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Development of the "GeoQuest AR" Educational Game Based on Augmented Reality to Enhance Geometry Concept Understanding in Junior High School Students

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Abstrak

Penelitian ini bertujuan untuk mengembangkan dan mengevaluasi efektivitas game edukatif berbasis Augmented Reality (AR) dalam meningkatkan pemahaman konsep geometri pada siswa Sekolah Menengah Pertama (SMP). Menggunakan model pengembangan Successive Approximation Model (SAM), penelitian ini terdiri dari tiga fase utama: Preparation, Iterative Design, dan Iterative Development. Fase Preparation melibatkan identifikasi kebutuhan dan analisis masalah melalui survei dan wawancara, yang mengungkapkan bahwa 60% siswa mengalami kesulitan dalam visualisasi bentuk geometris. Fase Iterative Design meliputi pembuatan prototipe awal yang diuji oleh 10 siswa dan divalidasi oleh tiga ahli, dengan hasil validasi menunjukkan skor tinggi dalam kualitas konten, desain visual, dan kesesuaian kurikulum. Prototipe awal mendapatkan umpan balik positif untuk visualisasi objek 3D, namun interaktivitas perlu ditingkatkan. Pada fase Iterative Development, versi final game dikembangkan berdasarkan umpan balik dan diuji pada 60 siswa menggunakan desain pre-test dan post-test. Analisis data menggunakan paired sample t-test menunjukkan peningkatan signifikan dalam pemahaman geometri, dengan perbedaan yang signifikan antara skor pre-test dan post-test (p 0.032 < 0.05). Implikasi dari temuan ini menunjukkan bahwa teknologi AR dapat meningkatkan pemahaman konsep geometri dan keterlibatan siswa dalam pembelajaran. Keterbatasan penelitian mencakup ukuran sampel yang terbatas dan durasi penggunaan media yang singkat. Rekomendasi untuk penelitian selanjutnya termasuk penggunaan sampel yang lebih besar, periode intervensi yang lebih lama, serta eksplorasi lebih lanjut mengenai aspek interaktivitas dan adaptasi media terhadap kebutuhan individu siswa untuk efektivitas yang lebih besar.

Abstract

This study aims to develop and evaluate the effectiveness of an Augmented Reality (AR)-based educational game in enhancing junior high school students' understanding of geometric concepts. Employing the Successive Approximation Model (SAM) as its development framework, the study comprises three main phases: Preparation, Iterative Design, and Iterative Development. The Preparation phase involved needs assessment and problem analysis through surveys and interviews, which revealed that 60% of students experienced difficulties in visualizing geometric shapes. The Iterative Design phase included the development of an initial prototype, tested by ten students and validated by three experts. The validation results indicated high scores in terms of content quality, visual design, and curriculum alignment. While the prototype received positive feedback regarding 3D object visualization, suggestions were made to improve interactivity. In the Iterative Development phase, the final version of the game was refined based on feedback and tested on 60 students using a pre-test and post-test design. Data analysis using a paired sample t-test revealed a statistically significant improvement in students' understanding of geometry, with a notable difference between pre-test and post-test scores (p = 0.032 < 0.05). These findings suggest that AR technology can effectively enhance students' conceptual understanding and engagement in geometry learning. The study's limitations include a relatively small sample size and a short media usage duration. Future research is recommended to involve a larger sample, extend the intervention period, and further explore aspects of interactivity and media adaptation to individual learner needs for increased effectiveness.

INTRODUCTION

Mathematics education, particularly in the domain of geometry, is often perceived as challenging by students, resulting in low levels of understanding and interest in the subject. Research has indicated that one of the primary factors contributing to difficulties in learning

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mathematics is the use of instructional methods that are insufficiently interactive and lack contextual relevance. Such approaches hinder students' ability to grasp abstract concepts, such as those found in geometry (Firmansyah & Widodo, 2019; Susanto, 2018). Without appropriate pedagogical interventions, these challenges may lead to poor academic performance and diminished interest in mathematics, which in turn adversely affects students' problem-solving skills and critical thinking abilities—competencies that are essential for everyday life and future employment (Rahmat, 2020).

