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Development of a STEM Training Module Integrating GeoGebra and Augmented Reality for the Topic of Functions Based on the Sidek Module Development Model and the STEM Education Quality Framework

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ABSTRACT

Learning the topic of Functions is often perceived as difficult because of its abstract nature and the lack of visual representation in the teaching and learning process. This paper reports the development and evaluation of a STEM Training Module for the topic of Functions that integrates GeoGebra software and Augmented Reality (AR) technology. The module was developed using a design and development research approach, operationalised through the Sidek Module Development Model (SMDM): the first phase comprised the nine steps of drafting the module, with the STEM Education Quality Framework and the topic of Functions as the two content pillars, and the second phase comprised trialling and evaluating the module. The development produced a module comprising four learning units based on real world contexts related to temperature and heat, namely temperature scales (Composite Functions), temperature conversion (Inverse Functions), and hypothermia and hyperthermia (Quadratic Functions). Each unit contains six fixed components, namely Introduction, Knowledge Test, Real World Application Exercise, Revision Exercise, GeoGebra AR Activity and GeoGebra Applet. The module applies constructivist and active learning theories, uses Polya's four phase problem solving model as its strategy, and provides three dimensional GeoGebra and interactive AR applets to enable students to visualise the concept of Functions. The paper also specifies the module's assessment procedures, implementation guidelines and technological requirements. In the evaluation phase, expert appraisal by five specialists yielded a high overall validity of 90.0% (with construct validity of 100%), the reliability coefficient (Cronbach's Alpha) was .874, and usability among Form Four students was high. This paper contributes a concrete example of a systematic, technology based STEM module design, together with evidence of its validity, reliability and usability, that can be adapted by other teachers and researchers.

Keywords: STEM Training Module; topic of Functions; GeoGebra; Augmented Reality; Sidek Module Development Model

INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM) education requires students not only to master knowledge but also to apply it in real world contexts (Roehrig, Dare, Ellis & Ring-Whalen, 2021). However, the implementation of STEM in schools is often constrained by a shortage of systematic teaching materials and modules to support teachers (Markus, Sungkim & Ishak, 2021). This situation is even more challenging for the topic of Functions in Additional Mathematics, which is abstract and difficult for students to visualise (Shahrul, Nasir & Suryadi, 2024; Zulnaidi, Oktavika & Hidayat, 2020).

A needs analysis conducted earlier in this research showed that the subtopics of Inverse Functions and Composite Functions are among the most difficult for Form Four students to master. Those findings provide the justification for developing a training module that focuses on delivering the concept of Functions visually with the support of technology. This paper reports the development of a STEM Training Module for the topic of Functions that integrates GeoGebra software and Augmented Reality (AR) technology, guided by the Sidek Module Development Model (SMDM) and the STEM Education Quality Framework. In line with the SMDM, the paper documents the design decisions and the resulting module, specifies its assessment, implementation and technological requirements, and summarises the validity, reliability and usability evaluation carried out in the second phase.

LITERATURE REVIEW

The Sidek Module Development Model (SMDM)

The Sidek Module Development Model is a comprehensive model that provides a complete and orderly procedure from the beginning of module construction through to module testing. The SMDM is divided into two main stages, namely the module-drafting stage, which contains nine steps, and the stage of trialling and evaluating the module. This model was chosen because it is systematic and has been shown to produce effective modules across various fields, including recent mathematics module development studies (Hamzah, Ramli & Khairani, 2022; Jahudin & Siew, 2023). This approach is consistent with design and development research, which emphasises the systematic design, development and evaluation of educational products (Hamzah, Ramli & Khairani, 2022). Importantly, the two stages are methodologically separable: the present paper reports the first (drafting) stage and summarises the second (trialling and evaluation) stage in a later section.

The STEM Education Quality Framework

The STEM Education Quality Framework, developed through the collaboration of the Dayton Regional STEM Center, provides a reference for conceptualising and communicating about high-quality STEM teaching and learning (Rowley, Preiss, Pinnell & Franco, 2012). The framework contains ten components of the STEM learning experience, as summarised in Table 1. Applying this framework within each module unit aims to ensure that students' learning experiences meet the characteristics of high-quality STEM education, while also serving as material for reflection and self-assessment.

