



Enhancing Secondary Students' Conceptual Understanding of 3D Geometry through a Pedagogically-Driven Integration of Augmented Reality and Internet of Things

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Abstract. This research investigates the integration of Augmented Reality (AR) and Internet of Things (IoT) technologies in teaching three-dimensional (3D) geometry to lower secondary students in Malaysia. By combining interactive AR features with real-time data from temperature sensors, the research aimed to enhance students' conceptual understanding, engagement, and learning motivation. A prototype learning application was developed and implemented using a design-based research methodology, which involved needs assessment, system development, classroom application, and evaluation. Findings from pre- and post-tests, as well as classroom observations, indicate significant improvements in students' performance and participation. The study also highlights the system's alignment with the national mathematics curriculum, demonstrating its practicality and potential for broader educational adoption.

Keywords: Augmented Reality, Internet of Things, Geometry Education, STEM, Smart Learning, Interactive Learning Environment

1 Introduction

Technology has moved in to take a pivotal position in the lives of students; the digital transformation is now setting itself as the platform on which students may learn. The traditional classroom is turning out to be layered with highly active tools to promote student engagement. The Internet of Things is one such emerging force that considerations smart classrooms with smart binary devices capable of collecting and sharing real-time data that can be synthesized into personalized insights, immediate feedback, or even different interactions with instructional content (Kadry & Smaili,

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2020; Dhage & Zanjali, 2021; Saidin et al., 2015; Akçayır & Akçayır, 2017; Yuen et al., 2011; Azuma, 1997).

An augmented reality (AR) system creates the prospect for educational innovation by superposing digital components onto the physical world. In the learning environment, especially those for STEM subjects, AR is proven beneficial in teaching students to comprehend complex topics. By allowing learners to view representations of ideas that are abstract or multi-dimensional, AR aids in closing the gap between theory and practice. The research has shown it to be successful in increasing learner engagement and motivation (Zhou et al., 2016; Billinghamurst & Duenser, 2022).

This study aims at exploring the use of AR integrated with IoT to develop students' comprehension in 3D geometry. Geometry, mainly involving spatial visualization of 3D shapes, is probably one of the most abstract and toughest subjects for students. Most students find it very difficult to perceive depth and relationships among geometric elements when taught with a few physical models or with only flat textbook diagrams. AR, with its inherent interactivity and the added real-time data-driven responses from IoT, may well provide that innovative solution.

In this study, an AR system was developed and paired with a temperature sensor to allow students to visualize and interact with 3D geometric shapes. The sensor manipulates the appearances of models to correlate with environmental data input such as a temperature change, giving an actual feeling to abstracts of mathematics. The system is prepared to dovetail with the Form 2 mathematics curriculum currently in place in Malaysia, making this not only a novel tool but a practical one as well. This study will look at in more detail how the technology can potentially increase student understanding, motivation, and teacher facilitation.

The term AR creates digital imagery projected over the real world; thus, AR allows students to indulge themselves in an immersive and interactive learning environment. Teaching difficult topics such as science and math to students using AR helps them visualize tough concepts and enhances their interest (Zhou et al., 2016; Billinghamurst & Duenser, 2022). Hence, this study aims to verify how combining AR with IoT can facilitate students in better learning 3D geometry—a subject that many consider abstract and complex.

Despite the increasing use of augmented reality in mathematics education, many existing studies emphasize visual enhancement rather than instructional depth. AR-based learning environments often present three-dimensional objects in an interactive form, yet they remain largely static in terms of contextual responsiveness. As a result, students may observe geometric structures without fully engaging in the reasoning processes that connect mathematical concepts to real-world situations.

In contrast, the Internet of Things offers the capability to introduce real-time environmental data into learning activities. However, current IoT applications in education are frequently limited to classroom monitoring or system automation, with minimal focus on direct conceptual learning. The lack of integration between pedagogically meaningful AR interactions and real-world data input highlights a gap in current educational research. This study addresses this gap by exploring how AR and IoT can be combined not merely as technical tools, but as a learning mechanism to support deeper conceptual understanding of three-dimensional geometry.

2 Literature Review

2.1 Augmented Reality in Geometry Learning

Previous studies have demonstrated that augmented reality can support students in visualizing complex geometric forms and improving spatial reasoning. By allowing learners to manipulate three-dimensional objects, AR reduces the cognitive load associated with interpreting flat textbook diagrams. Several studies report increased motivation and engagement when AR is introduced into geometry lessons. However, many AR applications function primarily as visualization tools, offering limited interaction beyond object rotation and observation.