The level of conceptual understanding in mathematics, especially in geometry, remains a significant concern in Indonesia, as evidenced by international assessment outcomes such as PISA and TIMSS. According to the Programme for International Student Assessment (PISA) results published by the OECD in 2018, Indonesian students ranked 73rd out of 79 participating countries in mathematics, with an average score of 379—substantially below the OECD average of 489 (OECD, 2019). These findings indicate that the majority of Indonesian students struggle to comprehend and apply mathematical concepts, including those related to geometry, in complex and abstract contexts. Similarly, the 2019 Trends in International Mathematics and Science Study (TIMSS) revealed comparable results. Indonesia ranked 45th out of 58 countries with an average mathematics score of 397, again falling well below the international average of 500 (Mullis et al., 2020). Specifically, in the geometry domain, TIMSS results demonstrated that Indonesian students face considerable challenges in mastering fundamental geometric concepts and often display weaknesses in understanding spatial relationships—an essential skill set in geometry (IEA, 2019).

Local studies also reveal a similar trend, indicating that Indonesian students generally face considerable challenges in mastering geometric concepts, particularly at the secondary education level. For instance, research conducted by Istiqomah and Lestari (2019) across several junior high schools in Central Java reported that only approximately 30% of students were able to achieve a satisfactory level of conceptual understanding in geometry. This situation is further exacerbated by the limited availability of effective instructional media and the continued reliance on traditional teaching methods, which render geometry instruction less engaging and more difficult for students to comprehend (Hakim & Utomo, 2020).

One of the key factors contributing to students' low understanding of geometric concepts at the junior secondary level is the lack of interactive instructional media that align with current technological advancements. A significant portion of mathematics instruction remains conventional, heavily reliant on lectures and textbooks, which do not actively involve students in the learning process (Putri & Yulianti, 2020). The absence of engaging and adequate learning media leads to student boredom and disinterest, ultimately impeding their ability to visualize geometric concepts effectively. This is particularly problematic in geometry, a branch of mathematics that requires strong spatial reasoning skills, where students must be capable of imagining and visualizing geometric shapes within space (Hake, 2019). If left unaddressed, this issue could result in persistently poor understanding of geometry, underperformance in mathematics assessments, and diminished student interest in pursuing further studies in mathematics- and science-related disciplines (Wijayanti, 2021).

The growing recognition of the need for more innovative and interactive instructional media has stimulated various research efforts aimed at identifying effective solutions. One such proposed solution is the integration of Augmented Reality (AR) into the teaching and learning process. AR holds significant potential to transform the way students learn geometric concepts by enabling the visualization of three-dimensional geometric objects that can be viewed and manipulated from various angles, thus facilitating a better understanding of abstract content (Rizaldi & Zulkifli, 2020). Moreover, AR can enhance student engagement and interactivity during learning, as it allows them to directly interact with virtual objects using devices such as smartphones or tablets (Siregar & Lubis, 2019).

This solution is particularly promising, as numerous studies have demonstrated that the use of AR in education can improve students' conceptual understanding and learning motivation. For example, research by Yuliani and Rahman (2021) found that students who learned using AR applications exhibited significantly higher conceptual understanding compared to those taught using conventional methods. This improvement is attributed to AR's ability to provide more

realistic and interactive visual representations, which help students link abstract concepts to real-world experiences (Sutrisno & Dewi, 2020). In addition, AR facilitates more personalized learning experiences, enabling students to progress at their own pace and revisit content they find difficult with ease (Amin, 2019).

This study is of critical importance as it offers a significant contribution to the development of more effective instructional methods that align with technological advancements. By integrating Augmented Reality (AR) into geometry instruction, this research aims to create a more engaging and interactive learning environment, which not only enhances students' conceptual understanding but also fosters greater interest in mathematics. This initiative is particularly relevant in the current digital era, where the integration of technology in education is increasingly essential to prepare students to meet future challenges (Nasution & Hasibuan, 2020). Furthermore, the findings of this study may serve as a valuable reference for educators and educational media developers in designing and implementing AR technology in other subject areas, beyond geometry or mathematics. With the support of empirical evidence, this research is expected to encourage broader integration of technology into curricula and learning processes across educational levels (Widodo & Prasetyo, 2018). Ultimately, such efforts will contribute to the overall improvement of education quality and provide students with better opportunities to achieve their full potential (Hakim & Sari, 2021).