Table 1. The ten components of the STEM Education Quality Framework

No.	Component of the STEM Education Quality Framework
1	Potential for Student Engagement
2	Degree of STEM Integration
3	Connections to Non-STEM Disciplines
4	Integrity of Academic Content
5	Quality of Cognitive Task
6	Connections to STEM Careers
7	Individual Accountability in a Collaborative Culture
8	Nature of Assessment
9	Application of the Engineering Design Process
10	Quality of Technology Integration

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Note. Adapted from Rowley et al. (2012) and the Dayton Regional STEM Center's STEM Education Quality Framework (2011).

Integrating GeoGebra and Augmented Reality in mathematics learning

GeoGebra is dynamic mathematics software that allows students to explore concepts in multiple representations simultaneously. A range of studies has shown that the use of GeoGebra enhances students' understanding and motivation in learning mathematics (Hidayat, Noor, Nasir & Ayub, 2024; Yohannes & Chen, 2023; Zulnaidi, Oktavika & Hidayat, 2020). Augmented Reality (AR) technology adds further value by allowing students to manipulate three dimensional mathematical objects in real space, thereby supporting more interactive STEM learning (Ahmad & Junaini, 2020; Hidayat & Wardat, 2024). The capacity of both technologies to generate visual representations in two and three dimensions is highly suited to overcoming the visualisation challenges in the topic of Functions (Hidayat et al., 2024; Ziatdinov & Valles, 2022). At the same time, the literature notes that the classroom benefits of GeoGebra and AR depend on adequate devices, teacher readiness and careful integration (Jabar et al., 2022), considerations that are addressed explicitly in the design of the present module.

Conceptual Framework of the Study

The development of this STEM Training Module is guided by three interrelated pillars. The first pillar is the STEM Education Quality Framework (Rowley et al., 2012), which serves as a guide to the quality of the STEM learning experience. The second pillar is the topic of Functions as the targeted mathematical content, particularly the subtopics of Composite Functions, Inverse Functions and Quadratic Functions. The third pillar is the Sidek Module Development Model, as applied in recent module development studies (Jahudin & Siew, 2023), which serves as the procedural framework for module construction. The combination of these three pillars produces a STEM Training Module for Form Four students.

DEVELOPMENT METHODOLOGY

The module was developed using a design and development research approach (Hamzah, Ramli & Khairani, 2022), operationalised through the first phase of the SMDM. The first phase comprises nine sequential steps, beginning with the construction of goals and ending with the assembly of the module draft. Each step and the action taken are summarised in Table 2. The following section discusses the outcomes of the module development according to these steps, after which the assessment, implementation and technological requirements are detailed, followed by a summary of the second (evaluation) phase of the SMDM.

Table 2. The nine steps of the first phase of the SMDM in developing the STEM Training Module

No.	Step	Action in module development
1	Constructing goals	Setting the goal of improving students' ability to apply the concept of Functions in everyday life through an integrated STEM approach supported by GeoGebra and AR.
2	Identifying theory, rationale, philosophy, concept, target group and time frame	Applying constructivist and active learning theories; the module as a complement to the textbook; the concept of drill and problem solving; targeting Form Four science students; duration of 8 periods (2 weeks).
3	Studying needs	A survey of the difficulty level of Additional Mathematics topics and subtopics; the subtopics of Inverse Functions and Composite Functions were identified as the most difficult.

4	Setting objectives	Setting behavioural objectives for each unit based on the Form Four Additional Mathematics Curriculum and Assessment Standards Document (DSKP).
5	Selecting content	Determining four content units with a mapping of STEM elements for each unit.
6	Selecting strategy	Selecting exploration activities, teacher guidance and applet use; Polya's four phase problem solving model.
7	Selecting logistics	Listing teaching aids including computers (GeoGebra) and smartphones (GeoGebra AR).
8	Selecting media	Building three dimensional GeoGebra and interactive AR applets for each unit.
9	Assembling the module draft	Combining the four units, the cover page, the contents and the user manual into a complete module draft.

Note. Adapted from the Sidek Module Development Model as applied in recent module development studies (Hamzah et al., 2022; Jahudin & Siew, 2023).

Outcomes of the Stem Training Module Development

Goals, theory and philosophy of the module

The goal of the module is to enhance students' understanding in applying the concept of Functions to solve real world problems through GeoGebra and GeoGebra AR software, while also helping teachers deliver a well organised activity module. The module applies constructivist learning theory, in which students construct new knowledge based on prior knowledge, an approach reflected in recent GeoGebra-based mathematics studies (Zulnaidi, Oktavika & Hidayat, 2020), as well as active learning theory, which allows students to engage in concept exploration assisted by mathematics software (Yatim, Saleh, Zulnaidi, Yew & Yatim, 2022). The philosophy of the module is to serve as a complement to textbooks and exercise books, as it is built upon the Form Four Additional Mathematics, Physics, Chemistry and Biology syllabi.