2.2 Internet of Things in Educational Settings

The Internet of Things has been widely discussed in the context of smart classrooms, learning analytics, and environmental monitoring. IoT technologies enable real-time data collection, providing opportunities for adaptive learning environments. Nevertheless, most educational implementations focus on operational efficiency rather than on how sensor-generated data can be used to enhance students' conceptual understanding of subject matter.

2.3 Pedagogical Gap in AR–IoT Integration

While AR and IoT have been independently explored in educational research, studies that examine their combined pedagogical impact remain limited. In particular, there is insufficient discussion on how real-world data can dynamically influence mathematical representations to support reasoning and conceptual learning. This gap suggests a need for instructional designs that integrate AR visualization with IoT responsiveness in a pedagogically meaningful manner, especially in abstract domains such as three-dimensional geometry.

3 Problem Statement

Despite the availability of various instructional resources, challenges in learning three-dimensional geometry remain persistent among secondary students. For instance, 2-D diagrams of nets and solids restrict students from visualizing the spatial relations as they exist in the geometric arrangement (Lee et al., 2019; Ahmad & Shahrill, 2020; Yusof & Zakaria, 2019; MOE Malaysia, 2019; OECD, 2019).

Learning styles, on the other hand, differ widely among students, yet teaching generally aims to serve all. This non-discriminatory approach engenders disenchantment, as a few students might not be able to absorb learning from conventional explanations and demonstrations. This deprivation of interactive features and instantaneous feedback ultimately leads to loss of attraction from the distracted

students and student-life lessons tailored to their unique learning needs (Ibanez & Delgado-Kloos, 2018).

Integrating AR and IoT presents an opportunity to establish a more responsive and inclusive learning environment. Real-time interactive digital models can be modified through real-world data inputs, say from temperature sensors, thus allowing students to intuitively explore and manipulate 3D shapes in a dynamic manner. This shift will greatly aid in demystifying and bringing mathematics closer to home (Lin, 2020).

IoT-enabled feedback further allows students to witness how changes to the physical environment affect virtual models. Changes in color, form, or both of the geometric shape within the AR space could be induced by a temperature change registered by the temperature sensor. This builds conceptual forces while merging theoretical knowledge with real-world application, rendering learning more meaningful and engaging.

Additionally, national assessments (e.g., PT3/TIMSS trend reports) indicate that Malaysian Form 2 students underperform on geometry and spatial-visualization items. In our needs analysis at MRSM Muadzam Shah, interviews with local mathematics teachers echoed these challenges—students struggle to interpret nets, relate 2D representations to 3D forms, and reason about faces/edges/vertices beyond textbook diagrams. These local findings strengthen the urgency and contextual relevance of the proposed AR–IoT intervention.

4 Research Objective

This research aims to explore the pedagogical benefits of integrating Augmented Reality (AR) and Internet of Things (IoT) technologies in secondary mathematics education, specifically for enhancing students' understanding of three-dimensional (3D) geometry. To ensure a focused and measurable study, the research objectives are as follows:

- i. To design and develop an AR-based learning application integrated with IoT temperature sensors to support the visualization and interaction with 3D geometric shapes.
- ii. To investigate the effectiveness of the AR-IoT learning environment in improving students' conceptual understanding of 3D geometry.
- iii. To evaluate the impact of the AR-IoT integration on student engagement and motivation during mathematics lessons.
- iv. To examine the feasibility of incorporating AR and IoT technologies into the existing Form 2 mathematics curriculum in Malaysian secondary schools.

Table 1 shows the research objectives and corresponding problem statements.

Table 1. Research Objectives and Corresponding Problem Statements

| Research Objective | Related Problem Statement |
|---|--|
| To design and develop an AR-based learning application integrated with IoT temperature sensors to support the visualization and interaction with 3D shapes. | Students struggle to visualize and comprehend 3D geometry using traditional resources like textbooks and static models. |
| To investigate the effectiveness of the AR-IoT learning environment in improving students' conceptual understanding of 3D geometry. | Abstract mathematical ideas are difficult to understand without engaging and interactive teaching aids. |
| To evaluate the impact of AR-IoT integration on student engagement and motivation during mathematics lessons. | Traditional instruction lacks personalization and real-time feedback, leading to low student motivation and limited attention. |
| To examine the feasibility of incorporating AR and IoT technologies into the existing Form 2 mathematics curriculum in Malaysian secondary schools. | Existing teaching methods do not fully support modern tools that can link theoretical concepts with real-world experiences, such as environmental changes influencing mathematical models. |

5 Methodology

Design-based research methodology was used to develop, test, and refine an educational intervention based on the integration of AR and IoT technologies in the teaching of 3D geometry. It entails four phases: needs assessment, prototype development, classroom implementation, and evaluation (Ishak & Yusof, 2020; Bujang & Tahir, 2022).

