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Research article

Development and usability of a traditional game simulation module with augmented reality technology (AR-SiGaSTEM) in online learning to strengthen STEM skills among students

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Abstract: STEM (science, technology, engineering, and mathematics) education is crucial for developing a workforce equipped for future technological demands. This study developed and evaluated the usability of an augmented reality (AR) teaching module called AR-SiGaSTEM, which applies game simulation techniques adapted from traditional games. The goal was to help teachers strengthen STEM skills among students through this innovative technology-enabled approach. The objectives were i) to identify teachers' perspectives on accepting AR-integrated teaching modules for online learning; ii) to develop an AR-SiGaSTEM module and game with content, functions and features suitable for online STEM learning; and iii) to evaluate the module's usability in teaching to enhance STEM skills across the curriculum. The study utilized design and development research methods in three phases: i) analyzing the content requirements and module design based on teachers' acceptance perspectives; ii) designing and developing the module following the ASSURE instructional model; and iii) evaluating usability with 16 STEM teachers. The AR-SiGaSTEM module targets Form One mathematics teachers. Data was collected via a Technology Acceptance Model (TAM) questionnaire and a usability questionnaire based on constructive alignment. The teachers agreed that well-designed, objective-aligned AR modules can effectively facilitate online learning. Usability testing showed the AR-SiGaSTEM module achieved high usability ratings. This educational technology module incorporates local wisdom through creative learning approaches aligned with the curriculum. It aims to develop science, technology, and innovation talents with knowledge/skills relevant to Industry 5.0, supporting Malaysia's National Science, Technology, and Innovation Policy. It exemplifies innovative pedagogical interventions to optimize creative teaching practices across STEM subjects.

Keywords: development and usability, traditional game, simulation, augmented reality, online learning, STEM, teaching module, industry 5.0

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1 Introduction

Education is one of the 10 socioeconomic drivers that play a major role in generating the country's economy. When it comes to technology education, the generation of new ideas about technology can lead to the invention, design, or evolution of new technologies that may then be created or actualized (Dakers, 2024). However, based on the latest official curriculum guidelines, the primary emphasis of technology education, be it oriented toward hands-on crafting activities or developing technological literacy, is to enhance students' problem-solving abilities and conceptual understanding. This connection is reflected in the rebranding of the subject by combining it with science, engineering, and mathematics into what is now known as STEM (science, technology, engineering, and mathematics) education. The purpose of education, especially in the field of science and technology, is to foster a creative society and a skilled workforce, in line with the future skill requirements stated by the World Economic Forum (Li, 2022). The field of science and technology, now better known as STEM (science, technology, engineering, and mathematics), is one of the critical domains that are seen as capable of generating knowledgeable, skilled, and innovative students through scientific processes that require STEM skills. In the context of the Industrial Revolution 5.0, STEM has become a critical domain, with technological and scientific skills as its competency values. Furthermore, skills in the STEM domain have become enablers in education that can be cultivated to increase the number of skilled workers and support a knowledgeable and highly trained community.

Cultivation related to science, technology, and innovation (STI) needs to be expanded to include not only informal STEM learning but also culture related to the application of technology at all levels of society, which would involve the collaboration of industry, academics, and the community as a whole. This would ensure that the technology that is developed benefits all groups. Instructional-based technology is growing, with various platforms and digital tools being applied as teaching materials to support online learning activities. A study by Abdul Bujang et al. (2020) listing the platforms and digital tools applied in Education 4.0 mentioned mobile learning applications, Open Learning Massive Open Online Courses (MOOC), video-based learning, augmented/virtual reality (AR/VR), and online educational games.

AR is a technology that enables interaction between the real world and virtual objects. AR technology is becoming increasingly popular in education because it has the potential to apply pedagogy that supports teaching and learning. In addition, AR technology is a powerful learning tool for increasing interaction, motivation, spatial and physical skills, as well as potential collaboration among students (Ibáñez & Delgado-Kloos, 2018). A study by Guerra, de Medeiros, and Gericota (2024) also supported the idea that the use of immersive AR in education is mainly caused by the increasingly dynamic teaching and learning environment. Besides, it allows students to enter an immersive environment in which they interact and learn effectively, which can improve the learning experience (Jesionkowska et al., 2020). Previous studies have vigorously evaluated AR technology applied in the teaching and learning process, finding that it has positive effects by reducing unrelated

cognitive load and promoting learning concepts, especially in the STEM domain (Altmeyer et al., 2020). Students acquire STEM skills, which consist of process skills and technical skills, while doing activities that involve AR technology as a digital learning tool. The global demand for a qualified and skilled STEM workforce is currently high compared to previous needs, when the world began to pay attention to what would be required in the Industrial Revolution 4.0 (Setyaningsih et al., 2021).