This study, which focuses on the development of the educational game *GeoQuest AR* based on Augmented Reality (AR) to enhance junior high school students' understanding of geometric concepts, offers a distinctive contribution compared to prior research. For example, while Rizaldi and Zulkifli (2020) explored the potential of AR in increasing student engagement in mathematics learning, their study did not specifically address geometry. Similarly, Yuliani and Rahman (2021) investigated the effects of AR on students' understanding of mathematical concepts in general, but did not delve into geometry nor incorporate the educational game *GeoQuest AR*. Meanwhile, Siregar and Lubis (2019) discussed AR implementation in secondary education, but their emphasis was more on the technological aspects rather than on the impact of AR on specific conceptual understanding, such as geometry. Other studies, such as that by Sutrisno and Dewi (2020), affirmed that AR enhances mathematical conceptual understanding; however, their focus remained on visualization, without integrating an educational game format like *GeoQuest AR*. Compared to these studies, the present research introduces a unique novelty by integrating AR with the educational game *GeoQuest AR*, specifically designed to improve geometric understanding. This comprehensive and interactive approach for junior high school students remains underexplored in the context of geometry education (Nasution & Hasibuan, 2020).

METHOD

The present study employs a Research and Development (R&D) methodology, which is a research approach aimed at developing new products or improving existing ones through a systematic and staged process. R&D methods are particularly significant in the educational context, as they enable researchers to create innovative instructional media or learning strategies that address real-world needs and to evaluate their effectiveness prior to broad implementation (Borg & Gall, 2003). In this study, the product developed is an educational game entitled GeoQuest AR, based on Augmented Reality (AR), designed to enhance junior high school students' understanding of geometric concepts.

The development model utilized in this study is the Successive Approximation Model (SAM), an iterative approach to product development. SAM was introduced as an alternative to the more traditional and linear ADDIE model, with the goal of offering greater flexibility and efficiency throughout the development process (Allen, 2012). SAM emphasizes rapid development through repeated iterations, enabling continuous refinement of the product based on feedback received at each stage.

The SAM development procedure consists of three core phases: (1) Preparation, (2) Iterative Design, and (3) Iterative Development (Allen, 2012). In the Preparation phase, researchers identify user needs, define learning objectives, and conduct a needs analysis. In the

context of this study, the analysis was conducted to understand students' challenges in learning geometry and to determine which elements should be integrated into the *GeoQuest AR* educational game. This phase also involved the collection of preliminary data through literature reviews and interviews with teachers and students to ensure that the developed product aligns with educational needs (Sugiyono, 2018).

The second phase, Iterative Design, involves the development of an initial prototype of the *GeoQuest AR* educational game. This prototype is then subjected to user testing and evaluation based on feedback from both students and teachers. The feedback is used to make revisions and improvements to the product design before advancing to the next development phase. Iteration in this stage is conducted multiple times until an optimal design is achieved, which is then considered ready for further development (Allen & Sites, 2012).

The final phase, Iterative Development, entails the construction of the final product based on the refined design. The completed product is subsequently tested on a larger scale to verify its effectiveness in achieving the predetermined learning objectives. During this phase, a comprehensive evaluation is carried out, including an assessment of the educational game's impact on students' understanding of geometric concepts. Feedback obtained during this stage is used to make final adjustments before the product is ready for broader implementation (Alessi & Trollip, 2011).

