Design of Three-Dimensional Geogebra and Augmented Reality Applets for Visualising the Concept of Functions in STEM Learning of form Four Additional Mathematics

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ABSTRACT

The concept of Functions in Additional Mathematics is abstract and difficult for students to visualise, particularly the subtopics of Composite Functions and Inverse Functions. This paper presents the design of three-dimensional GeoGebra and Augmented Reality (AR) applets developed to help students visualise the concept of Functions in STEM learning. The design was guided by the Quality of Technology Integration component of the STEM Education Quality Framework. GeoGebra was chosen for its dynamic, free, two and three dimensional rendering, while AR was added to overcome GeoGebra's inability to display the real world camera view. The applets were integrated into four learning units based on temperature and heat contexts, namely temperature scales (Composite Functions), temperature conversion (Inverse Functions), and hypothermia and hyperthermia (Quadratic Functions). Each unit provides two components: a GeoGebra AR Activity for exploring function graphs in three dimensions, and a GeoGebra Applet for self-checking answers, together supporting constructivist and active learning. Accessing the AR activities requires a device supporting ARCore on Android or ARKit on iOS. Users without these devices can use the 2D applets and the GeoGebra web view instead. A companion evaluation of the module recorded high usability among Form Four students, and a quasi experimental study of learning outcomes is proposed as the next step. This paper contributes a technology integration design framework that can be adapted for other abstract mathematics topics.

Keywords: GeoGebra, Augmented Reality, visualisation, concept of Functions, STEM education

INTRODUCTION

Technology has become a key pillar of 21st-century Science, Technology, Engineering and Mathematics (STEM) education. Within the STEM Education Quality Framework, the Quality of Technology Integration component calls for learning experiences that meaningfully expose students to the use of a variety of technologies (Rowley, Preiss, Pinnell & Franco, 2012). For the subject of Additional Mathematics, technology integration is highly relevant because many concepts are abstract and difficult to represent statically.

The topic of Functions is one of the topics often perceived as difficult because of its abstract nature, particularly when students need to understand concepts in graphical form (Shahrul, Nasir & Suryadi, 2024; Zulnaidi, Oktavika & Hidayat, 2020). Learning Functions without visual representation hinders the development of students' understanding. Accordingly, this paper discusses the design of three-dimensional GeoGebra and Augmented Reality (AR) applets developed specifically to help students visualise the concept of Functions within a STEM Training Module for Form Four students.

LITERATURE REVIEW

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Visualisation challenges in learning Functions

The concept of Functions, particularly Composite Functions and Inverse Functions, has its own language for describing real-world situations, which makes it difficult for students (Shahrul, Nasir & Suryadi, 2024). Students are often able to solve problems algebraically but fail when confronted with graphical representations (Zulnaidi, Oktavika & Hidayat, 2020). The lack of visual representation has been identified as the main cause of this difficulty, and the ability to form representations in two and three dimensions can improve students' skills in visualising mathematical problems (Hidayat, Noor, Nasir & Ayub, 2024; Zhang, Wang, Jia, Zhang & Chen, 2025).

Dynamic mathematics software and GeoGebra

Mathematics software ranges from commercial packages to open-source tools such as GeoGebra. Complex computer algebra systems are powerful but require longer instructional time, whereas dynamic mathematics software such as GeoGebra is easy to use and effective even over short instructional periods (Celen, 2020; Zhang, Wang, Jia, Zhang & Chen, 2025). A range of studies has shown that GeoGebra enhances students' performance, motivation and positive attitudes across various mathematics topics (Yatim, Saleh, Zulnaidi, Yew & Yatim, 2022; Yohannes & Chen, 2023; Zulnaidi, Oktavika & Hidayat, 2020). GeoGebra makes the learning of mathematics more practical and accessible and reinforces abstract concepts (Celen, 2020; Hamzah & Hidayat, 2022).

Augmented Reality in STEM education

Augmented Reality (AR) is an effective platform for increasing students' engagement and the quality of their learning in STEM, and is expected to become a standard component of STEM education (Chang et al., 2022; Hidayat & Wardat, 2024). AR is used to build three dimensional graphics and multimedia that help students see, connect and remember abstract topics, making it well suited to understanding the abstract concept of Functions (Ahmad & Junaini, 2020; Bulut & Borromeo Ferri, 2023). Although GeoGebra can display objects in two and three dimensions, it cannot display video or the real-world camera view, and it is precisely this gap that AR fills.

Applet Design

Rationale for choosing GeoGebra and AR

The STEM Training Module uses applets built with a combination of two technologies, namely three-dimensional GeoGebra and interactive AR. These two technologies were chosen for their complementary roles, as summarised in Table 1. GeoGebra provides a dynamic mathematics environment that allows students to manipulate function graphs directly, while AR adds an experiential dimension by allowing students to view three-dimensional mathematical objects in real space.