Implementing AR technology in classrooms faces challenges, including teachers' limited knowledge about AR, their readiness and ability to handle the technology, and the need to complete the teaching syllabus (Shafeey & Lakulu, 2021). In the Malaysian educational context, AR technology has been seldom introduced in schools, so teachers lack confidence in applying it to the teaching and learning process. This is a crucial element in the 21st-century educational landscape, where teachers act as facilitators. Only a small number of teachers directly use this new technology in classrooms, resulting in few students benefiting from its advantages. This is partly due to the excessive curriculum content and resource constraints in schools, leading to a scarcity of technology-based educational applications that have sufficient content and learning materials (Jesionkowska et al., 2020). Teachers require more support and training in didactic knowledge (scientific and consistent) to leverage AR technology by adapting teaching pedagogies and achieving the desired learning outcomes (Freese et al., 2023).

To address the aforementioned challenges, this article presents the findings from the development and evaluation of a module entitled "A STEM Skills Module: Simulation of Traditional Games with Augmented Reality Technology in Online Learning" (the AR-SiGaSTEM Module). The research findings elucidate three key aspects: i) teachers' perspectives on the acceptance of AR technology-integrated teaching modules for online learning; ii) the development process of an AR-enabled module with functions and features suitable for online learning implementation; and iii) the module's usability in facilitating teachers' instructions to strengthen STEM skills across the curriculum. The module integrates traditional game simulation techniques through AR technology to assist teachers in managing the teaching process and enhancing STEM skills among students. A complementary simulation mobile game, AR-SiGaSTEM, enables teachers to conduct more interactive activities, creating an engaging learning environment through AR technology. Simulation games offer the potential for comprehensive and flexible gameplay. According to Ajit et al. (2021), most simulation-based applications incorporate AR technology, allowing users, including students and teachers, to apply concepts involving virtual learning content in real-world environments, both inside and outside the classroom. The selection of traditional games as the module's theme aimed to introduce and preserve Malaysia's local wisdom and cultural heritage.

In an increasingly digital age, traditional games are often overlooked in the context of modern education, despite their value in developing students' cognitive and social skills. Traditional games provide opportunities to not only train critical thinking and problem-solving skills but also integrate important STEM elements (Chuah et al., 2021). Notably,

the traditional game *Gasing*, utilized as the primary asset in the AR-SiGaSTEM game, requires students to develop skills in determining the appropriate distance and force for throwing the *Gasing*, necessitating STEM knowledge and skills. Therefore, traditional games needed to be assessed in this study to examine their potential to improve students' STEM skills. With the introduction of technologies such as AR, traditional games may be used in new learning tools and introduced into online learning environments that provide a more engaging and interactive learning experience. The need to integrate traditional games into AR technology was also caused by the challenge of increasing students' interest in STEM, which requires a more creative and effective approach to learning.

The implications of this study contribute to a paradigm shift in teaching, fostering a more authentic and engaging approach. An educational technology-oriented module incorporating local wisdom through a creative learning approach was developed in alignment with the current curriculum. The module aims to nurture knowledgeable, skilled, and positive talents in the science, technology, and innovation (STI) field, thus meeting the demands of Industry 5.0. Furthermore, this study supports initiatives to lead STEM education by creating a standardized STEM teaching and education module, providing a foundation for innovative pedagogical intervention processes to optimize creative teaching practices across the curriculum.

2 Methodology

The main objective of this study was to develop and evaluate the usability of a module that is equipped with a game called AR-SiGaSTEM, using AR technology. This form of study is suitable for adoption in the research design paradigm of Design and Development Research (DDR), as advocated by Richey and Klein (2014), given its ability to examine theoretical constructs and ensure their practical viability. This is because the goal of research design and development tends to be more general, enabling this AR-SiGaSTEM module to be used in various environments and by various target users. It can improve the final level of the module produced. This research refers to the modified DDR by Saedah et al. (2020), which combined the design phase and the implementation phase of the original DDR devised by Richey and Klein (2014) to create a design and development phase that was seen as more suitable for the conceptual study of digital product development, STEM, and pedagogical innovation. To achieve the second objective of this research, three (3) phases were involved in the DDR modification, as outlined below.