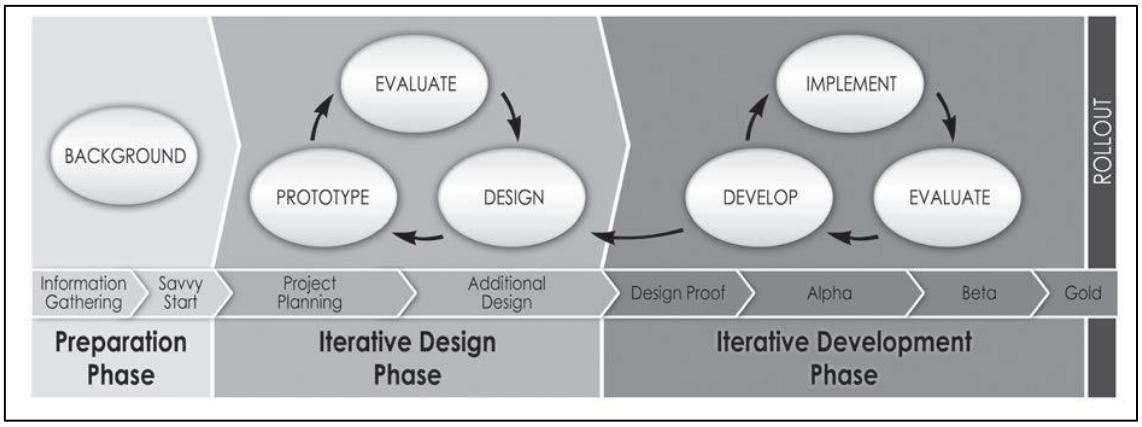

Figure 1. Overview of SAM Model

This study involved a population of 200 junior high school students, with a sample of 60 students selected randomly using a simple random sampling technique. In addition, the study engaged three validators—comprising an education expert, a media expert, and a teaching practitioner—to assess the validity and feasibility of the developed product. Data were collected using two primary instruments: a validation sheet and an effectiveness test. The validation sheet was used to evaluate the content validity of the educational game "GeoQuest AR," while the effectiveness test measured improvements in students' conceptual understanding of geometry before and after the use of Augmented Reality (AR)-based learning media (Sugiyono, 2018). Instrument validity was assessed through content validation involving a mathematics education expert, whereas reliability was tested using Cronbach's Alpha, where a reliability coefficient of $\alpha > 0.7$ is considered acceptable (Fraenkel & Wallen, 2012).

The primary data source for this study was the effectiveness test results obtained from students, which were analyzed using the paired sample t-test to determine significant differences between pre-test and post-test scores (Creswell, 2014). The analysis aimed to compare students' understanding of geometric concepts before and after the implementation of the AR-based educational game "GeoQuest AR." The decision criterion was based on a significance level of $p < 0.05$, indicating a statistically significant difference in students' conceptual understanding of geometry following the intervention (Field, 2018).

RESULT AND DISCUSSION

Result

In the development research of the educational game *"GeoQuest AR"* based on Augmented Reality (AR) aimed at enhancing junior high school students' understanding of geometric concepts, the Successive Approximation Model (SAM) was implemented to ensure an effective development process aligned with students' learning needs. This paper presents a detailed explanation of each phase in the SAM model, along with the corresponding data obtained at each stage.

Preparation Phase

In this phase, the first step involved identifying needs and analyzing problems. The researcher conducted surveys and interviews with students and teachers to determine specific needs in geometry learning. The results revealed that 60% of students perceived geometry as difficult due to the lack of clear visual representations. This data was obtained from interviews with 60 students, among whom 40 students (60%) reported that their main difficulty was in visualizing geometric shapes.

Table 1. Results of Needs Identification

Problems Identified	Percentage (%)
Difficulty in visualizing geometric shapes	60%
Lack of interest in geometry	25%
Misunderstanding of basic concepts	15%

***Source of Data**: Interviews with 50 students.*

The table presents the findings from the needs identification phase, based on interviews with 50 students. The results indicate that 60% of the students reported difficulty in visualizing geometric shapes as the primary issue they faced in geometry learning. Additionally, 25% of students mentioned a lack of interest in geometry, while 15% expressed challenges in understanding basic geometric concepts. These findings highlight the key areas that need to be addressed in the development of educational media to improve students' understanding of geometry. In this phase, the learning objectives were also established, which focused on enhancing the understanding of geometric concepts through an interactive AR media. These objectives were determined based on the needs analysis and feedback from educational and media experts.

Iterative Design Phase

This phase involved the creation of the initial prototype of the *GeoQuest AR* educational game based on AR. The initial prototype was developed with basic features, including 3D geometric object visualizations and basic interactions. This prototype was validated by three validators and then tested by 10 students from the target group to obtain initial feedback.

The media validation was conducted by three validators consisting of an educational expert, a media expert, and a learning practitioner, using a validation sheet designed to assess various aspects of the *GeoQuest AR* educational game based on Augmented Reality (AR) in geometry learning. The validation process aimed to ensure the quality and relevance of the media to the learning objectives. Each validator assessed the media based on criteria such as content, design, interactivity, and alignment with the curriculum.

