Beyond Static Textbook Illustrations: Development of Augmented Reality-Based Materials (ARM) for Geometry

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***Abstract*—Augmented Reality (AR) in mathematics education provides a novel method for rendering abstract concepts to concrete representation. This paper is a design and development research aimed at investigating the challenges students face in understanding plane and solid geometry and developing Augmented Reality-Based Materials (ARM) to address these challenges. A survey of 200 college students and 20 mathematics teachers identified several key challenges, including difficulty visualizing 3D objects, lack of engagement with traditional materials, and difficulty understanding geometric transformations. To address these issues, an ARM was developed using the Context, Input, Process, and Product (CIPP) model. The ARM incorporated interactive 3D models, step-by-step problem-solving guides, gamified learning elements, and real-time feedback. The ARM was evaluated for acceptability by 50 students, 2 teachers, and 5 experts, and it received acceptable in terms of its objectives (M = 3.78), content and activities (M = 3.76), and assessment (M = 3.66). Students reported increased engagement, improved understanding of geometric concepts, and enhanced visualization of geometric shapes. The study concluded that AR-based materials hold significant promise for enhancing geometry education by making abstract concepts more accessible and engaging. It is recommended to expand the use of AR technology in education and provide professional development for teachers to effectively integrate AR into their teaching practices. This research contributes to the growing body of literature on the use of AR in education and supports the idea of moving "beyond static textbook illustrations" to create more dynamic and interactive learning experiences.**

***Keywords*—design and development research, mathematics education, augmented reality, instructional material**

I. Introduction

Contemporary technological advancements have significantly impacted the educational process at all levels, from primary to higher education institutions. One area where this impact is particularly evident is in the use of renewable technologies such as mobile phones, tablets, and other communication devices, which have transformed learning mechanisms. Today, mobile phones boast a wide range of functionalities, from basic communication to advanced features like internet access and browsing, social media and networking, photography and videography, entertainment, navigation, health and fitness tracking, and financial management. The Internet facilitates access to documents, visualizations, animations, and audio-visual materials, thereby enhancing the learning experience [1]. This diverse multimedia content caters to various learning styles and simplifies the comprehension of complex concepts.

The shift toward advanced technological tools in education has extended beyond mobile devices. Computers, with their ability to visually represent the three-dimensional nature of real-life objects, have become critical in teaching fields such as geometry. However, many students struggle with visualizing and drawing 3D geometric shapes, which hampers their understanding and motivation [2]. Research highlights persistent issues related to students' ability to visualize 3D objects from 2D representations. This is evident in their difficulty with tasks such as imagining cube nets as cubes or drawing the surfaces of cubes from different perspectives [3]. To address these challenges, educators are encouraged to design learning environments that foster spatial skills and three-dimensional visualization [4]. Without experiences that cultivate spatial skills and 3D visualization, students often resort to rote memorization. This reliance on memorizing procedures and formulas without understanding the underlying concepts can lead to superficial learning, where students replicate familiar procedures but struggle to apply their knowledge in new or unfamiliar contexts. Poor spatial visualization skills worsen this issue, as students lack the ability to deeply engage with concepts, relationships, and proofs [5].

For example, in geometry, a student relying solely on rote learning might easily identify a cube from a standard image but struggle to visualize its rotations or imagine its net unfolded. Such limitations in spatial reasoning highlight the need to transition from rote memorization to deep learning approaches that enhance reasoning skills, enabling students to apply knowledge flexibly and meaningfully across various contexts.

Spatial abilities are considered essential not only in mathematics but also in other disciplines including architecture, physics and engineering. These abilities allow learners and individuals to mentally manipulate objects, visualize complex structures, interpret spatial relationships, and solve relevant practical problems. In mathematics education, spatial abilities play a vital role in connecting algebraic and geometric concepts. They facilitate the transition from symbolic (algebraic) representations to visual (geometric) representations, allowing students to better understand and internalize mathematical concepts. By providing the foundational skills necessary for visualizing ideas such as shapes, patterns, and transformations, spatial abilities are critical for mathematical reasoning and problem-solving.

Spatial competence, which involves the cognitive ability to manipulate and mentally transform objects, is particularly relevant in mathematics. This skill includes actions like shifting, rotating, or flipping objects in both two-dimensional and three-dimensional spaces [6]. While there is broad agreement on the importance of spatial competence, defining its specific components remains a challenge. Scholars have identified three primary categories of spatial abilities: spatial

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visualization, which refers to mentally manipulating and restructuring complex objects [7]; mental rotation, the capacity to rotate objects mentally in space [8]; and spatial orientation, the ability to understand and navigate spatial relationships from different perspectives [9]. These components collectively play significant roles in STEM disciplines, particularly in mathematics, where they help students interpret abstract problems, visualize transformations, and connect theoretical concepts to real-world applications.

Emerging technologies, particularly Augmented Reality (AR), present new opportunities to enhance spatial intelligence and visualization skills. AR can overlay visual components onto real-world objects, making it easier for students to understand complex phenomena and mathematical processes [10]. For example, AR technology effectively bridges the gap between abstract mathematical concepts and real-world applications by enabling learners to visualize and interact with geometric structures from multiple perspectives [11, 12].

Augmented Reality (AR) in education improves understanding, engagement, and motivation. Unlike static textbook images, AR offers interactive 3D visuals, helping students, especially those with low spatial ability, better grasp complex concepts [13, 14].