2.1 Requirements analysis phase

Requirements analysis constitutes a crucial aspect of educational research and served as a fundamental component of the development of the AR-SiGaSTEM module. The objective of the needs analysis in this study was to obtain information regarding the target users' acceptance of the module and application to be developed, as well as the content and

interface design of the AR-SiGaSTEM module. The requirements analysis was conducted using two methods:

1. Library research involving content analysis meticulously examined the Form One (secondary school) mathematics curriculum syllabus, learning methods/strategies, simulation techniques, STEM principles, and elements that could be translated into traditional games suitable for development through an AR application. Various data sources for this research were collected from Standard Curriculum and Assessment Documents, textbooks, journals, articles, conference papers, and books related to this field. Extensive literature selection was carefully conducted by focusing on relevant and authentic sources to support the development of the AR-SiGaSTEM module. This study considered various existing studies (those by Ajit et al., 2021; Faria, 2024; Ibáñez & Delgado-Kloos, 2018; Mystakidis et al., 2022; and Rocha et al., 2024) that discussed the application of AR technology in STEM learning. The literature selection process aimed to ensure that the information obtained was up-to-date, relevant, and in line with the study objective, which was to integrate traditional games in the context of STEM education using AR technology. The subject's content and traditional game gameplay were mapped to identify appropriate gameplay and STEM activities to embed into the AR-SiGaSTEM module.
2. A survey was conducted to ascertain teachers' perspectives on the acceptance of teaching modules and AR game applications that integrate AR applications. The survey was distributed online to 16 teachers with experience of teaching Form One mathematics in secondary schools. This survey employed a four-point Likert scale questionnaire, with responses ranging from 4 (*strongly agree*), 3 (*agree*), and 2 (*disagree*), to 1 (*strongly disagree*). The four-point scale is commonly utilized to provide a more precise evaluation of respondents' attitudes or opinions while minimizing the number of categories and simplifying data interpretation (Cohen et al., 2018). The questionnaire instrument was adapted from the Technology Acceptance Model (TAM), which comprises five (5) main constructs: i) perceived usefulness (PU); ii) perceived ease of use (PEU); iii) perceived enjoyment (PE); iv) attitude toward use (AU); and v) behavioral intention of use (BI), as devised by Mokmin et al. (2022). In line with the TAM model, the successful adoption of new technology in the educational sector today hinges on positive attitudes to two specific factors. Additionally, the questionnaire surveyed the teachers' expectations regarding the module's design to ensure that the developed module met their needs and provided comfortable utilization.

2.2 Design and development phase

The AR-SiGaSTEM module was developed based on the ASSURE model to plan the module development process and the effective integration of AR applications into the curriculum. The ASSURE model is an instructional model that can provide opportunities for teachers to plan and implement teaching effectively with technological support (Heinich et al., 1999). The ASSURE model has six (6) steps, represented by acronyms, which describe certain phases and tasks when using educational technology. The six steps (6) are listed in Table 1.

Table 1. Implementation of the AR-SiGaSTEM module design and development phase based on the ASSURE model

Steps	Activities
A: Analyze teacher criteria and requirements.	The researchers identify teachers' needs, involving their existing skill levels in and knowledge of using digital tools in teaching; the teaching challenges they face in teaching STEM subjects; the teaching style; and the learning needs. The requirements analysis data obtained during Phase 1 form the basis for the construction of the design of the module.
S: State learning objectives.	Traditional game types, learning topics, and STEM skills involved in the module are determined according to the learning objectives to be achieved, as shown in Table 2 (see Appendix). The requirements analysis data obtained during Phase 2 form the basis for selecting the simulation techniques and forms of AR technology in this module.
S: Select the instructional method, media, and learning materials.	The AR-SiGaSTEM module is equipped with a simulation game adapted from traditional games (*Wau, Gasing*, and *Baling Tin)* according to the topic learning based on the 5E inquiry learning model (engage, explore, explain, elaborate, evaluate). The 5E model has proven beneficial and successful in enhancing students' learning outcomes, especially in STEM education (Ong et al., 2021). The design of this simulation game in the AR-SiGaSTEM game uses marker-based and marker-less AR methods, multimedia elements, and digital materials that have been chosen and further developed using Unity software. In addition, the AR application design and development guidelines are based on the principles and practices suggested by Schmalstieg and Hollerer (2016). Examples of the AR-SiGaSTEM module pages and AR-SiGaSTEM game interfaces are shown in Figures 1 and 2.
U: Utilize methods, media, and materials.	The AR-SigaSTEM module and the AR-SiGaSTEM game application are used in teaching sessions through a pilot study to obtain teachers' feedback on their experience of using this module in an online environment.
R: Require feedback from respondents.	Feedback from teachers related to their experience of using the AR-SiGaSTEM module and AR-SiGaSTEM game in the pilot study was used as the basis for module improvements.
E: Evaluate AR-SiGaSTEM module.	The AR-SiGaSTEM module and AR-SiGaSTEM game application are validated by three experts in the field of STEM and multimedia during the evaluation phase of the study to determine the module's level of validity and applicability (in terms of content, feature, and functionality) using Cohen's Kappa expert agreement.