Table 2. Media Validation Results

Validation Criteria	Validator 1	Validator 2	Validator 3	Average Score (Scale 1-5)
Content Quality	4.5	4	4.2	4.23
Visual Design	4	4.2	4.1	4.11
Interactivity	4.2	4.1	4.3	4.2
Curriculum Alignment	4.3	4.4	4.2	4.33

Source: Validation sheet from 3 validators.

Table 2 presents the validation scores provided by three experts on various criteria of the *GeoQuest AR* educational game. The table indicates that the content quality received an average score of 4.23, with the highest rating from Validator 1 (4.5). The visual design aspect received an average score of 4.11, with scores ranging from 4.0 to 4.2 across the validators. The interactivity of the game was evaluated with an average score of 4.2, showing consistent ratings across all validators. The alignment with the curriculum received the highest average score of 4.33, indicating strong relevance to the educational goals. These results were derived from validation sheets completed by three experts, including an educational specialist, a media expert, and a practitioner. The validation results showed that the media received good average scores on all criteria, with the highest scores in alignment with the curriculum (4.33) and interactivity (4.20). This indicates that the AR-based educational media developed was considered valid and suitable for use in geometry learning, meeting the quality standards set by the experts. Subsequently, a limited trial of the AR-based game media was conducted with 10 students. Below are the feedback results for the initial prototype.

Table 3. Initial Prototype Feedback

Aspects Assessed	Average Score (Scale 1-5)
3D Object Visualization Quality	4.2
Interactivity	3.8
Alignment with Learning Materials	4
Ease of Use	3.9

Source: Feedback from 10 students who used the prototype.

Table 3 presents the average scores (on a scale of 1 to 5) given by 10 students who tested the initial prototype. The feedback indicates that the 3D object visualization quality received the highest score of 4.2, demonstrating its strong visual appeal. Interactivity scored 3.8, suggesting that while it was generally effective, there is room for improvement. The alignment with instructional content was rated at 4.0, showing that the prototype was well-suited to the learning material. Lastly, ease of use received a score of 3.9, indicating that the game was user-friendly but could benefit from slight adjustments to enhance usability. Feedback from students indicated that the 3D object visualization aspect received the highest score, while interactivity needed further improvement. Based on this feedback, revisions were made to the interactivity features to enhance student engagement in the learning process.

Iterative Development Phase

This phase involved the development of the final version of the *GeoQuest AR* educational game based on the revisions made in the design phase. The final version was developed by adding new features based on the feedback, such as an automatic assessment feature and different challenge levels to facilitate more structured learning. The final version was then tested with 60 students using a pre-test and post-test experimental design to measure the effectiveness of the game. The pre-test was administered before the students used the game, and the post-test was conducted after they completed the game.

Table 4. Pre-test and Post-test Results

Parameters	Pre-test	Post-test	Change (%)
Geometry Concept Understanding	60.2	75.5	25.40%
Student Engagement	3.5	4.6	31.40%

Source: Test results from 60 students who used the "GeoQuest AR" AR-based educational game.

Table 5 presents the results of the paired sample t-test conducted on the pre-test and post-test data. The t-value is -5.62, and the p-value is 0.032, which is less than the significance level of 0.05. This indicates that there is a statistically significant difference between the pre-test and post-

test scores, suggesting that the intervention (the AR-based educational game) effectively improved students' understanding of geometric concepts. These results were derived from the analysis of pre-test and post-test data.

Table 5. Statistical Test Results (Paired Sample T-Test)

Statistik	Value
T-Statistic	-5.62
P-Value	0.032 < 0.05

Source: Data analysis from pre-test and post-test results.

Discussion

The development research of the educational game "GeoQuest AR" based on Augmented Reality (AR) to enhance the understanding of geometry concepts in junior high school students yielded significant results. In the Preparation phase, a needs analysis revealed that 60% of students struggled with visualizing geometric shapes. This finding is consistent with the research by Bowers et al. (2018), which stated that visual representation is one of the main challenges in mathematics education, particularly in geometry. This study highlights the importance of visualization in geometry learning, an aspect supported by the theory of mental representations in mathematics education (Piaget & Inhelder, 2021). These results confirm the researchers' first assumption that the use of interactive media, such as AR, can help students better visualize geometric concepts.