AR benefits various subjects, increasing student success through immersive learning. It helps visualize concepts like biological structures [15], aids English learners [16], and makes history more engaging [17].

Overall, AR boosts achievement, motivation, and confidence by providing interactive and personalized learning experiences.

Incorporating augmented reality into mathematics education holds particular promise. AR has the potential to transform mathematics education by making complex concepts more accessible and engaging [18]. It can overcome the limitations of traditional classroom resources by enabling students to visualize geometric transformations on mobile devices or tablets, making abstract concepts more tangible and accessible. Additionally, AR has the potential to improve students' problem-solving skills by offering real-time feedback on their interactions with virtual objects, allowing for immediate correction and deeper conceptual understanding.

This study generally aims to assist geometry learners and teachers in understanding lessons by presenting a learning material that may increase engagement and facilitate smooth learning process among students. Specifically, this study sought to:

1) Analyze the challenges faced by students in understanding plane and solid geometry.
2) Develop Augmented Reality-based Materials to address the challenges faced by students in understanding plane and solid geometry.
3) Determine the level of acceptability of the developed Augmented Reality-based geometry materials.

A learning material with AR content specifically designed for mathematics instruction will be developed and evaluated. The material focuses on enhancing students' comprehension of three-dimensional geometric forms. The efficacy of the ARM in improving learning outcomes will be assessed in three perspectives: the teachers', the students' and the experts'.

The learning material developed in this study utilizes augmented reality elements that are specific to the challenges or difficulties that learners experience in studying a specific topic (i.e., plane and solid geometry). These unique characteristics of the ARM sets this research apart from previous studies which usually utilizes AR in a more general perspective. More often than not, AR is typically applied for learners in the elementary level of education [19]. In this current study, AR-based material is developed specific to the needs of tertiary level students.

Moreover, as a mathematics topic, plane and solid geometry involves complex spatial reasoning which is a common struggle among students in terms of visualizing objects and understanding relevant concepts [20–22]. This current study provides empirical data on the distinct challenges or difficulties of tertiary level learners in plane and solid geometry. More importantly, a useful instructional material is developed with the elements of augmented reality and focusing on particular challenges in geometry. This study can become a stepping stone to a more specified examination of learning challenges and learner needs in studying geometry and provide groundwork for developing instructional materials utilizing AR elements.

The findings will provide a foundation for educators to create a more dynamic and interactive classroom environment, ultimately enriching the teaching and learning of mathematics through a contextualized and digital approach.

II. Literature Review

A. The Use of Design and Development Research

The research informs on the use of design and development research in developing an instructional material, which is anchored on the concept of augmented reality in the field of mathematics. General studies, Design, and Development Researches (DDR) usually focus on developing and evaluating educational programs, educational materials, and educational practices. It is a mixed approach of both quantitative and qualitative research techniques that enhances instructional design through the evaluation of theories, models, and frameworks. This research approach oftentimes seems complex but it is simply because it is a technique that allows instructional designers and teachers confirm that their methods are effective and continuously contribute to achieving learning outcomes. The assessment of instructional products, tools, programs, and models is fundamental to both instructional design and technology [23]. DDR helps current frameworks and practices to be continuously improved in addition to supporting the creation of new educational artifacts. As a result, the field of instructional design continues to change. DDR aids in bridging the gap between theory and practice in all areas of education by emphasizing practical applications.

Similarly, the purpose of this study is to develop and assess instructional materials based on augmented reality for plane and solid geometry. The use of DDR enabled the researcher to meet the aims while adhering to the relevant theories and ideas underlying the study's variables. The variables include augmented reality, mathematics education and training manual development.

B. Augmented Reality in Geometry Education

The integration of Augmented Reality (AR) technology into educational settings significantly enhances students' learning experiences and academic performance. AR's interactive and visually appealing nature captures students' attention and fosters deeper engagement with the material, as supported by studies [24, 25]. Specifically, AR-based activities have been shown to improve the teaching and learning process by making abstract concepts more tangible and accessible, especially in content areas like mathematics and science [25]. By presenting information in an interactive, three-dimensional format, AR facilitates a better understanding of complex topics that traditional methods often struggle to convey effectively.

Moreover, AR enables the creation of hybrid learning experiences that encourage critical thinking, problem-solving, and effective communication through collaborative exercises [26]. These collaborative elements not only enhance individual learning but also promote teamwork and interaction among students, preparing them for real-world challenges. AR's ability to personalize learning experiences ensures that students can progress at their own pace, catering to diverse learning styles and needs. This adaptability, combined with its capacity to improve engagement and learning outcomes, highlights its transformative potential in education [27].

When compared to traditional tools, AR in interactive learning environments demonstrates a significant improvement in overall learning effectiveness. By bridging the gap between theoretical knowledge and practical application, AR offers a unique approach to teaching that aligns with the demands of modern education systems. Its ability to transform conventional classrooms into immersive, interactive spaces makes it an indispensable tool for fostering innovation in education [28]. Through its numerous benefits, AR not only revolutionizes how students learn geometry but also sets a benchmark for integrating technology into teaching practices across various disciplines.

