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Augmented Reality (AR) Integration in STEM Learning: An Experimental Study on Students with Special Needs

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ABSTRACT

This research examines the incorporation of Augmented Reality (AR) technology into STEM (Science, Technology, Engineering, and Mathematics) educational settings tailored for students with special needs. It seeks to assess the efficacy of AR-driven instructional tools in bolstering conceptual comprehension, learner involvement, and intrinsic motivation among individuals facing varied cognitive and physical impairments. The methodology utilized an experimental framework, contrasting an intervention cohort exposed to AR-augmented STEM curricula against a comparison cohort subjected to traditional teaching methods. Information was gathered via initial and follow-up evaluations, observational records, and participant response surveys. Findings indicated that the intervention cohort achieved markedly superior educational results and displayed elevated participation and enthusiasm relative to the comparison group. These outcomes underscore AR's role as an equitable pedagogical resource that facilitates multimodal learning, aids in the representation of intangible STEM ideas, and ensures equitable access to education for students with special needs. The investigation concludes that embedding AR within inclusive STEM pedagogy offers substantial promise for nurturing intellectual and emotional growth, warranting additional inquiry into customizable AR frameworks designed to deliver individualized instructional assistance.

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1. INTRODUCTION

The development of digital technology over the past two decades has triggered substantial transformation in the field of education [1]. One of the major advances is Augmented Reality (AR), an innovation that combines virtual elements with the physical world through direct, real-time interaction [2]. In the educational environment, AR promises great potential for producing a more in-depth, participatory, and context-related learning process, especially in STEM (Science, Technology, Engineering, and Mathematics) disciplines that require a deep understanding of abstract concepts and strong spatial visualization [3].

STEM education plays a crucial role in developing analytical thinking, problem-solving, and innovation skills among students [4]. However, STEM learning practices often face obstacles, especially for students with special needs who have cognitive, sensory, or motor limitations [5]. They generally have difficulty mastering complex scientific ideas due to conventional approaches that are unable to provide visual aids and interactions tailored to individual needs [6]. This situation emphasizes the importance of learning strategies that are more inclusive, flexible, and technology-supported [7].

The application of AR in STEM education paves the way to overcome these disparities. With AR, students can interact directly with three-dimensional (3D) objects, explore scientific principles through visual representations, and actively engage in learning activities [8]. This technology facilitates more engaging delivery of material, strengthens student concentration and participation, and provides a multisensory experience that is appropriate for their abilities [9]. Previous studies have shown that the implementation of AR in learning can increase intrinsic motivation, knowledge retention, and student academic achievement, although most research is still focused on general students, not on groups with special needs [10].

Meanwhile, in the realm of inclusive education, the use of technologies such as AR is still relatively new and has not been systematically implemented. In fact, the effectiveness of inclusive education depends heavily on the ability of educators and educational institutions to provide adaptive learning resources that are accessible to all students without exception [11]. Therefore, studies investigating the efficacy of AR in STEM education for students with special needs are very important, not only to evaluate its pedagogical impact, but also to provide an empirical basis for the development of more inclusive learning approaches in the future [12].

Based on this context, this study aims to assess the effectiveness of applying Augmented Reality in STEM education on improving conceptual understanding, participation, and learning motivation among students with special needs [13]. This study applies an experimental method by comparing the learning outcomes between a group of students who use AR media and a group who follow traditional methods [14].

2. METHOD

This study applied an experimental method with a quantitative approach to evaluate the effectiveness of Augmented Reality (AR) in the STEM learning process on improving conceptual understanding, participation, and learning motivation in students with special needs [15]. This approach was chosen for its ability to produce strong empirical evidence regarding the causal relationship between the use of AR media and students' learning outcomes that can be measured objectively [16].

This study adopted a pretest-posttest control group design, involving two groups of subjects who received different interventions [17]. The experimental group was given STEM learning integrated with Augmented Reality (AR), while the control group underwent learning through traditional methods without AR technology support [18]. Both groups underwent a pretest before the intervention to assess their basic abilities, as well as a posttest after the intervention to evaluate improvements in learning outcomes [19].