Figure 1. Examples of the AR-SiGaSTEM module pages

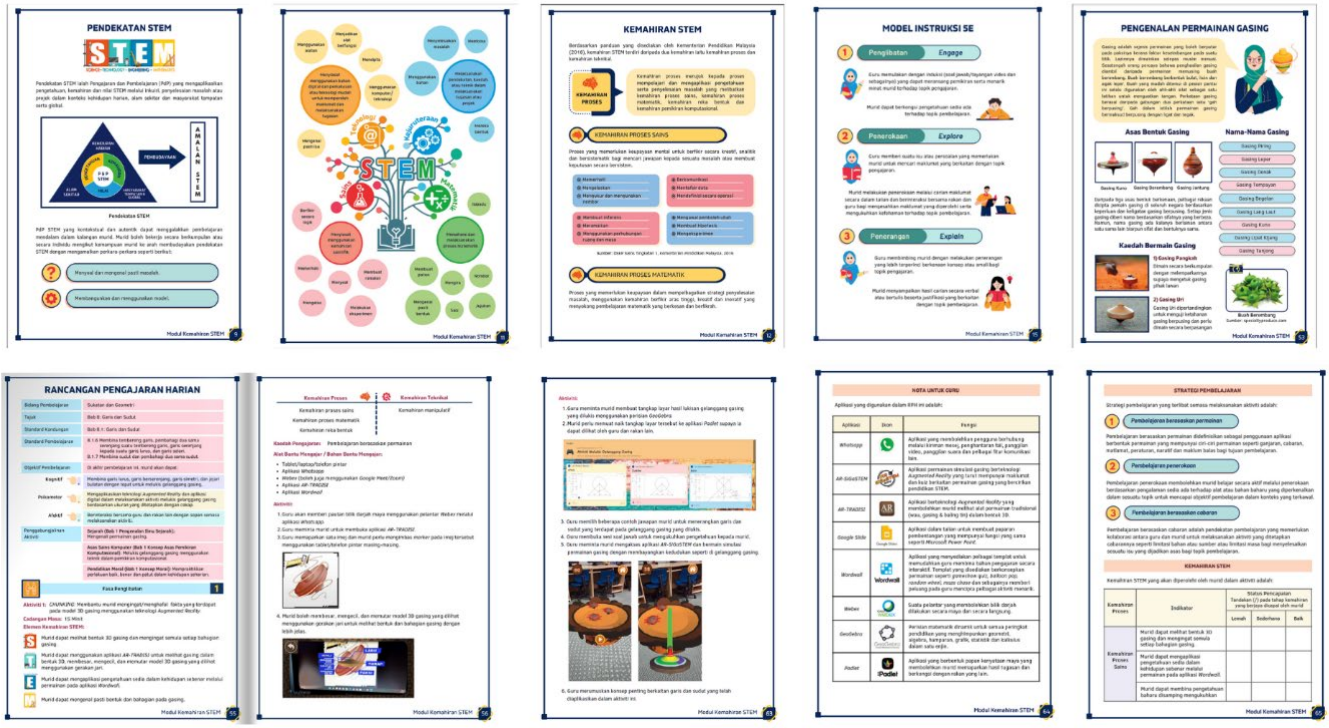

Figure 2. The AR-SiGaSTEM game interface

2.3 Evaluation phase

The module underwent rigorous validation through expert evaluation by three subject-matter experts specializing in STEM education and multimedia technology. These experts conducted comprehensive assessments of the module's pedagogical appropriateness and technological efficacy within their respective domains of expertise. Inter-rater reliability was established using Cohen's Kappa coefficient to quantify the degree of consensus among the expert evaluators. Regarding instrument validation, the study employed an established instrument adopted from Mokmin et al. (2022), who successfully implemented the Technology Acceptance Model (TAM) in technology-integrated module development. The adoption of this previously validated instrument, which has demonstrated robust psychometric properties in analogous contexts, provided substantial empirical support for the construct validity of this new investigation.