C. Challenges in Incorporating AR into the Curriculum

AR has presented varied educational benefits in the recent years. However, the implementation of interactive Augmented Reality (AR) materials for teaching geometry presents several challenges that need to be addressed to maximize their potential in educational settings. Methodologically, the design and execution of control groups in research studies remain a significant hurdle, complicating efforts to measure the true effectiveness of AR-based interventions. Practical barriers also persist, particularly in developing affordable and accessible AR tools that can be integrated seamlessly into diverse learning environments [24].

Additionally, device availability often restricts AR integration, as not all students or schools possess the necessary hardware to support AR applications. This issue is further compounded by the challenge of creating effective AR experiences that balance interactivity and educational outcomes, requiring meticulous design and development efforts. Another critical barrier is the initial investment in AR technology, which can be prohibitively expensive for many schools, particularly those with limited funding. Beyond financial considerations, the lack of adequate teacher training remains a pressing issue. Teachers must acquire the necessary skills to effectively incorporate AR into their teaching practices, ensuring that the technology enhances learning rather than creating additional complexity [29].

Furthermore, disparities in access and effectiveness of AR tools highlight equity concerns. The impact of AR technology on learning outcomes appears to vary significantly between students in public and private schools, with those in under-resourced public schools often at a disadvantage. These disparities suggest the need for targeted strategies to bridge the gap in access and to ensure that AR-based educational materials benefit all students equitably, regardless of their socioeconomic background [30]. Addressing these challenges through thoughtful research and policy interventions is crucial for realizing the full potential of AR in transforming geometry.

D. The Potential of AR in Elevating Educational Quality

Despite the challenges in embedding augmented reality into the education landscape, AR continuously evolves positively and opens many opportunities in the teaching-learning process. AR market is anticipated to expand exponentially in the coming years, underscoring the immense potential of this technology to revolutionize teaching and learning environments [10]. AR has already demonstrated its ability to transform static learning experiences into dynamic, interactive ones, particularly in subjects like geometry, where visualization and spatial reasoning are crucial. By integrating AR into geometry instruction, students gain opportunities to interact with three-dimensional shapes and concepts, enabling them to explore geometric principles in ways that traditional methods cannot replicate.

Moreover, AR-based geometry materials have the potential for continuous development, offering adaptive learning pathways tailored to individual students' needs and abilities. This adaptability can foster a deeper understanding of foundational concepts while building critical thinking and problem-solving skills. As AR technology advances, it could incorporate features like real-time feedback, collaborative virtual environments, and integration with artificial intelligence to personalize learning experiences further. These innovations highlight the transformative role AR can play in creating engaging and effective educational settings, cementing its place as a cornerstone of future teaching methodologies [31].

III. Research Design and Methodology

A. Research Design

Design and Development Research (DDR). Design and Development Research (DDR) is employed in this study for its effectiveness in bridging theory and practice, ensuring the systematic design, development, and evaluation of instructional materials. DDR is also referred to as design-based research, formative research, or design research [32, 33]. It establishes innovative procedures, techniques, and tools through needs analysis and iterative testing, making educational interventions both theoretically sound and practically viable [34].

Moreover, the Context, Input, Process, and Product (CIPP) model served as a guide to produce an effective design for the development of AR-based materials. Its application in this study provided a structured framework for the entire research process, ensuring a systematic approach to both the development and evaluation of the ARM. Created in the 1960s by Daniel Stufflebeam, the CIPP model systematically evaluates educational programs by analyzing their goals (Context), resources (Input), implementation (Process), and outcomes (Product) to ensure continuous improvement [35]. Users of this model typically focus on management-oriented evaluation, as the framework incorporates four stages of evaluation. It emphasizes continuous improvement by addressing four key areas of a program: the overall goals or mission (Context), the plans and resources (Input), the activities or components (Process), and the outcomes or objectives (Product).

This research utilizes two distinct designs/models in order to comprehensively tackle the objectives. The Design and Development Research (DDR) uses the CIPP model (Context, Input, Process, Product) to evaluate and improve learning materials by assessing their design, development, and implementation. This model ensures that instructional content is high-quality and meets the needs of both educators and learners. The Context component helps determine the relevance of learning materials by analyzing the needs and goals of students. The Input component ensures that resources, curriculum, and infrastructure align with learning objectives, making materials engaging and effective.

The Process component evaluates how well learning programs are implemented, ensuring that teaching methods and materials function as intended. Finally, the Product component assesses the overall acceptability of the learning materials, including feedbacks from students, teachers, and experts of the developed instructional tools.

DDR, in conjunction with the CIPP model, assesses and refines learning materials by aligning content with learner needs, optimizing resources, evaluating instructional effectiveness, and measuring overall acceptability. This structured approach ensures that AR-based materials enhance engagement and comprehension while maintaining high instructional quality. By following this structured approach, DDR ensures that learning materials are systematically designed, tested, and refined to enhance educational outcomes.

B. Participants

The participants in this study comprised 200 college students and 20 mathematics teachers from different State Universities and Colleges (SUCs) within the region. A purposive sampling technique was employed to ensure the inclusion of individuals who had direct experience with teaching and learning Plane and Solid Geometry. This method is widely recognized for its ability to focus on specific populations relevant to the research objectives [36].

The selection criteria for students included those currently enrolled in geometry courses or who had recently completed them. Teachers were selected based on their areas of expertise and on their length of experience in teaching the topic Plane and Solid Geometry; which should at least be three years SUCs within the Region were selected to ensure diverse representation, considering urban and rural settings, as well as public and private institutions. This approach aligned with Creswell's [37] recommendation to use targeted sampling for in-depth exploration of specific educational challenges.

