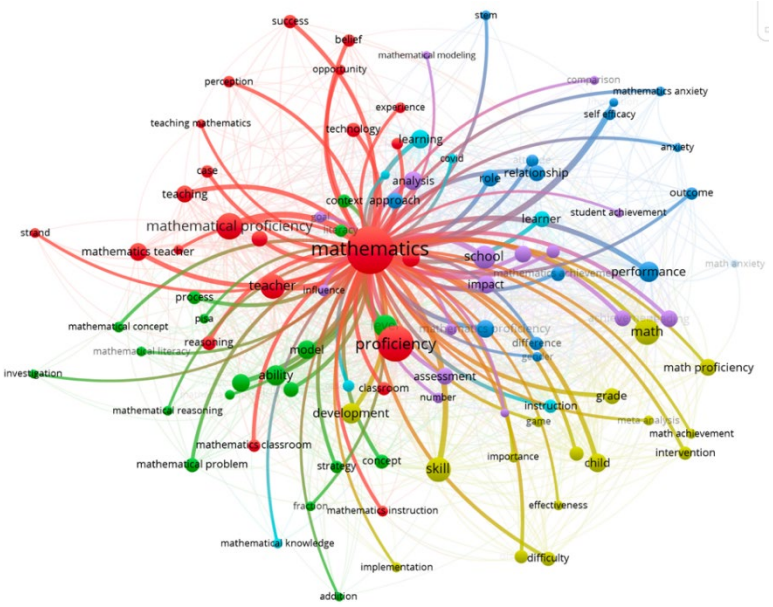

Fig. 2. Network visualization of cluster 1 [15].

Figure 2 shows that the terms used as keywords are in cluster 1, such as mathematics which has 475 occurrences with a total link strength of 1715, proficiency which has 270 occurrences with a total link strength of 1051, and mathematical proficiency which has 135 occurrences with a total link strength 455 [15]. In addition, the network visualization of cluster 1 shows that mathematical proficiency is related to technology. Technology in learning is needed to improve students' mathematical proficiency. Therefore, the exploration of MathCityMap augmented reality technology in this research is expected to be able to contribute to the development of research related to students' mathematical proficiency.

2. Literature Review

2.1. MathCityMap

MathCityMap was developed at the Geothe-University of Frankfurt by combining the math trail concept with the use of technology to bring the math trail into the 21st century, by designing an online platform and the possibility to use a mobile application [16]. The math trail concept in MathCityMap is oriented towards solving authentic outdoor mathematical problems so that it can foster a positive attitude and additional motivation for the study of mathematics, which allows students to realize the application of mathematics [17]. The tasks in MathCityMap start with real-world problems, where students must translate the problem into mathematical form to solve it, and then translate their results back to the real world and interpret their solutions. The MathCityMap project is designed as mathematics assignments based on various topics and places which students can access via a mobile phone application or on the MathCityMap website. Learners complete the math trail using the MathCityMap-App, which shows the coordinates of the task location, the route to the location, the tools needed to solve the problem on the spot, and instructions about task completion requests.

Students can input their answers and receive direct feedback from the system. MathCityMap offers math tasks on real-life objects where users can practice their skills. The implementation of MathCityMap in the learning process provides the benefits of stimulation for students to solve mathematical problems through communication, connection, reasoning, and problem-solving. The MathCityMap trail display is presented in Fig. 3.

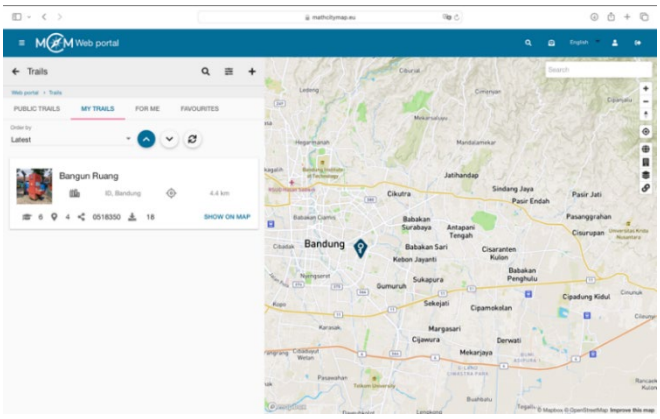

Fig. 3. MathCityMap trail.