The usability of the AR-SiGaSTEM module was evaluated through empirical testing, which was conducted with a sample of 16 mathematics teachers from secondary schools in the Perak Hilir district. This testing session received support from the Learning Sector of the District Education Office in Hilir Perak, which facilitated the selection of participants teaching the Form One mathematics curriculum in the schools around the Hilir Perak district. For the testing session, the participating teachers from various schools were convened and briefed on the AR-SiGaSTEM module and its intended utilization, led by the principal investigator of the study. Written informed consent was obtained from all the participants before proceeding. Subsequent to the demonstration, the teachers completed a usability test questionnaire employing a four-point Likert scale to evaluate several constructs: content suitability (five items), activity suitability (five items), module design integrated with the augmented reality (AR) game application (five items), and module functionality with the AR game application (five items). Descriptive statistical analyses were conducted on the collected data, with the mean values and standard deviation calculated for each construct.

3 Results, findings, and discussion

3.1 The teachers' perspectives on the acceptance of teaching modules with the integration of AR technology in the online teaching and learning process

Tailoring educational modules to directly address the learners' specific educational requirements and aligning the modules with their respective academic aptitude levels (Ab Kadir & Mohammad Hussain, 2023) can significantly enhance the effectiveness of online teaching and learning initiatives. Moreover, the incorporation of interactive simulation learning activities (Ajit et al., 2021) and game principles (Silmi et al., 2022), the utilization of digital applications (Abdul Bujang et al., 2020), and the integration of AR technology

(Ibáñez & Delgado-Kloos, 2018) have consistently yielded positive outcomes in terms of fostering engagement, motivation, and knowledge acquisition among learners across diverse educational settings.

In the context of this study, with reference to the Curriculum and Assessment Standard Document for Form One mathematics, the researchers undertook a meticulous mapping exercise to identify and associate appropriate traditional games that would correspond to the prescribed content standards, learning standards, learning objectives, and STEM skills. The results of this content alignment are presented in a comprehensive tabular format (see Table 2 in the Appendix), providing a coherent alignment for the subsequent development and implementation of the educational module.

The survey results after assessing the teachers' perspectives on modules that integrate digital applications and AR technology revealed predominantly positive acceptance, with the mean value across all the items being 3.02 (a high level), as illustrated in Table 3. This finding is particularly noteworthy given that the majority of the participating teachers (75%, n=12) self-reported limited prior exposure to AR applications. Such a positive reception from educators with relatively little experience in this domain underscores the potential appeal and efficacy of integrating cutting-edge technologies like AR into educational curricula. With the advent of technology, integrating AR modules into STEM education can leverage immersive experiences and interactive visualizations, making positive contributions to students' learning, engagement, and motivation by bringing STEM concepts application to life in a captivating and multi-sensory manner.

Analysis based on the Technology Acceptance Model (TAM) provided deeper insights into the teachers' acceptance of the use of AR technology in teaching. Analysis of the perceived usefulness (PU) construct revealed mean values ranging from 3.00 to 3.06, indicating favorable recognition of the pedagogical potential of AR. Educators acknowledged its capacity to enhance conceptual comprehension and facilitate skill acquisition among students. This positive perception aligns with contemporary research demonstrating the efficacy with which AR can promote student engagement, motivation, achievement, and performance in STEM education contexts (Mystakidis et al., 2022). This convinces teachers to believe in its potential as an effective teaching tool.

However, the perceived ease of use (PEU) construct exhibited comparatively lower mean values (2.69-2.81), suggesting that the educators perceived implementation challenges. These findings indicate concerns regarding the accessibility of AR technology and the requisite competencies for its effective pedagogical integration. This observation corresponds with extant literature highlighting how technological proficiency and professional development deficits can impede educational technology implementation (Mpuangnan, 2024).

Examination of the perceived enjoyment (PE) construct yielded high mean values (2.87-3.25), reflecting the positive affective responses to AR implementation among both teachers and students. Notably, teachers were confident that student engagement and en-

thusiasm were enhanced during AR-mediated learning activities. This finding is consistent with the concept of interactivity in AR (Ajit et al., 2021), demonstrating the ability of AR to enhance learning engagement through increased interactivity.

The attitude toward use (AU) construct demonstrated robust mean values (3.06-3.25), indicating generally favorable dispositions toward AR integration in educational contexts. Teachers recognized the potential of AR to enrich instructional delivery and foster interactive learning environments. However, moderate concerns regarding potential student disengagement warrant consideration in subsequent module iterations.