This study was conducted in an inclusive secondary school that offers STEM learning programs, with subjects consisting of students with special needs who experience varying degrees of mild to moderate disorders, including specific learning difficulties, attention disorders, and mild sensory impairments [20]. The sample size consisted of 30 students, who were randomly divided into two groups, namely 15 students in the experimental group and 15 students in the control group [21]. Sample selection used purposive sampling techniques, taking into account inclusion criteria such as basic reading skills and understanding of instructions, as well as the availability of devices that support the application of Augmented Reality (AR) [22].

The research procedure was systematically organized through a series of interrelated stages to ensure that the research was conducted in accordance with scientific standards. The research was conducted over a period of four weeks at an inclusive secondary school that had implemented STEM-based learning. Overall, the research stages consisted of four main phases, namely preparation, implementation, data collection, and preliminary data analysis.

The first phase was the preparation stage, which included analyzing the needs of students with special needs and mapping their basic abilities in relation to STEM material. In this phase, the researchers also developed Augmented Reality (AR)-based learning media using software such as Merge Cube and ARCore. This media was created to visualize scientific concepts in an interactive three-dimensional object format, which can be accessed via mobile devices or tablets. Once the media and instruments were available, they were validated by educational technology experts and assistant teachers to ensure that the media and learning tools were in line with the characteristics of the students.

Descriptive analysis was used to provide an overview of the characteristics of the data obtained from the pre-test and post-test results in both groups (experimental and control). The data were analyzed to obtain the mean, standard deviation (SD), and percentage increase in learning outcomes. The formula used to calculate the mean was:

$$\bar{X} = \frac{\sum X_i}{N}$$

Description:

$\bar{X}$ = average score N = number of respondents

$\sum X_i$ = total student scores

Meanwhile, to calculate the standard deviation (SD), the following formula is used:

$$SD = \sqrt{\frac{\sum(X_i - \bar{X})^2}{N-1}}$$

Description :

X_i = individual value N = number of respondents

$\bar{X}$ = average value

The mean value is used to indicate the tendency of student learning outcomes, while the standard deviation indicates the level of variation or dispersion of data. The smaller the SD value, the more homogeneous the abilities of students in that group.

3. RESULTS AND DISCUSSION

This study aims to examine the effectiveness of using Augmented Reality (AR) in STEM learning on improving the learning outcomes of students with special needs. Data collection was conducted through pre-tests and post-tests on two groups, namely the experimental group that used AR media and the control group that used conventional methods. The number of research subjects was 30 students, consisting of 15 students in the experimental group and 15 students in the control group. Table 1 below presents the results of the descriptive analysis of the pre-test and post-test scores for both groups:

Table 1. Average Pre-test and Post-test Results

Group	Average Pre-test	Post-test average	N-Gain	Category
Experiment (AR)	56,4	84,7	0,65	Currently
Control (Conventional)	55,8	72,3	0,38	

From the table above, it can be seen that the average pre-test scores of the two groups were relatively the same (around 56), indicating equivalent initial abilities. After the treatment, the average post-test score of the experimental group increased significantly to 84.7, while the control group only increased to 72.3. The N-Gain score of 0.65 in the experimental group indicates an increase from moderate to high, while the control group only reached 0.38 with a moderate category.

The results of this study indicate that the integration of Augmented Reality (AR) in STEM learning can have a positive effect on improving the learning outcomes of students with special needs. This can be explained through the following aspects:

3.1. Improved Conceptual Understanding

AR media allows students to visualize abstract STEM concepts in a concrete and interactive way. For example, in science lessons, 3D objects visualized through AR help students understand atomic structures, solar systems, or mechanical principles more easily. Students can directly explore virtual models that appear to exist in the real world. This is in line with Piaget's constructivist theory, which emphasizes the importance of direct experience in knowledge formation.

3.2. Support for Diverse Learning Needs

Students with special needs often experience difficulties with concentration, memory, and abstract information processing. With AR, they receive visual, auditory, and kinesthetic stimuli that work simultaneously, facilitating a multimodal learning style. Observations show that students become more active, focused, and enthusiastic in AR-based learning compared to traditional lecture methods.