2.2. Block and cube concept

A block is a three-dimensional shape formed by three pairs of squares, or rectangles with at least one pair of different sizes (Fig. 4). The number of sides on the block is 6, 4 sides are rectangular, and 2 sides are square and parallel. Has 12 edges, 8 pairs of edges are the same length. The total number of vertices is 8. The surface area of the block is $2 \times [(p \times l) + (p \times t) + (l \times t)]$. The volume of the block is $p \times l \times t$.

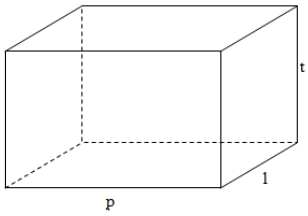

Fig. 4. Block.

A cube is a three-dimensional geometric figure bounded by six congruent square-shaped sides (Fig. 5). This regular cube or hexagon has 6 sides, 12 edges and 8 vertices. It can also be said that a cube is considered as a block whose length, width and height are the same. Surface area of a cube is $6a^2$ in square units. The volume of the cube is a^3 cubic units.

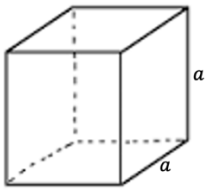

Fig. 5. Cube.

2.3. Mathematical proficiency

Mathematical proficiency is a skill that a person needs starting from expertise, competence, knowledge, and skills in mathematics to determine success in mathematics and other fields [18]. Mathematical proficiency is used to explain aspects of expertise, competence, knowledge, and facilities in mathematics so that you become successful. Mathematical proficiency has five interrelated components, namely: 1) conceptual understanding, 2) procedural fluency, 3) strategic competence, 4) adaptive reasoning, and 5) productive disposition [19]. These five components form strands and support each other as in Fig. 6.

The five components of mathematical proficiency are related to each other [19]. Conceptual understanding is understanding mathematical concepts, operations, and relationships. Conceptual understanding is the basis for students to achieve good mathematical proficiency. Procedural fluency is the skill of using steps flexibly, accurately, and efficiently. Procedural fluency abilities without using conceptual understanding abilities result in students memorizing without understanding what

they are doing and causing the use of inappropriate procedures. Strategic competence is being able to formulate, present, and solve mathematical problems. Strategic competence abilities without conceptual understanding and procedural fluency result in students having limitations regarding the strategies that can be used to solve problems. Adaptive reasoning is logical thinking between situations and mathematical concepts, the ability to think reflectively, explain, and justify. Adaptive reasoning abilities without conceptual understanding, procedural fluency, and strategic competence will result in students being unable to solve problems because they do not have sufficient conceptual understanding and strategic competence in solving problems. Productive disposition is mathematical thinking that is useful and valuable, beneficial, seeing oneself as an effective learner.

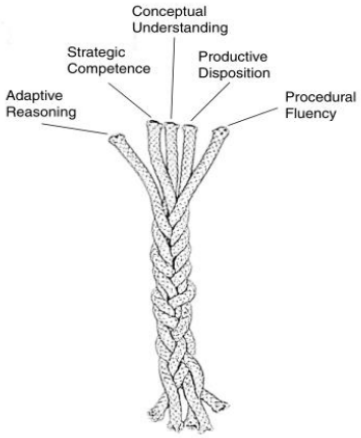

Fig. 6. Intertwined strands of mathematical proficiency.

3. Method

The research methodology uses a quasi-experimental design with a pretest-posttest framework to evaluate the effectiveness of the discovery learning and MathCityMap learning models in increasing students' mathematical proficiency in the concepts of surface area and volume. The subjects of this research were class VI students at 066 Halimun, Bandung, Indonesia. This research consisted of four sessions: an initial pretest, two learning sessions using MathCityMap, and a posttest to measure students' mathematical proficiency. Data collection techniques use tests, observation, and documentation. Data analysis was carried out using SPSS to identify statistically significant improvements in students' mathematical abilities [20, 21].

4. Results and Discussion

The technological exploration of augmented reality MathCityMap begins with creating a trail which is the point of the problem that will be solved by students. The steps for creating a trail in MCM are described in Table 1.