The first stage involved conducting needs assessments through surveys and interviews with the mathematics teachers and Form 2 students of MRSM Muadzam Shah so as to determine particular difficulties in learning 3D geometry; and to also find out if AR and IoT tools were appropriate to solve those problems.

This was followed by the development of an AR prototype application in Unity3D using the Vuforia SDK. This application allowed the presentation of geometric shapes as interactive 3D models integrated with a DHT11 temperature sensor connected to an Arduino microcontroller. The Arduino received the sensor data and transmitted it to the AR system, which altered the visual characteristics of the models in real time. Consequently, the environment changes were reinforced conceptually with mathematical properties.

The use of the prototype took place in the classroom stage. In this stage, the prototype was presented to a group of Form 2 students. The participants consisted of a single intact class involving 32 Form 2 students aged 14, representing mixed achievement levels. A pre-test and post-test design was employed to examine changes

in students' understanding before and after the intervention. Teachers learned the use of the system and also how to fit it into the lesson plans they already had. Classroom observations, notes, questionnaires to student participants, and pre-tests and post-tests to assess shifts in understanding and engagement, were collected. The last phase of the study involved analysis of the data to assess the effectiveness, usability, and pedagogical experience of the AR-IoT system, which will also then guide further development of the prototype.

6 Result

The application of the AR-IoT learning environment demonstrated effective results in a number of areas. From the pre- and post-test study, students showed a measurable increase in their understanding of concepts associated with 3D geometry. On average, the scores for student assessments increased by 23% from pre-test to post-test data for students that used the AR-IoT environmental app. The post-test scores showed an average increase of 23% compared to the pre-test results. This improvement indicates a measurable change in student performance following the implementation of the AR-IoT learning environment.

The engagement levels of students were also positively impacted as the intervention progressed. As students engaged with AR-IoT and spatial concepts, observer logs indicated that students had increased participation levels and were more willing participants to explore geometric shapes rather than exclusively horizontal or vertical translations. Students reported enjoyment of the interactive features of the AR-IoT application, particularly models that changed color based on temperature. Students indicated the model color changes aided their understanding of spatial relationships and properties. Feedback from teachers indicated the system provided teachers with a more personalized and dynamic approach to teaching. The real-time data from IoT sensors helped teachers notice which students required additional support and to tailor their instruction. Teachers indicated that students who normally struggled with spatial visualization appeared more confident and completed geometry-related tasks with more accuracy.

Overall, the pilot study showed that the integration of AR and IoT in mathematics education can enhance conceptual understanding, increase engagement, and improve pedagogical practices. These results will support further innovation and development of smart learning environments in secondary education. Table 2 shows the summary of discussion and results.

Table 2. Summary of Discussion and Results.

| Theme | Discussion Highlights | Supporting Results |
|--------------------|--|--|
| Student Engagement | AR-IoT made geometry more interactive and immersive, encouraging exploration and curiosity through real-time feedback and hands-on manipulation. | Average test scores increased by 23%; students reported higher motivation and active participation during lessons. |

| | | |
|---------------------------|---|--|
| Teaching Practices | Teachers could monitor student progress in real-time, enabling more targeted and differentiated instruction. | Educators observed increased student confidence, especially among those with lower spatial reasoning skills. |
| Curriculum Integration | Activities were aligned with the Form 2 Mathematics syllabus, especially on the topic of 3D shapes, allowing seamless incorporation into existing lesson plans. | Teachers easily integrated the tool into their classes without needing major adjustments to content or delivery. |
| Real-World Responsiveness | IoT temperature sensors made virtual models respond to environmental changes, helping students relate abstract math to real-life applications. | Students better understood how physical conditions influence geometry, enhancing relevance and retention. |

7 Discussion

The findings of this study provide insight into how the integration of AR and IoT can influence students' learning experiences beyond surface-level engagement. The discussion highlights the pedagogical implications and practical benefits of integrating Augmented Reality (AR) and Internet of Things (IoT) technologies in secondary mathematics education. Drawing from the data collected and observed outcomes, this section aims to elaborate on how the AR-IoT system influenced student engagement, supported teaching practices, and aligned with the curriculum. Each aspect is critically analyzed to provide a deeper understanding of the role these technologies can play in enhancing the learning and teaching of three-dimensional geometry (Ibáñez et al., 2020; Dunleavy & Dede, 2014; Abd Majid & Husnin, 2021).