The decision to involve both students and teachers ensured a comprehensive understanding of the challenges in teaching and learning geometry. Teachers provided insights into instructional methods and observed difficulties, while students' responses highlighted their learning experiences. This dual perspective enhances the validity and reliability of the findings [38].

C. Research Instrument

To gather data for the study, two researcher-made and expert-validated research instruments were used, namely, a survey instrument for challenges faced by students in Plane and Solid Geometry and Augmented Reality-based material evaluation sheet.

Survey Instrument for Challenges Faced by Students in Plane and Solid Geometry**.** The survey instrument used in this study was a structured questionnaire administered online via Google Forms, designed to identify specific challenges faced by students in Plane and Solid Geometry. The questionnaire consisted of 20 items, divided into three sections:

Cognitive Challenges: Questions focusing on students' understanding of geometric concepts, visualization abilities, and problem-solving skills.

Affective Factors: Items assessing students' engagement, motivation, and interest in geometry.

Instructional Issues: Questions addressing the effectiveness of teaching methods and materials used in geometry instruction. Each item was rated on a 5-point Likert scale, where 1 indicated "Strongly Disagree" and 5 indicated "Strongly Agree."

To ensure the validity of the instrument, it underwent a rigorous validation process. First, an expert panel comprising three mathematics education specialists, including university professors and experienced high school geometry teachers, reviewed the initial draft. Their feedback refined the wording, clarity, and relevance of the questions. Next, the revised instrument was pilot-tested with a small sample of 30 students and 5 teachers who were not part of the main study, ensuring the questions were comprehensible and appropriately targeted the intended challenges.

Additionally, to ensure the reliability of the survey instrument, a pilot test was conducted with 30 students and 5 teachers who were not part of the main study. The responses were analyzed using Cronbach's alpha to determine internal consistency. The overall reliability coefficient was found to be 0.85, indicating a high level of reliability [39]. Adjustments were made to items with lower correlation values to improve reliability further.

Augmented Reality-based Material Evaluation Sheet. The evaluation sheet was utilized to assess the acceptability and areas for improvement in the Augmented Reality-based Materials (ARM). It was organized into three sections, each comprising ten statements that address the objectives, content, and assessment components of the material. The objectives section evaluated the clarity, relevance, and achievability of the materials' goals. The content section examined the accuracy, comprehensiveness, and engagement of the material. The assessment section focused on the methods and tools employed to evaluate learners' progress and understanding.

The researcher-developed instrument, structured as a Likert scale, underwent rigorous content validity testing prior to implementation. To ensure reliability, the Cronbach's alpha coefficient was calculated, yielding a value of $\alpha = 0.80$, which indicates the instrument's reliability. Participants rated each item on a five-point scale, with responses ranging from 5 (Strongly Agree) to 1 (Strongly Disagree). This structured approach ensured a systematic evaluation of the ARM, offering valuable insights for its refinement and enhancement.

To interpret the results of the evaluation of the ARM, the study utilized a scale adopted from Galupar *et al.* [40]. The scale categorizes responses into four levels based on the computed mean scores. A rating of 3.51–4.00 (Highly Acceptable) indicates that respondents strongly perceive the item as effective, appropriate, or satisfactory. Scores ranging from 2.51–3.50 (Acceptable) suggest that the item meets the required standards but may have minor areas for improvement. A mean score of 1.51–2.50 (Slightly Acceptable) implies that the item is somewhat acceptable but may require significant modifications to enhance its effectiveness. Lastly, a score of 1.00–1.50 (Not Acceptable) indicates that the item is deemed unsuitable or ineffective based on the respondents' evaluation.

Moreover, a feedback form was also used to gather supplementary data for the evaluation sheets. The feedback form assessed the ARM based on key metrics. It evaluated whether the materials increased student engagement, improved understanding of concepts, enhanced visualization of geometric shapes, and if students preferred it over traditional methods. These insights highlighted the ARM's effectiveness in boosting engagement and learning outcomes.

D. Data Collection Procedure

The CIPP model [41] provided a comprehensive framework for the development and evaluation of educational materials, and its application in creating an Augmented Reality-based materials for teaching Plane and Solid Geometry that helped address the unique challenges students face in understanding these complex subjects.

Context. The CIPP model began with a thorough analysis of the context. This involve surveying students and teachers to identify the specific challenges they faced in understanding and teaching Plane and Solid Geometry through online surveys via Google Forms. By analyzing the responses, both individual and group scores were generated for each category, and the mean, standard deviation, and rank helped pinpoint the areas where students experienced the most challenges. Comparisons between student and teacher responses ensured a holistic understanding of these challenges. The top five difficulties identified included issues such as difficulty visualizing three-dimensional objects, understanding abstract geometric concepts, lack of engagement, difficulty in solving complex problems, and the lack of perceived real-world application of geometry concepts. These challenges directly informed the design of the AR materials, which aimed to create a more immersive, interactive, and accessible learning environment.