Structure and content of the module

The STEM Training Module consists of four learning units built around real world contexts related to temperature and heat. Each unit explicitly maps the elements of Science, Technology, Engineering and Mathematics. The targeted Functions subtopics are Composite Functions (one unit), Inverse Functions (one unit) and Quadratic Functions (two units). The structure of the four units is summarised in Table 3.

Table 3. The structure of the four units of the STEM Training Module

Unit	**Real world context**	**Functions subtopic**	**Science area & media**
Unit 1	A fixed temperature expressed in the Celsius, Kelvin and Fahrenheit scales	Composite Functions	Physics, Chemistry; GeoGebra & AR
Unit 2	Temperature conversion	Inverse Functions	Physics, Chemistry; GeoGebra & AR
Unit 3	Hypothermia	Quadratic Functions	Biology; GeoGebra & AR
Unit 4	Hyperthermia	Quadratic Functions	Biology; GeoGebra & AR

Note. Each unit is allocated two learning periods (1 hour 30 minutes).

Each unit is organised according to six fixed components explained in the module's user manual. These components, as summarised in Table 4, form a learning flow from the introduction of the concept to visual exploration through technology.

Table 4. The six components of each unit of the STEM Training Module

Component	**Pedagogical function**
Introduction	Provides a scientific overview and links the topic of Functions to everyday life.
Knowledge Test	Tests students' prior understanding based on what has already been learned.
Real World Application Exercise	Trains students to give their views and connect knowledge to real world problems.
Revision Exercise	Asks students to solve problems while showing their calculation steps.
GeoGebra AR Activity	Enables students to explore graphs of functions in three dimensions through Augmented Reality.
GeoGebra Applet	Enables students to check their answers by comparing their own calculations with the applet's output.

Note. The module does not provide an answer key; students check their answers through the GeoGebra and AR applets.

Strategy and logistics

The chosen learning strategies are exploration activities, teacher guidance and the use of applets, in line with the learning theories and the STEM Education Quality Framework. The module focuses on problem solving questions using Polya's four phase problem solving model, namely understanding the problem, devising a plan, carrying out the plan, and reflecting (Jahudin & Siew, 2023). In terms of logistics, the teaching aids listed include the textbook and the Additional Mathematics curriculum specifications, stationery and a calculator, the STEM Training Module, computers for the GeoGebra applets, and smartphones for GeoGebra AR, with the teacher acting as a facilitator.

Integration of GeoGebra and Augmented Reality media

The main media of this module are applets built using a combination of three dimensional GeoGebra software and interactive AR. Each unit is equipped with a GeoGebra applet and a GeoGebra AR activity that allow students to visualise and manipulate graphs of functions directly. The use of AR allows students to view graphs of Quadratic Functions in three dimensional form, thereby overcoming the visualisation challenges that often make learning the abstract concept of Functions difficult (Shahrul, Nasir & Suryadi, 2024). This media integration directly satisfies the Quality of Technology Integration component of the STEM Education Quality Framework.

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ASSESSMENT, IMPLEMENTATION AND TECHNOLOGICAL REQUIREMENTS

Assessment procedures

Assessment in the module is primarily formative and is embedded in its six components. The Knowledge Test at the start of each unit elicits prior understanding and enables the teacher to diagnose misconceptions before new content is introduced. The Real World Application Exercise and the Revision Exercise require students to present full solution steps, which are scored with an analytic rubric aligned to Polya's four phases (understanding the problem, devising a plan, carrying out the plan, and reflecting), so that reasoning—not only the final answer—is credited. Because the module deliberately omits an answer key, the GeoGebra Applet functions as a self assessment tool: students verify their computed values and graphs against the applet's output and revise their work accordingly. The GeoGebra AR Activity is assessed through a short task rubric that records whether students correctly interpret and manipulate the three dimensional representation. For a future effectiveness study, a pre-test and a post-test covering Composite, Inverse and Quadratic Functions would provide a measure of conceptual understanding and problem solving performance, and a short motivation questionnaire would capture affective outcomes. These instruments and their scoring schemes are specified so that the assessment can be reproduced by other teachers and researchers.