Table 1. The complementary roles of GeoGebra and Augmented Reality in the applet design

Feature	**GeoGebra**	**Augmented Reality (AR)**
Main nature	Dynamic and free mathematics software	Technology for displaying 3D graphics in real space
Representation	Two and three dimensions, with algebraic and geometric manipulation	Three-dimensional objects viewable through the camera
Strength	Dynamic exploration and answer-checking	Visualisation of abstract concepts and high engagement
Limitation	Cannot display the real-world camera view	Requires a device that supports iOS

Note. *Adapted from the design rationale of the source thesis and from Hidayat and Wardat (2024).*

Applet design by unit

The applets are integrated into four learning units, each based on a real-world context related to temperature and heat. Each unit is equipped with a GeoGebra applet and a GeoGebra AR activity tailored to the targeted Functions subtopic, as shown in Table 2.

Table 2. Applet design by unit of the STEM Training Module

Unit	Real-world context	Functions subtopic	Technology components
Unit 1	A fixed temperature expressed in the Celsius, Kelvin and Fahrenheit scales	Composite Functions	GeoGebra Applet & GeoGebra AR
Unit 2	Temperature conversion	Inverse Functions	GeoGebra Applet & GeoGebra AR
Unit 3	Hypothermia	Quadratic Functions	GeoGebra Applet & GeoGebra AR
Unit 4	Hyperthermia	Quadratic Functions	GeoGebra Applet & GeoGebra AR

Note. *The applets use three-dimensional GeoGebra and interactive AR.*

Pedagogical function of the applets

Within each unit, the two technology components play different but mutually supporting pedagogical roles, as summarised in Table 3. The GeoGebra AR Activity component allows students to explore function graphs, particularly Quadratic Functions, in three-dimensional form through the AR display. The GeoGebra Applet component, in turn, allows students to answer questions by showing their own calculation steps and then comparing their answers with the applet's output for the purpose of self-checking. This design supports constructivist learning, as students actively construct and verify their understanding.

Table 3. The pedagogical function of the two technology components

Technology component	Pedagogical function
GeoGebra AR Activity	Allows students to explore and manipulate function graphs in three dimensions through the Augmented Reality display, thereby visualising abstract concepts.
GeoGebra Applet	Allows students to self-check their answers by comparing their own calculations with the applet's output, encouraging self-directed learning.

Note. *The module does not provide an answer key; checking is carried out through the applets.*

Alignment with the STEM Education Quality Framework

This applet design directly satisfies the Quality of Technology Integration component of the STEM Education Quality Framework, namely exposing students to the use of a variety of technologies in their learning experience. In addition, the use of the applets within real-world contexts related to temperature and heat also supports other components of the framework, such as Degree of STEM Integration and Connections to Non-STEM Disciplines, because it connects the concept of Functions to the fields of Physics, Chemistry and Biology.

DISCUSSION

This applet design shows how two complementary technologies can be combined to overcome the visualisation challenges in learning Functions. GeoGebra provides dynamic manipulation and self-checking capabilities, while AR adds the experience of three-dimensional visualisation in real space. This combination addresses the need identified in the literature, namely that the abstract concept of Functions requires strong visual support (Hidayat, Noor, Nasir & Ayub, 2024; Shahrul, Nasir & Suryadi, 2024; Zhang, Wang, Jia, Zhang & Chen, 2025).

Hardware requirements for AR activities present an accessibility consideration. GeoGebra AR is not limited to one platform; the GeoGebra 3D Calculator provides AR on Android devices featuring ARCore and iOS devices featuring ARKit, alongside a 3D browser view for other systems (GeoGebra, n.d.). Ultimately, the main limitation is having a device equipped for AR rather than needing a specific operating system, as students lacking ARCore or ARKit support cannot access the AR view. To preserve equity, the design allows these students to use the two dimensional GeoGebra applets or the web view, to work in small groups with shared AR capable devices, and to access all applets through QR-coded resource links. Future technology integration designs should continue to plan for a range of devices so that the benefits of visualisation reach all students.

Because this paper reports a design, the effectiveness of the applets on learning has not been established here. Within the same research project, however, the STEM Training Module that houses these applets underwent a companion evaluation of its validity, reliability and usability, in which a usability pilot with Form Four students recorded a high level of agreement and students specifically valued the capacity of GeoGebra AR to represent graphs of Functions (Raja Lailatul Zuraida et al., in preparation). What remains is to test the applets' effect on learning outcomes directly. A controlled or quasi experimental study is therefore proposed, comparing the conceptual understanding, visualisation ability and engagement of students who learn Functions with the applets against those taught conventionally, complemented by structured usability testing with both teachers and students to refine the interface and confirm classroom practicality.

CONCLUSION AND RECOMMENDATIONS

This paper has discussed the design of three dimensional GeoGebra and Augmented Reality applets for visualising the concept of Functions in STEM learning of Form Four Additional Mathematics. The design combines the strengths of GeoGebra and AR, is aligned with the STEM Education Quality Framework, and is integrated into four units based on real world contexts. This paper contributes a technology integration design framework that can be adapted for other abstract mathematics topics.

It is recommended that future studies empirically evaluate the effect of these applets on students' conceptual understanding, visualisation ability and engagement, ideally through a controlled or quasi experimental design, and that usability testing be extended to both teachers and students to inform interface design and classroom practicality. Because GeoGebra AR already runs on ARCore capable Android devices and ARKit-capable iOS devices, delivery should make deliberate use of both platforms, together with the GeoGebra web view, to maximise accessibility and equity.

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