Input. In this stage, the researcher sought to determine the resources and tools required to meet the goals of enhancing students' ability to visualize complex spatial relationships and abstract concepts in three-dimensional space. The Input stage focused on identifying the necessary resources based on the challenges outlined in the Context stage. To address these challenges, the researcher selected readily accessible and free tools, including Quiver, a free AR application compatible with both Android and iOS, which allowed for interactive 3D models that students could manipulate. This tool specifically addressed difficulties in visualizing 3D objects, enabling students to interact with geometric shapes in ways that traditional methods cannot. Additionally, Canva, a free online layout platform, was used to design materials incorporating scannable Quick Response (QR) codes linked to Quiver's 3D models. This deliberate selection ensured the feasibility and potential for wider adoption of the AR-based materials without requiring specialized or expensive hardware, making the learning process more inclusive and accessible.

Process. This stage involved the actual development of the AR materials,

guided by the challenges identified in the context stage. The materials incorporated interactive 3D models that allowed students to rotate, zoom, and dissect shapes, enhancing their understanding of geometric properties and relationships. Step-by-step problem-solving guides with AR overlays helped break down complex geometric problems, while gamified learning elements, such as quizzes and challenges, were integrated to boost engagement. Real-time feedback provided students with instant insights into their performance, fostering self-paced learning. The Process stage of the CIPP model played a crucial role in shaping these materials, ensuring that each feature directly addressed visualization difficulties and engagement barriers. The iterative nature of DDR was evident, as feedback from the initial trial led to refinements, including the addition of teacher orientation and technical support suggestions to enhance the effectiveness and accessibility of the AR materials.

Product. This is the last stage of the CIPP model. In this stage, the AR materials were implemented in a Plane and Solid Geometry class during the second semester of the academic year 2023–2024 at a state university. Teachers provided valuable feedback during the trial, which revealed challenges such as device and connectivity issues, where AR apps may require specific hardware or software that isn't always available. To address this, the researcher added a note to ensure the materials were tested on a variety of devices to guarantee compatibility and provided technical support during the trial, as well as options for offline use. Another challenge identified was the teachers' preparedness to integrate AR into their lessons, which could result in ineffective use of the technology. To address this challenge, the researcher incorporated a suggested pre-implementation activity into the materials. This activity includes an orientation and training session for teachers, equipping them with the knowledge and confidence needed to effectively use the ARM.

A further pedagogical limitation observed during implementation was students' initial familiarity with AR technology. Students have varying levels of prior experience with AR. Those unfamiliar with the technology might initially require more support and time to navigate the interactive elements, potentially affecting their immediate learning experience. This highlights the need for introductory guidance and equitable access to compatible devices to mitigate these limitations. After the trial and refinement, the AR materials were evaluated by teachers, students, educational technology experts, and instructional design experts. The evaluation of the ARM was a critical element of Design and Development Research (DDR) because it provides feedback to all stages of developing materials for continuous improvement. DDR can address the needs of diverse learners, even those who require special needs in learning a topic. Hence, the evaluation method was designed to target these outcomes.

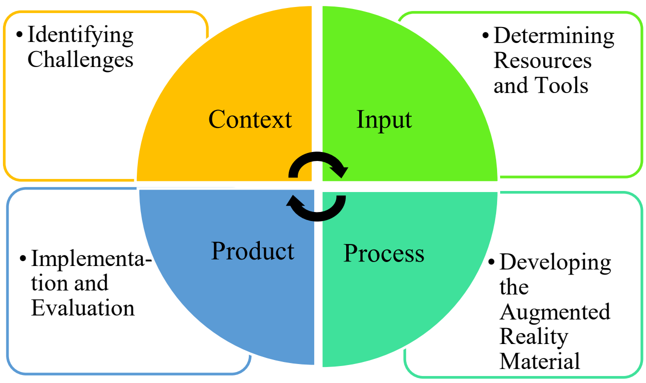

Fig. 1. The CIPP model for the augmented reality-based material development.

The evaluation focused on the materials' objectives, content, and overall effectiveness in meeting educational goals. Teachers assessed how well the materials aligned with the curriculum, while students provided feedback on how engaging and effective the AR resources were in improving their understanding. Educational technology experts evaluated the usability of the AR app and instructional designers reviewed the pedagogical quality of the materials. To summarize the results from the evaluation, mean scores and standard deviations were calculated for each of the evaluation items. The mean scores provided an overall measure of the materials' effectiveness, while the standard deviations highlighted the variability in responses, identifying areas of consensus or disagreement among the evaluators. This statistical analysis helped pinpoint strengths and areas for improvement, ensuring that the AR materials were both technically sound and pedagogically effective. This comprehensive evaluation process ensured that the AR materials met their intended goals set in the context stage and were refined based on feedback for future use. Thus, the CIPP cycle was complete. Fig. 1 shows a visual representation of the CIPP model-based procedure of this research.

E. Data Analysis Procedure

This study utilized two instruments: Survey Instrument for Challenges Faced by Students in Plane and Solid Geometry and the Augmented Reality-based Material Evaluation Sheet. Data collected from both instruments were analyzed using statistical measures including the mean and the standard deviation.

Data on the challenges students face in plane and solid geometry were summarized and statistically processed to obtain the mean and standard deviation for each area or topic. The areas or topics that obtained the highest means were identified as the top challenges students face in learning plane and solid geometry.

Meanwhile, data on the evaluation of the ARM was analyzed and the mean and standard deviation were also measured to determine the material's acceptability level.