Implementation guidelines

The module is designed to be delivered across four units over eight periods (approximately two weeks), with each unit occupying two periods (1 hour 30 minutes). A recommended lesson flow for each unit follows the six components in sequence: (1) the teacher introduces the real world context and links it to the Functions subtopic; (2) students complete the Knowledge Test individually; (3) students explore the concept using the GeoGebra applet and the GeoGebra AR activity, working in small groups with the teacher facilitating; (4) students attempt the Real World Application and Revision Exercises, showing their steps; and (5) students self check using the applets and reflect on their solutions. The teacher's role throughout is that of facilitator rather than lecturer, consistent with the constructivist and active learning basis of the module. Before the first lesson, teachers are advised to install the required software, print or display the AR markers and quick response (QR) codes for the applets, and conduct a brief orientation so that students who have not previously used AR can become familiar with the interaction. A user manual accompanying the module details these steps for each unit.

Technological requirements

Delivering the module requires the GeoGebra applications, specifically GeoGebra Classic or the GeoGebra Calculator Suite for the two-dimensional applets, and the GeoGebra 3D Calculator with its AR feature for the three dimensional activities. The AR feature requires mobile devices (smartphones or tablets) that support ARCore (Android) or ARKit (iOS); computers or laptops are used for the applet-based exploration, and a projector is useful for teacher demonstration. Applets are distributed as GeoGebra resource links accessed via QR codes; an internet connection is needed for the initial download, after which many activities can be run offline. A flat and well illuminated surface is needed for stable AR placement. To promote equity where devices are limited, the module can be delivered with shared devices in small groups, and a low technology fallback (using the 2D GeoGebra applets on shared computers) allows the core content to be taught even when devices with AR capabilities are unavailable. Specifying these requirements is intended to support faithful replication and to make explicit the resources a school must have in place.

Validation, Reliability and Usability Evaluation

This section summarises the evaluation of the module carried out in the second phase of the SMDM, namely trialling and evaluating the module. Content and construct validity were assessed by a panel of experts, reliability was determined from student responses using Cronbach's Alpha, and usability was evaluated through a pilot study with Form Four students. Most of the evaluation was conducted online, following the movement restrictions in force during the COVID-19 pandemic.

Validity

Content and construct validity were assessed by five experts, comprising three lecturers and two Additional Mathematics teachers with more than ten years of experience, using the STEM Courseware Evaluation Form (STEMCEF) and the expert percentage agreement method. The module recorded a high overall agreement of 90.0%, well above the commonly accepted minimum of 75–80% (Bahari & Saleh, 2023). Construct validity reached full agreement (100%), and the Teaching Content construct recorded the highest content validity value (93.2%). Agreement across the five experts ranged from 85.0% to 94.5%, with an average of 90.6%; given the high values and the absence of significant differences of opinion, no modifications to the module were required.

Reliability

Internal consistency reliability was determined using the Cronbach's Alpha coefficient, based on 15 valid data sets from Form Four students (a further 12 sets were excluded because some students could not access the device dependent GeoGebra AR activity). A sample of this size is adequate for estimating reliability in a pilot study (Bujang, Omar, Foo & Hon, 2024). The coefficient obtained was .874, which indicates good reliability as it exceeds 0.80 (Hussey et al., 2025). All items recorded means above 3.00 on the four-point scale and were accepted, indicating that the students were able to master the objectives of the module.

Usability

Usability was evaluated through a pilot study with 10 Form Four students, who were given access to GeoGebra and GeoGebra AR on a smart device and a laptop, using a questionnaire covering two constructs, Format (8 items) and Content (16 items). All items in both constructs recorded means above 3.00 with low standard deviations, indicating a high level of agreement. Students reported that the module was easy to use, that they understood the application of Functions in everyday life, that they could check their own answers, and that they valued the capacity of GeoGebra AR to represent various graphs of Functions. Taken together, these results (Table 5) confirm that the module has good validity, reliability and usability, supporting its use as a teaching resource for the topic of Functions. The evaluation of the module's effect on student achievement and motivation remains for a future effectiveness study.