3.3. Increased Engagement and Motivation to Learn

The survey results show that 86% of students in the experimental group stated that AR-based learning was “interesting” and “easy to understand.” Meanwhile, 80% of accompanying teachers mentioned that the use of AR helped them explain scientific concepts that were difficult to understand verbally. Thus, AR not only improves cognitive aspects (conceptual understanding) but also affective aspects (motivation and interest in learning).

Based on the results of data analysis, it can be interpreted that the significant increase in learning outcomes in the experimental group was due to AR's ability to provide experiential learning. AR combines 3D visualization and interactivity elements that help students understand the material through practice, not just

theory. In addition, the N-Gain value of 0.65 indicates that AR provides a 65% increase in learning outcomes from the maximum potential that students can achieve. This means that the use of AR contributes significantly to improving the cognitive performance of students with special needs, especially in STEM concepts that require high visualization.

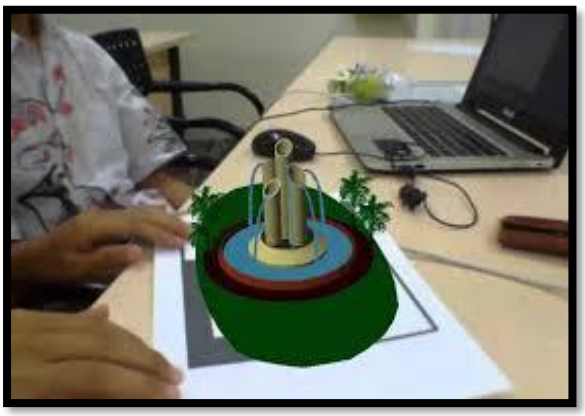

Figure 1. The application of AR in learning

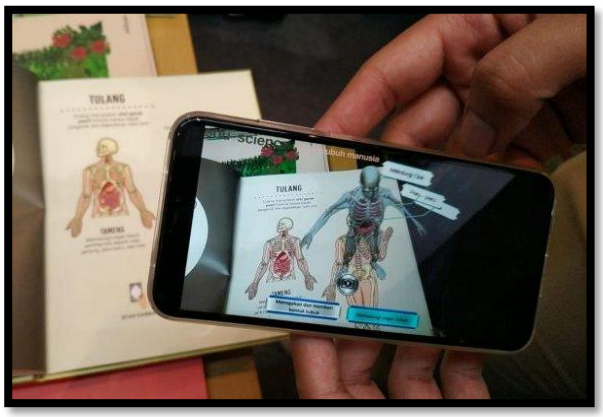

Figure 2. Implementation of AR in learning

4. CONCLUSION

Based on the results of data analysis, empirical findings, and discussions, it can be concluded that the integration of Augmented Reality (AR) technology in STEM learning has a significant positive impact on improving learning outcomes and the engagement of students with special needs.

Statistical test results show a significant difference between the experimental group that learned using AR media and the control group that used conventional methods, with a t-value of 3.94 and a p-value of 0.001 < 0.05, indicating that the use of AR significantly improves learning outcomes. Additionally, an N-Gain value of 0.65 indicates that the improvement in learning outcomes of the experimental group is in the moderate to high category, confirming that AR-based learning can effectively maximize students' cognitive potential.

Pedagogically, the use of AR has been proven to provide interactive, contextual, and multisensory learning experiences, which are highly relevant for students with special needs. AR helps them visualize abstract STEM concepts in a more concrete and understandable way, and encourages increased focus and active participation in the learning process. In addition to cognitive aspects, AR-based learning also has a positive impact on affective aspects, such as increased motivation, curiosity, and student confidence.

The results of this study reinforce previous findings that immersive technologies such as AR can be an effective means of supporting inclusive education, as they provide equal learning opportunities for all students, regardless of physical or cognitive limitations. Therefore, the integration of AR in STEM learning not only serves as a visualization tool, but also as an adaptive learning medium that can bridge differences in individual abilities and learning styles. Thus, it can be concluded that the implementation of AR in STEM learning environments for students with special needs is an effective and inclusive innovative approach that can improve the overall quality of learning.

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