The behavioral intention of use (BI) construct exhibited moderate mean values (2.81-2.94), suggesting tentative commitment to sustained AR implementation. This hesitancy may be attributed to insufficient professional development support and challenges in curriculum integration. The model proposed by Ateş and Garzón (2023) integrates psychological and technological dimensions, demonstrating that educators prioritize learning environments that optimize instructional effectiveness, operational efficiency, and student engagement. This paradigm would consequently motivate pedagogical innovation and experimentation with novel instructional approaches.

Table 3. Mean values of teachers' acceptance perspectives, based on the TAM model

Constructs	Items	Mean value	Standard Deviation
PU: Perceived usefulness	I believe the use of modules with AR technology can make it easier for my students to understand certain concepts.	3.00	0.37
	I believe the use of modules with AR technology is useful to teach students more effectively.	3.06	0.44
	I believe my students performance (knowledge & skills) will increase with the use of AR technology as a learning tool/material.	3.00	0.52
PEU: Perceived ease of use	I believe that I can handle teaching modules equipped with AR technology easily.	2.69	0.60
	I believe that teaching modules equipped with AR technology are easy to learn.	2.81	0.54
PE: Perceived enjoyment	I believe I will be excited to teach when using modules equipped with AR technology.	2.87	0.62
	I believe my students are also excited to learn when this involves activities that use AR technology.	3.19	0.66
	I believe my students can learn while playing when using AR technology.	3.25	0.58
AU: Attitude toward use	I believe learning becomes more interactive with AR technology.	3.25	0.58
	I believe AR technology is a good innovation in learning.	3.25	0.45

	I believe my students don't get bored quickly when performing activities that use AR technology.	3.13	0.50
	I am interested in teaching using AR technology.	3.06	0.44
BI: Behavioral intention of use	I am interested in creating learning/teaching innovations based on AR technology.	2.81	0.66
	I think there is a need for a teaching module that uses AR technology.	2.94	0.44
OVERALL		**3.02**	**0.40**

These findings, corroborated by the broader literature, highlight the potential benefits of adopting a multifaceted approach that combines tailored educational content, interactive simulations, digital applications, and emerging technologies like AR to enhance the online teaching and learning experience. By addressing learners' diverse needs, aptitudes, and preferences through a blended methodology, such initiatives can foster a more engaging, immersive, and ultimately effective educational environment.

3.2 Experts' validation of the content, features, and functions of the AR-SiGa-STEM module with the AR-SiGaSTEM game application

The data findings pertaining to expert agreement on the levels of validity and applicability of the AR-SiGaSTEM module and the AR-SiGaSTEM game application for online teaching and learning purposes were evaluated using Cohen's Kappa coefficient, with the results presented in Table 4. Expert evaluation was carried out based on the construct validity of the module, the compatibility of the game application with the module, its usability in online learning, and the efficiency of use by teachers. Three subject matter experts in the domains of STEM education and multimedia technology were consulted to provide a comprehensive assessment of the module's alignment with curriculum standards and its suitability for integration into the current school syllabus.

Table 4. Findings of expert agreement on the levels of validity and applicability of the AR-SiGaSTEM module with the AR-SiGaSTEM game application

Expert evaluator	Cohen's kappa coefficient (κ)	Level of expert agreement
Expert 1	0.75	Good
Expert 2	0.85	Excellence
Expert 3	0.87	Excellence

According to the experts' evaluation, the AR-SiGaSTEM module demonstrated strong adherence to the prescribed curriculum requirements, effectively aligning its content with the contemporary learning objectives and competencies outlined in the syllabus. Moreover, the seamless compatibility of the AR-SiGaSTEM game application, an innovative

technological component integrated into the module, was lauded for its added value. Incorporating games and elements into lessons can help students better understand concepts and applications, as well as foster meaningful learning in an engaging and enjoyable manner (Zaharin et al., 2021). The experts acknowledged that the application's features and functionality were well-suited to facilitate an engaging and immersive online learning experience, thereby lending a distinct novelty and uniqueness to the overall module.

However, the experts also highlighted several considerations that warrant attention to ensure the successful implementation of this module in educational settings. Firstly, the levels of proficiency and expertise among teachers in handling and operating the AR-SiGaSTEM game application were identified as potential challenges, so adequate training and support would be needed to ensure seamless adoption. Secondly, concerns were raised regarding the time constraints associated with executing the module's activities, particularly in the context of an already demanding curriculum. Effective time management strategies and careful planning would be essential to mitigate potential disruptions to the overall learning schedule.