F. Ethical Consideration

This study was conducted in accordance with the ethical policies and guidelines established by the American Psychological Association [42] and the institution with which the researcher is affiliated. The researcher ensured that no physical or psychological harm was inflicted upon the participants. Furthermore, participation in the study was entirely voluntary, with participants having the right to withdraw at any time. Confidentiality was strictly maintained, and the researcher took all necessary measures to protect the anonymity and identity of the participants. In cases where the participants' identities might be revealed, such as through the publication of photographs, explicit permission and informed consent were obtained. The study also incorporated an online survey, further ensuring that participants were given clear instructions and the opportunity to engage in the study remotely, while maintaining the same level of confidentiality and voluntary participation.

IV. Results and Discussion

In attaining the objectives of this research, the CIPP Model was followed.

A. Challenges Faced by Students in Understanding Plane and Solid Geometry

In the Context stage, a survey was conducted among students and mathematics teachers to identify the challenges students encounter in understanding plane and solid geometry. Determining the challenges that students encounter in understanding plane and solid geometry is necessary for creating an effective mathematics curriculum. This information allows teachers to execute successful interventions in instructional material development, customize learning experiences, and offer specialized teaching methodologies [40].

The survey identified key areas where students struggle. The findings were shown in Table 1.

The survey conducted among students and teachers revealed several significant challenges in the teaching and learning of Geometry, emphasizing the need for innovative approaches such as Augmented Reality-based Materials (ARM). The extremely challenging aspect identified was the difficulty in visualizing 3D objects with a mean (M) of 4.71 and standard deviation (SD) of 0.4, which was echoed by both students ($M = 4.76$, $SD = 0.43$) and teachers ($M = 4.65$, $SD = 0.38$). This common issue, attributed to Geometry's abstract nature, highlighted the need for innovative approaches like Augmented Reality-Based Materials (ARM). Studies, such as Patil *et al.* (2017), show AR effectively enhances spatial reasoning and conceptual understanding by enabling real-time interaction with virtual 3D objects. Similarly, AR, like robotics, bridges abstract concepts and practical applications, enhancing spatial reasoning and conceptual understanding.

Integrating robotics, such as maze navigation, further reinforces spatial reasoning while linking abstract concepts to real-world applications [40].

Table 1. Survey results on students challenges in geometry

Challenge	Students		Teachers		Overall		Rank
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Difficulty visualizing 3D objects	4.76	0.43	4.65	0.38	4.71	0.41	1
Understanding geometric transformations	4.43	0.73	4.37	0.47	4.40	0.61	3
Applying geometric concepts to problems	4.20	0.58	4.58	0.23	4.39	0.44	4.5
Lack of engagement with traditional materials	4.51	0.34	4.76	0.71	4.64	0.56	2
Poor retention of geometric principles	4.36	0.59	4.41	0.45	4.39	0.52	4.5

The second extremely challenging aspect was the lack of engagement with traditional materials ($M = 4.64$, $SD = 0.56$), which ranked high among identified issues. Both students ($M = 4.51$, $SD = 0.34$) and teachers ($M = 4.76$, $SD = 0.71$) expressed dissatisfaction with conventional instructional tools, suggesting that traditional approaches often fail to capture interest and sustain active participation. These findings aligned with AlGerafi *et al.* [43], who emphasized the importance of interactive technologies like Augmented Reality (AR) in fostering student engagement through immersive and visually stimulating learning experiences. Similarly, studies by Sagge and Segura [44] and Nabayra [45] highlighted the limitations of traditional instructional tools in promoting active learning, particularly in mathematics education. They advocate for adopting innovative approaches that integrate technology, interactive elements, and personalized learning to better engage students and maintain participation.

The third challenge, understanding geometric transformations ($M = 4.40$, $SD = 0.61$), further highlighted the complexity of comprehending abstract concepts such as rotation, translation, and reflection. Traditional materials often lack the dynamic features needed to illustrate these transformations effectively, whereas AR tools can offer animations and step-by-step demonstrations. As Rios *et al.* [46] suggested, such features enhance students' ability to visualize and comprehend the relationships between geometric elements. Similarly, the study by Sagge and Bacio [47] highlighted the challenges faced in statistics courses, which are often perceived as difficult due to their abstract nature and mathematical foundations. Traditional materials also fall short in engaging students, but the integration of video explainers and e-modules, which incorporate visual and auditory elements, improves student performance by making abstract concepts more accessible—much like AR tools help students visualize geometric transformations.

Another critical issue identified was the application of geometric concepts to problem-solving ($M = 4.39$, $SD = 0.44$), which ranked alongside poor retention of geometric principles ($M = 4.39$, $SD = 0.52$). The difficulty in retaining and applying geometric knowledge highlights the importance of contextualized and interactive learning tools. AR-based materials can integrate problem-based activities and real-world applications, prompting learners to think critically and apply concepts in meaningful contexts. Kiourexidou *et al.* [48] supported this idea, demonstrating that AR enhances knowledge retention by promoting active engagement and enabling learners to revisit concepts through virtual simulations. Additionally, Wibowo [49] found that AR encourages critical thinking and problem-solving skills by providing interactive and dynamic learning experiences.

In the Input stage, resources and tools were determined based on the results of the survey.