7.1 Boosting Student Engagement

The integration of Augmented Reality (AR) and Internet of Things (IoT) technologies significantly improved student engagement by transforming abstract mathematical content into an interactive and responsive learning experience. Through the AR application, students were able to manipulate 3D models in real-time, which not only made the content more accessible but also encouraged them to actively participate in lessons. The added layer of environmental interaction—such as the real-time temperature sensor that influenced the appearance of the 3D shapes—piqued students' curiosity and provided an additional dimension of relevance. This multisensory interaction contributed to sustained attention and fostered intrinsic motivation, allowing learners to explore geometric relationships in a hands-on, experimental manner. As a

result, students were not just passive recipients of information but were immersed in a learning process that valued exploration and discovery.

7.2 Supporting Teachers and Teaching Practices

The implementation of the AR-IoT system provided valuable pedagogical support to teachers by offering real-time insights into student engagement and progress. The sensor data allowed educators to monitor how students interacted with the AR models, making it easier to identify learners who were struggling or excelling. This enabled more personalized instruction, allowing teachers to intervene early with targeted support or enrichment activities. Additionally, the visual and interactive nature of the content allowed teachers to explain complex geometric ideas more clearly, especially for students who had difficulties with spatial visualization. The system encouraged a shift in teaching strategy—from teacher-centered instruction to student-centered exploration—by placing students at the core of the learning process and positioning the teacher as a facilitator. This shift contributed to more dynamic, inclusive, and effective classroom environments.

7.3 Fit with the Curriculum

The AR-IoT intervention was intentionally aligned with the Malaysian Form 2 mathematics curriculum, particularly the section on three-dimensional geometry. The learning outcomes targeted—such as identifying, constructing, and analyzing 3D shapes—were addressed through carefully designed activities within the AR application. By allowing students to manipulate virtual objects that mirrored real-world conditions, the intervention extended traditional textbook exercises into a more engaging, real-time learning experience. Teachers could integrate the technology without needing to significantly alter their lesson plans, making the solution practical and scalable. Furthermore, the flexibility of the AR platform allowed for the inclusion of curriculum-relevant scenarios and assessments, supporting both formative and summative evaluation of student learning. This curriculum alignment ensured that technological innovation was not introduced as a novelty, but as an enhancement to existing educational standards and practices.

7.4 Real-World Responsiveness

One of the standout features of the AR-IoT integration is its ability to bridge abstract mathematical concepts with real-world environmental stimuli, offering students a contextually grounded learning experience. The temperature sensor embedded in the system allowed for direct interaction between physical surroundings and digital learning content. For instance, fluctuations in classroom temperature triggered changes in the visual attributes of 3D geometric models, such as color variations. This real-time responsiveness helped students draw meaningful connections between theoretical knowledge and practical observations, reinforcing the idea that mathematics is not confined to textbooks but is relevant and applicable in everyday life. Furthermore, this aspect of the system provided a dynamic and evolving learning environment where students could experiment and immediately see the impact of real-world data on

mathematical representations. Such experiential learning not only enhanced cognitive engagement but also promoted deeper reflection and inquiry. By making mathematical concepts more tangible and relatable, the system fostered a learning environment rooted in exploration, discovery, and relevance to students' lived experiences.

8 Conclusion

This study indicates that the blending of Augmented Reality (AR) and the Internet of Things (IoT) in secondary mathematics classrooms could be a powerful enhancement to students' conceptual understanding, engagement, and motivation. If students can engage in 3D geometric shapes in real time and examine how these models react to the environmental conditions around them, we feel the learning association becomes clearer, more meaningful, and ultimately more effective. The application we created out of this research closely aligned with the national curriculum, which provided a practical context that teachers described as easy to implement (Wang et al., 2013).

The research findings suggest that teachers also benefitted from these technologies as they provided improved perspectives on student performance and the possibility of altering instruction based on real-time student learning. The system ultimately helps to promote personalized, student-centred learning and promotes innovative teaching. The evidence provided through success provides further support for the ongoing conversation regarding whether educational technology should augment or disrupt current systems and practices with the goal of achieving an impact on how students learn.

Education continues to transform in our rapidly changing digital reality; AR and IoT present a unique opportunity to establish more immersive, inclusive, and effective learning environments. Future research should investigate how this method can be applied to a wider range of subject areas, as well as in different contexts and how it will impact student achievement and digital literacy over the long-term. This research marks an exciting starting point for re-imagining educational experiences a smart, responsive classroom.

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