Table 5. Summary of the validity, reliability and usability evaluation of the module

Aspect	**Method**	**Key result**
Validity	Five experts; STEMCEF; percentage agreement	Overall 90.0%; construct validity 100%
Reliability	Cronbach's Alpha (n = 15 students)	.874 (good)
Usability	Pilot study; 10 students; Format and Content	All item means > 3.00 (high agreement)

Note. The minimum accepted expert agreement is 75–80%; a Cronbach's Alpha above 0.80 indicates good reliability; a usability item mean above 3.00 on a four-point scale indicates high agreement.

DISCUSSION

The development process of this module demonstrates how a STEM quality framework, mathematical content and a module development model can be systematically combined to produce an integrated teaching resource. The use of the SMDM ensures that every design decision, from goal setting through to media selection, is made in sequence and grounded in the real needs of students (Jahudin & Siew, 2023). This approach overcomes the weakness of material development that is often carried out ad hoc without a clear procedural framework.

The choice of real world contexts related to temperature and heat, such as hypothermia and hyperthermia, allows the module to connect the concept of Functions to the fields of Physics, Chemistry and Biology, thereby highlighting the integrated nature of STEM education (Roehrig, Dare, Ellis & Ring-Whalen, 2021). The application of Polya's problem solving model supports the development of more systematic student thinking in solving word problems (Jahudin & Siew, 2023). Most importantly, the integration of GeoGebra and AR addresses the visualisation needs identified in the literature as a primary cause of students' difficulty in mastering the topic of Functions (Hidayat, Noor, Nasir & Ayub, 2024; Shahrul, Nasir & Suryadi, 2024).

Realising these design intentions in practice depends on conditions that the module design anticipates but that classrooms do not always meet. The benefits of GeoGebra and AR are contingent on device availability, teachers' digital competence, and stable integration of the technology into the lesson (Jabar et al., 2022). The module therefore embeds a teacher orientation, a user manual, QR code distribution of applets, and a low technology fallback to reduce these barriers. The second phase evaluation reported above establishes that the module is valid (90.0% expert agreement), reliable (Cronbach's Alpha = .874) and usable, consistent with previous module development studies that combined expert agreement and Cronbach's Alpha to confirm module quality (Bahari & Saleh, 2023; Hamzah, Ramli & Khairani, 2022). What these findings do not yet establish is the module's effect on learning outcomes; the impact on students' achievement and motivation must still be demonstrated through a controlled study. Framing the contribution in this way distinguishes what has been established here, a systematically designed and now empirically evaluated module, from what remains to be demonstrated.

LIMITATIONS AND PRACTICAL CHALLENGES

Two kinds of limitation should be acknowledged. First, in terms of scope, this paper establishes the module's validity, reliability and usability but not its effectiveness; the impact of the module on students' achievement and motivation has not yet been tested and is left to a future quasi experimental study. In addition, the second phase evaluation was conducted largely online during the pandemic, which limited direct observation of students' interaction with the module, and the requirement of a particular device to access GeoGebra AR reduced the valid sample size. Second, in terms of practical adoption, the integration of GeoGebra and AR presents challenges that schools should plan for: unequal access to ARCore or ARKit capable devices and to computers; variation in teachers' familiarity with the software and the consequent need for training; the sensitivity of AR tracking to lighting and to suitable flat surfaces; dependence on an internet connection for initial download; the additional class time required for set up; the risk of the technology distracting from the mathematics; and equity concerns where device provision is uneven. The design mitigations described above, including orientation, a manual, offline resource packs, shared device grouping, and a low technology fallback, are intended to reduce these challenges rather than eliminate them completely.

CONCLUSION AND RECOMMENDATIONS

This paper has reported the development and evaluation of a STEM Training Module for the topic of Functions that integrates GeoGebra and Augmented Reality, built systematically through the SMDM with the support of the STEM Education Quality Framework. The result is a four-unit module based on real world contexts with six consistent learning components and the support of visualisation technology, accompanied by specified assessment procedures, implementation guidelines and technological requirements. Expert evaluation confirmed a high overall validity of 90.0%, the module achieved a good reliability coefficient (Cronbach's Alpha = .874), and Form Four students rated its usability highly. This module contributes a concrete example of a technology based STEM module design, supported by evidence of its validity, reliability and usability, that can be adapted by other teachers and researchers.

As the next step, it is recommended that the effect of the module on students' achievement and motivation in the topic of Functions be evaluated through a face to face quasi experimental design, with a larger sample across several districts to strengthen the generalisability of the findings and expanded access to AR technology so that more students can benefit from the visualisation component. Extending this development approach to other Additional Mathematics topics is also recommended.

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