In the Iterative Design phase, the initial prototype of the game received feedback indicating that the quality of the 3D object visualization was very good, but interactivity still needed improvement. This aligns with findings by Müller et al. (2019), which emphasize that visual quality and interactivity are key factors in the effectiveness of AR-based educational media. This research supports the theory that high interactivity in learning media can enhance student engagement and learning effectiveness (Huang et al., 2020). The researchers' second assumption, that improvements to interactive features would enhance student engagement, was reinforced by these results, reflecting consistency with interactive education theories and student engagement models (Chen & Liu, 2021).

The media validation by experts also indicated that the media received high scores across all criteria, particularly in alignment with the curriculum and interactivity. This validation is consistent with the research by Kucuk & Sahin (2022), which emphasizes the importance of curriculum alignment and design in effective learning media. It also aligns with the views of educational experts who argue that validation by third parties, such as curriculum and media experts, is an essential step in ensuring the quality of educational media (Liu et al., 2021). The researchers' second assumption that the developed AR media meets the curriculum needs and can enhance student engagement was supported by these validation data, showing that the media developed meets the necessary quality standards for effective learning.

In the Iterative Development phase, testing of the final version showed a significant improvement in understanding geometry concepts, with a significant difference between the pre-test and post-test results. This improvement is consistent with research by Li et al. (2021), which found that the use of AR technology in mathematics education can significantly enhance conceptual understanding. This data is also in line with research by Ustun et al. (2020), which shows that the "GeoQuest AR" educational game based on AR can measurably improve mathematics learning outcomes. The theory of constructivism in mathematics education supports the idea that technology that enables active exploration and manipulation of concepts can deepen students' understanding (Brusilovsky & Millán, 2019). The researchers' first assumption that AR media can enhance student understanding was supported by these results, demonstrating that the application of technology in geometry learning can provide tangible benefits.

Data analysis using the paired sample t-test in the development of the "GeoQuest AR" educational game based on AR showed a significant difference between the pre-test and post-test results, with a p-value of 0.032 < 0.05. These findings indicate that the use of the "GeoQuest AR"

educational game based on AR is effective in enhancing students' understanding of geometry concepts.

First, the paired sample t-test results showed that the average score for students' understanding of geometry concepts increased from 60.2 in the pre-test to 75.5 in the post-test, representing an improvement of 25.4%. This significant increase is supported by a p-value of 0.032 < 0.05, indicating that the difference was not due to chance. These results align with research by Li, Cheng, and Tsai (2021), which found that AR technology significantly improves student learning outcomes in mathematics, including geometry. This study strengthens the theory that the use of interactive technology, such as AR, can improve conceptual understanding by providing richer visualizations and interactions (Huang et al., 2020).

Second, this analysis supports the assumption that the "GeoQuest AR" educational game based on AR is capable of increasing student engagement and their understanding of geometry material. This is consistent with findings by Müller, Kroschewski, and Schallert (2019), which indicate that interactive learning media, including AR, can enhance student engagement through more appealing and interactive visualizations. This research also aligns with constructivist theory, which posits that learning that involves direct manipulation and active exploration can deepen conceptual understanding (Brusilovsky & Millán, 2019).

Furthermore, the importance of the paired sample t-test in this context lies in its ability to show measurable and significant changes in students' learning outcomes. The test results demonstrate that the "GeoQuest AR" educational game based on AR not only significantly enhances students' understanding but also that these changes are large enough to be considered pedagogically important. As noted by Chen and Liu (2021), educational media that can significantly alter students' understanding are media with the potential for widespread application in educational contexts.

CONCLUSION

This study demonstrates that the educational game "GeoQuest AR" based on Augmented Reality (AR) has been validated and significantly improves the understanding of geometry concepts among junior high school students, with paired sample t-test analysis showing a significant increase in scores between the pre-test and post-test. The implications of these findings are that the integration of AR technology in mathematics learning can effectively enhance student engagement and understanding. However, this study has limitations, including a small sample size and a short duration of media usage, which may affect the generalization of the results. Recommendations for future research include using a larger sample size and a longer intervention period, as well as exploring the long-term impact of AR usage in various learning contexts. Further research is also expected to explore additional aspects of interactivity and the adaptation of media to meet individual student needs.

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