The quantitative data gathered from the survey highlights key factors contributing to students' challenges in learning solid and plane geometry. The most significant difficulty reported was visualizing 3D objects ($M = 4.71$, $SD = 0.41$), which indicates that many students struggle with understanding abstract geometric concepts. Another major issue was lack of engagement with traditional materials ($M = 4.64$, $SD = 0.56$), suggesting that conventional teaching methods fail to capture student interest. Additional challenges included understanding geometric transformations ($M = 4.40$, $SD = 0.61$), applying geometric concepts to problem-solving ($M = 4.39$, $SD = 0.44$), and retaining geometric principles ($M = 4.39$, $SD = 0.52$). These findings emphasize the need for more interactive and visually engaging learning tools.

B. Augmented Reality-based Material in Plane and Solid Geometry

In the Process stage, the Augmented Reality-based Material was developed.

The developed AR-based materials for Plane and Solid Geometry addressed key challenges identified in the survey, particularly the difficulty in visualizing 3D objects, lack of engagement with traditional materials, and understanding geometric transformations. Using Canva for the layout and Quiver for AR interactivity, the materials provided students with an engaging and immersive learning experience that fostered a deeper understanding of geometric concepts.

The cover page introduced the materials with a vibrant geometric design, incorporating 3D shapes and AR symbols to indicate interactive content. A QR code allowed students to access the AR experience through the Quiver app. The introduction page explained the benefits of AR in Geometry learning, emphasizing how it overcame traditional challenges, such as abstract visualization and low engagement with conventional materials.

The materials began with an interactive AR activity on Tangrams, where students manipulated the seven pieces of the puzzle in 3D space to form different shapes. This hands-on experience demonstrated key geometric concepts like symmetry, angles, and transformations, such as rotation and reflection. The next section focused on the volume of solid figures, where students scanned various 3D shapes like cubes, spheres, and pyramids. They interacted with these shapes in AR, adjusting dimensions to see how changes affected their volume, accompanied by a virtual calculator for real-time calculations.

Students then explored the net of solid figures through AR, where they unfolded and folded the net of a 3D shape to reveal its 2D counterpart, enhancing their understanding of how the two related. This was followed by an AR demonstration of surface area, where students measured the area of each face of a 3D figure and calculated the total surface area by interacting with the shape. The section on circles allowed students to examine properties such as radius, diameter, circumference, and area, with real-time calculations visible through AR as they manipulated the circle.

For triangles, students interacted with various types, such as isosceles, equilateral, and scalene, manipulating angles and sides to explore their properties. This section helped students gain a deeper understanding of triangle geometry and measurement. A key feature of the materials was an AR tool for geometric transformations, where students rotated, translated, and reflected shapes in real-time, gaining a clear understanding of these transformations through direct interaction.

Fig. 2. Samples of AR-based materials.

The materials ended with a summary page reinforcing the key concepts covered and the benefits of AR in learning Geometry. An optional assessment page provided a quiz with AR questions, allowing students to demonstrate their understanding of concepts such as volume, surface area, and geometric transformations. These ARM not only enhanced students' spatial reasoning but also actively engaged them in learning, making abstract geometric concepts more accessible and interactive.

Ultimately, the Augmented Reality-based Material (ARM) specifically addressed the identified challenges by providing interactive 3D models, dynamic animations, and real-time manipulation of geometric shapes. Students could visualize 3D objects, understand transformations through direct interaction, and apply concepts in problem-solving activities. The use of AR significantly improved engagement (90% of students agreed), enhanced visualization of geometric shapes (92%), and led to better understanding of concepts (88%). Furthermore, 85% of students preferred AR-based learning over traditional methods, demonstrating its effectiveness in making geometry more accessible and engaging. These results confirm that AR materials help bridge the gap between abstract concepts and practical understanding, ultimately enhancing learning outcomes.

The sample ARM is shown at Fig 2 and the link for the drive where the AR videos are found. https://drive.google.com/drive/folders/17UcM_D9z1ZMkMTFi3ojUYWw98nfApvRU?usp=sharing

C. Acceptability of Augmented Reality Materials

The last stage was the Product stage where the material was implemented and evaluated. The evaluation of the Augmented Reality-based Materials (ARM) in Plane and Solid Geometry, involving 50 students, 2 teachers, and 5 experts, revealed high acceptability across its components as shown in Table 2. With an overall mean score of 3.73 (*SD* = 0.45), indicating its suitability for students. The content and activities section received the highest rating (*M* = 3.79, *SD* = 0.41), followed by the objectives (*M* = 3.75, *SD* = 0.44). The assessment section, though slightly lower (*M* = 3.66, *SD* = 0.50), was still rated as highly acceptable. The high evaluation also indicated that the materials met expectations and can serve as effective instructional materials [50–52]. This also confirmed that the ARM aligned well with curriculum standards and were ready for wider implementation. This aligned with findings from a systematic review on augmented reality in mathematics education, which highlighted the potential of AR to enhance interactive learning environments and improve student engagement and understanding of mathematical concepts [53].

Additionally, a study on geometry teaching supported by augmented reality teaching materials found that such materials significantly increased students' 3D thinking skills, indicating the effectiveness of AR in enhancing geometric understanding [54].

Furthermore, research on augmented reality in mathematics education emphasizes the importance of aligning AR materials with curriculum standards to ensure their effectiveness and suitability for learners [55].