The trail created in the research, namely at 066 Halimun Elementary School, Bandung, West Java, Indonesia, consists of four tasks related to spatial material, and the points on the trail are shown in Fig. 7. The first task is to calculate the surface area of the plant pot between the sides. the outer and inner sides which are

in front of the IC class. The second task is to determine the costs needed to paint the block-shaped prayer room cupboard. The third task is to calculate the volume of the six bookshelf boxes in the prayer room. The fourth task is to determine the difference in volume of the trophy box in the school corridor.

Table 1. Steps for creating a trail in MathCityMap.

No.	Steps	Description
1.	Download the MCM platform application on your smartphone	The MCM application can be downloaded on Google Play or the App Store
2.	Take photos of objects that will become problems for students	Activate map location when photographing objects
3.	Make questions related to the objects that have been photographed	The questions are in the form of story problems related to material in the mathematical concepts
4.	Create clues to answer questions	The maximum number of instructions that can be given is 3 instructions
5.	Measure objects to determine solutions	Measurements are carried out as a process of creating solutions
6.	Create a solution	Solutions are written in numerical form
7.	Create tasks from predefined objects	One task consists of one predetermined photo
8.	Create a trial that will be tested on students	Combines all tasks that have been created

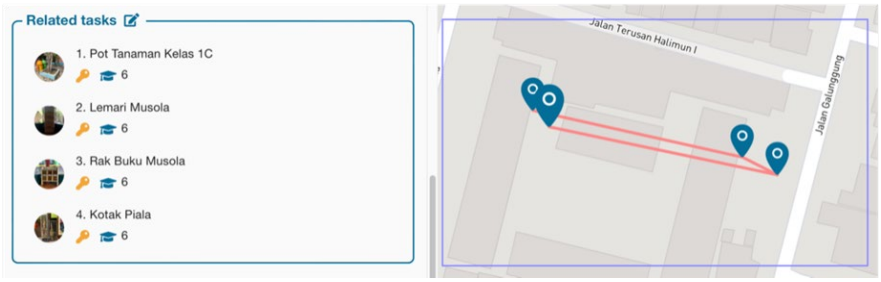

Fig. 7. Space building trail at 066 Halimun Elementary School, Bandung, Indonesia.

Furthermore, the trail can be accessed by the student's MCM account by entering the trail code, namely 0518350. Students will be directed to each task with the help of maps (see Fig. 8). Students must arrive at the map point for each assignment to work on the questions on that assignment. After the student reaches the point where the object in the task is located, the student can answer the question by first clicking on the clue. Students take measurements and write answers in the solution column provided in the application. If students answer with the correct solution they will be directed to the next task. However, if the student answers incorrectly then the student must rewrite the answer until they find the correct answer.

The study utilized the discovery learning model and MathCityMap media to teach the surface area and volume of cubes and blocks, with students initially assessed through a pretest [22]. The activities included greetings, prayers, singing the national compulsory song, and grouping based on cognitive ability. Previous research has shown that the discovery learning model enhances students' mathematical reasoning

and understanding by allowing them to independently explore and manipulate concrete objects to build knowledge [23]. Additionally, the use of discovery learning has been linked to improved mathematical communication skills and problem-solving abilities [24, 25]. These findings support the effectiveness of incorporating discovery learning and technology like MathCityMap in mathematics education. The use of MathCityMap by sixth-grade elementary school students in learning cubes and blocks in this study is illustrated in Fig. 9.

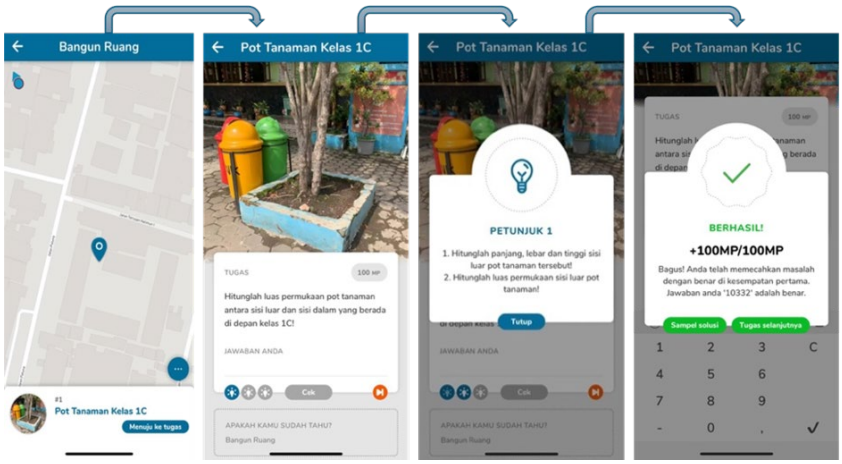

Fig. 8. The process of completing one of the tasks on MathCityMap.