Additionally, the experts emphasized the critical role of reliable and consistent internet access in facilitating the seamless utilization of the digital application. Connectivity issues could hinder the module's implementation and discourage teachers from fully embracing this innovative approach. Acknowledging these challenges, the experts underscored the importance of prudent decision-making by educators in selecting and planning an appropriate medium to ensure the effective delivery of learning objectives, echoing the sentiments expressed by Zhu et al. (2022). To address these concerns, the AR-SiGaSTEM module provides comprehensive guidelines and exemplars of learning activities that effectively integrate digital tools and the AR-SiGaSTEM game application. These resources serve as a valuable reference for educators, offering practical strategies and best practices for seamlessly incorporating technology-enhanced learning experiences into their classrooms while navigating potential obstacles.

3.3 The usability of the AR-SiGaSTEM module in teachers' teaching to strengthen STEM skills across the curriculum

The results of a usability survey conducted on 16 mathematics teachers in the Hilir Perak district revealed valuable insights into the usability of the AR-SiGaSTEM module. The findings indicated a high level of usability in terms of content suitability (mean=3.14, SD=0.38) and the design of the module integrated with the AR game application (mean=3.31, SD=0.48). The majority of the teachers stated that the topics chosen in this module aligned well with the learning standards and had the potential to foster students' STEM skills through the engaging theme of traditional games. Incorporating AR content into STEM lessons empowers teachers to create engaging, interactive, and immersive learning environments that actively involve students in the learning process (Vahidy, 2019). This approach not only deepens their understanding of complex topics but also

cultivates essential skills such as problem-solving, critical thinking, and the ability to apply theoretical knowledge to real-world situations. Moreover, the user-friendly interface design of the AR-SiGaSTEM game application, coupled with an appropriate combination of multimedia elements, was perceived as capable of attracting students' interest and increasing their focus during the learning process. This finding corroborates the studies by Ibáñez and Delgado-Kloos (2018) and Lee et al. (2022), who asserted that AR applications have the potential to apply pedagogy that supports learning and teaching, in addition to increasing interaction, motivation, and spatial and physical skills, as well as facilitating collaboration among students.

However, the survey results also indicated that the usability of the AR-SiGaSTEM module was rated as moderate in terms of the suitability of the activities (mean=2.90, SD=0.47) and the convenience of the module integrated with the AR game (mean=2.96, SD=0.54). These moderate ratings can be attributed to several factors. Firstly, the teachers expressed some uncertainty regarding their ability to undertake the proposed activities within the designated time frame due to constraints such as limited internet access, varying levels of students' competence in performing the activities, and the teachers' own competence in handling various digital applications. Secondly, the increasing workload on teachers poses a challenge in terms of preparing online learning materials, with many teachers tending to be more comfortable utilizing the existing methods and materials (Ahmad Saifudin & Hamzah, 2021).

These findings highlight the need to address the identified challenges in order to ensure the successful implementation of the AR-SiGaSTEM module. Providing adequate training and support for teachers in navigating digital applications and effectively integrating these applications into their teaching practices could enhance the educators' confidence and competence in utilizing the module effectively. Additionally, addressing infrastructure limitations, such as internet access, would facilitate the implementation process. Furthermore, incorporating strategies to manage teachers' workloads and provide them with the necessary resources and support could increase their willingness to adopt new teaching methods and materials, such as the AR-SiGaSTEM module.

4 Conclusions

Since the pandemic phase enabled hybrid learning, technologies such as AR have been seen as tools to enhance student learning experiences and enrich online learning, especially in improving STEM skills. The AR-SiGaSTEM module, which integrates an AR game application, the aim being for it to serve as an alternative teaching aid and tool for educators, allowing students to access more interactive and visually engaging learning content that would facilitate their understanding of STEM concepts. This initiative aligns with the goals of the NSTIP 2021-2030, which emphasize the importance of developing innovative educational resources to meet the rapidly growing demands in the fields of science, technology, engineering, and mathematics.

The AR-SiGaSTEM module has the potential to improve the quality of teaching and learning in schools, with the possibility of its implementation being expanded into higher education. Through various learning approaches and digital applications utilized in traditional game-themed activities, this module can provide a more engaging and interactive teaching experience for teachers while simultaneously capturing students' interest in learning. Ultimately, this initiative aims to produce a more competitive and skilled workforce who are prepared to thrive in an increasingly competitive job market.