Finally, to illustrate the trend in results, it is evident in Table 3 that a high percentage of students reported positive impacts from the ARM in Plane and Solid Geometry. Specifically, 90% agreed it increased engagement, 88% noted improved understanding, and 92% experienced enhanced visualization. This consistently high agreement across these key areas underscores the potential of AR to address the previously identified challenges with traditional learning materials. In comparison to the known difficulties students face with static textbook illustrations— such as the challenge of lack of engagement, difficulty in visualizing and interacting with 3D objects, and trouble grasping complex topics. Furthermore, 85% of students preferred the AR materials over traditional methods, reflecting their appeal and potential for transforming how geometry is taught. These metrics collectively demonstrate that the ARM contributed to more engaging, effective, and visually enriched learning experiences in geometry education.

Table 2. Acceptability level of the ARM in plane and solid geometry

Indicators	Standard Deviation	Mean	Description
Objective	0.44	3.75	Highly Acceptable
Content and Activities	0.41	3.79	Highly Acceptable
Assessment	0.50	3.66	Highly Acceptable
Grand Mean	0.45	3.73	Highly Acceptable

Note: "Highly Acceptable" (3.51–4.00)

Table 3. Feedback metric among students

Feedback Metric	Percentage of Students Agreeing
Increased engagement	90%
Improved understanding of concepts	88%
Enhanced visualization of geometric shapes	92%
Preference over traditional methods	85%

Overall, this study advances research on Augmented Reality-Based Materials (ARM) by applying the CIPP model to systematically address key learning challenges in geometry, such as visualizing 3D objects, understanding transformations, and low engagement with traditional materials. Unlike previous studies that broadly highlight AR's benefits, this research provides empirical evidence of its effectiveness in enhancing spatial reasoning, conceptual understanding, and retention through structured, interactive modules.

Future research can explore AR's long-term impact on learning outcomes and expand its applications to other mathematical fields, sciences, and humanities. Additionally, integrating AR with AI-driven adaptive learning and robotics presents opportunities for personalized education. Continuous refinement and evaluation of AR materials can further establish AR as a transformative tool for education, enhancing engagement and comprehension across disciplines.

V. Conclusion

The integration of Augmented Reality-Based Materials (ARM) in geometry education has proven to be a promising solution to the challenges students face in understanding complex geometric concepts. Unlike static textbook illustrations, which often fail to fully engage students or adequately convey the depth of geometric relationships, AR-based materials provide dynamic, interactive learning experiences that enhance spatial reasoning, improve visualization of 3D objects, and foster deeper engagement with the subject. This innovative approach bridges the gap between abstract concepts and practical understanding, enabling students to explore Geometry in ways that traditional methods cannot achieve.

This research makes a significant contribution by providing new empirical data on the acceptability of Augmented Reality (AR)-based geometry learning materials, particularly in plane and solid geometry. The findings offer fresh insights into the integration of AR in geometry education, emphasizing the development of learning materials using the CIPP model to address learners' specific needs in these topics.

Unlike previous studies on AR-based geometry learning, which often focus on general applications, this research applies the CIPP model to design instructional materials that target the specific challenges learners face in plane and solid geometry. By moving beyond traditional static textbook illustrations, this study provides empirical evidence on how AR enhances learners' ability to visualize 3D objects, analyze geometric transformations, and solve geometric problems. This interactive approach fosters deeper engagement and improves retention of geometric principles, ultimately enriching the learning experience.

Given these promising outcomes, it is crucial to expand the use of AR technology in educational settings, particularly in teaching geometry and other abstract mathematical concepts. Schools and educational institutions should prioritize the development and adoption of AR-based teaching materials as a complement to traditional resources. This should be accompanied by comprehensive professional development for educators, enabling them to effectively integrate AR tools into their teaching practices in ways aligned with curriculum objectives. With proper training, teachers can harness AR's capabilities to transform static textbook illustrations into dynamic, interactive models, making learning more accessible and engaging.

Moreover, further research into the long-term effects of AR on students' academic performance and retention of mathematical concepts is essential. Such studies can offer deeper insights into how AR can not only enhance immediate learning outcomes but also foster enduring understanding and advanced problem-solving skills in mathematics. For instance, in algebra, AR can transform abstract equations into interactive visual models, enabling students to manipulate variables and observe real-time effects. In trigonometry, AR tools can dynamically demonstrate sine, cosine, and tangent functions, providing an intuitive way to explore angles, ratios, and their practical applications. Similarly, in calculus, AR can vividly illustrate concepts like derivatives and integrals, allowing students to visualize slopes, rates of change, and areas under curves in three-dimensional space. By extending the application of AR across various branches of mathematics, educators can create a more integrated and engaging teaching approach, enriching the learning experience for students at all levels. Additionally, AR-based materials can also be studied further in other areas or disciplines other than Mathematics, like the sciences and humanities. For instance, science disciplines like Biology study objects and things that are mostly common and familiar to the learners and which they can easily find in their surroundings. Utilizing AR-based learning materials in these topics can help learners recognize the significance of studying biology or any other science discipline in real-life situations. AR-based materials may present potential in increasing learners' success in other fields of study.

Finally, the continuous refinement of AR content is essential. Educational materials should be regularly updated based on student feedback and advancements in AR technology, ensuring their relevance, engagement, and pedagogical effectiveness. By embracing the idea of "Beyond Static Textbook Illustrations" and adopting AR in a thoughtful and structured manner, educators can significantly enhance the learning experience, revolutionize how mathematics is taught, and ultimately contribute to better academic outcomes for students.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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