Fig. 9. MathCityMap exploration in learning.

The study observed varying levels of students' ability to use surface area and volume formulas for cubes and blocks. While some students provided correct answers, they struggled with including units in their responses. The volume formula activities mirrored those of a previous meeting, with additional emphasis on volume concepts. Although most students could use the formula correctly, some faced challenges in providing definitive answers. Previous research has shown that students' proficiency in mathematics can be influenced by factors such as language proficiency, motor skills, and the use of technology in teaching methods [26, 27]. These studies emphasize the importance of considering various aspects that can impact students' mathematical abilities and the effectiveness of instructional approaches.

The posttest assessed students' progress in comprehending surface area and volume concepts, highlighting difficulties in calculating painting costs for a cupboard and offering comprehensive solutions [28]. Studies have indicated that

students' conceptualization of geometric principles may differ depending on their mathematical skills [29]. Moreover, the integration of technology such as robots in math education has been proven to boost students' ability to represent concepts effectively [30]. These findings emphasize the significance of addressing students' diverse learning requirements and the influence of instructional approaches on their mathematical comprehension.

Based on the results of the paired sample t-test from the pretest and posttest, the value of sig. = 0.000 < α = 0.05 (with α = 5%) then H_0 is rejected and H_1 is accepted, meaning that there is a difference in the average mathematical ability of students in learning mathematics before and after using MathCityMap media. Apart from that, the pretest and posttest increase in this study used a normalized gain test. With a pretest average of 38 and a posttest average of 76, there is a visible difference in the average pretest and posttest mathematics ability scores of students when learning mathematics using MathCityMap media. The increase in students' mathematical proficiency can be seen from the n-gain result of 0.62 and is included in the medium category. The statistical analysis conducted indicates a significant difference in students' mathematical proficiency before and after using MathCityMap media, as the obtained significance value of 0.000 is less than the set alpha value of 0.05, leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis [31]. This finding aligns with research showing that there are statistically significant differences in math proficiency attributed to academic achievement [32]. Additionally, studies have highlighted the importance of teaching practices in enhancing students' mathematical proficiency [33]. The relationship between English reading proficiency and academic achievement has also been noted as a predictor of success in science and mathematics studies [34].

The achievement of each component in mathematical proficiency, namely conceptual understanding reached 89%, procedural fluency reached 73%, strategic competence reached 70%, adaptive reasoning reached 75%, and productive disposition reached 75%. The average achievement of the five mathematical proficiency components is 76%. These results are quite good, students can apply a concept which is translated into problem solving steps, students can choose the right procedure to use or modify existing steps to make them more efficient, students can draw logical conclusions, estimate answers, and provide explanation of the concept of the answer and the procedures used to make the answer mathematically correct [35].

Differing perspectives on the impact of learning media on mathematical proficiency are evident in the literature. highlighted the importance of matching learning media with students' characteristics [36], while evaluating professional development in mathematics education using various approaches, emphasizing the complexity of assessing educational interventions [37]. These studies underscore the need for a comprehensive understanding of the effectiveness of MathCityMap media beyond just N-gain outcomes to determine its true impact on students' mathematical proficiency. This study can help and add new information regarding current studies in mathematics [38-47].

5. Conclusion

This study validates the effectiveness of combining the discovery learning model with MathCityMap media to enhance mathematical proficiency in surface area and

volume concepts, with significant improvements observed through pretest and posttest analyses. These findings underscore the importance of innovative teaching and technology in mathematics education, promoting a deeper conceptual understanding and accommodating diverse learning styles. Recommendations include wider use of technology-enhanced tools, practical applications, conceptual focus, differentiated instruction, teacher development, and further research on diverse instructional impacts and factors affecting mathematical learning. This approach not only boosts mathematical skills but also enriches the learning experience, highlighting the need for adaptive and engaging education strategies.

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