While the AR-SiGaSTEM module presents numerous benefits, educators need to consider several factors during its implementation. These include the availability of suitable devices, reliable internet access for online applications, educators' technological literacy skills, and sufficient time to implement activities, given the demanding curriculum. Although AR applications can enhance the learning experience in STEM fields, it is crucial to recognize that technology cannot entirely replace the pivotal role of teachers in guiding and facilitating student learning.

In conclusion, the AR-SiGaSTEM module offers significant advantages for teachers, particularly in diversifying their teaching methods and incorporating more technologically advanced teaching aids, thus aligning with the country's goal of improving education through technology integration. Additionally, this AR-SiGaSTEM module fosters the preservation of local wisdom and heritage by incorporating traditional game themes into the STEM learning curriculum. By addressing the existing limitations and maximizing the benefits of this innovative approach, the AR-SiGaSTEM module can serve as an effective teaching material or tool in preparing today's generation with the STEM skills needed to meet the demands and challenges of future careers in science, technology, and innovation.

Research ethics

Author contributions

Laili Farhana Md Ibharim: Conducting the research and investigation process, specifically performing the data collection, writing—original draft preparation, writing—review and editing.
Mazlini Adnan: Management and coordination responsibility for the research activity planning and execution, writing—review, editing and corresponding.
Wong Yoke Seng: Design of methodology, development of instruments, formal analysis, writing—review and editing.
Yee I-Van: Provision of study materials, development of AR-SiGaSTEM module and game application.
Sukirman: Preparation of the published work, writing—review and editing.

All the authors have read and agreed to the published version of the manuscript.

Artificial intelligence

This paper was partially written with the assistance of Claude, an AI language model by Anthropic, which was used to rephrase and refine certain sections of the text.

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Informed consent statement

Informed consent was obtained from all the research participants.

Data availability statement

LUMAT encourages scholars to share their research data. Please provide details regarding where to find data supporting the reported results, including links to publicly archived datasets. A data availability statement is required even if no new data were gathered or if data were unavailable due to privacy or ethical restrictions.

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Conflicts of interest

The authors declare no conflicts of interest.

Appendix A

The mapping of traditional games that are appropriate based on content standards, learning standards, learning objectives, and the STEM skills involved.

Table 5. Alignment of traditional games with content standards, learning standards, learning objectives, and STEM skills development

Traditional Game	Subject Content Standard	Learning Standard	Learning Objective	STEM Skills Involve
Wau	Chapter 4.1: Ratios	4.1.1: Represent the relation between three quantities in the form of a:b:c.	Students can accurately represent the relationship between the three sizes of the *Wau* drawn in the form of a ratio of three quantities.	Process skills: • Science process skills. • Mathematical process skills. • Design skills. Technical skills: • Manipulative skills. • Skills in handling materials, tools and machines. • Information management skills.
	Chapter 9.1: Polygons	9.1.2: Draw polygons, label vertices of polygons and name the polygons based on the labeled vertices.	Students can correctly label polygons based on the characteristics of polygons that form the basis of pattern design on *Wau* bodies.	Process skills: • Science process skills. • Mathematical process skills. • Design skills. Technical skills: • Manipulative skills. • Skills in handling materials, tools and machines. • Project management skills.
Gasing	Chapter 8.1: Lines and Angles	8.1.6: Construct i) line segments; ii) perpendicular bisectors of line segments; iii) perpendicular line to a straight line; iv) parallel lines; iv) parallel lines and explain the rationale of construction steps. 8.1.7: Construct angles and angle bisectors, and explain the rationale of construction steps.	Students can construct straight lines, perpendicular lines, lines of symmetry, and the radius of a circle accurately to draw a *Gasing* court.	Process skills: • Science process skills. • Mathematical process skills. • Design skills. • Computational thinking skills. Technical skills: • Manipulative skills. • Skills in handling materials, tools and machines. • Data management skills

	Chapter 10.1: Perimeter	10.1.2: Estimate the perimeter of various shapes, and then evaluate the accuracy of estimation by comparing with the measured value.	Students can estimate and evaluate the accuracy of the approximate perimeter of a *Gasing* shape using different methods correctly.	Process skills: • Science process skills. • Mathematical process skills. • Design skills Technical skills: • Manipulative skills • Skills in handling materials, tools and machines. • Data management skills.
Baling Tin	Chapter 4.5: Relationship between ratios, rates and propositions with percentages, fractions and decimals.	4.5.1: Determine the relationship between percentages and ratios.	Students can correctly express percentage and ratio relationships based on can construction.	Process skills: • Science process skills. • Mathematical process skills. • Design skills. • Computational thinking skills. Technical skills: • Manipulative skills. • Skills in handling materials, tools and machines.

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