Systematic Literature Review: Use of Technology in Assessing Students' Scientific Skills

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ABSTRACT

This paper presents a systematic literature review (SLR) on the use of technology in the assessment of scientific skills among students in Malaysia. The integration of digital tools in education has transformed traditional assessment methods and provides innovative ways to assess students' psychomotor abilities and scientific skills. The study summarizes the findings of 21 selected articles identified through a rigorous screening process and categorizes the technologies into four main themes: digital engagement platforms, visual and interactive tools, blended and adaptive learning environments, and specialized assessment instruments. The findings highlight the positive impact of technology in promoting critical thinking, personalized learning and comprehensive skills assessment. These innovations allow for a more comprehensive evaluation of students' abilities, extending beyond rote memorization to include process-based learning and problem-solving skills. However, some limitations were also identified. The availability and accessibility of technology remains uneven, potentially widening the digital divide and leading to inequalities in educational assessment. Furthermore, while technology facilitates more dynamic assessments, the implementation of such tools requires robust teacher training and infrastructural support, which may not be uniformly available across educational contexts. This study highlights the importance of integrating technology into the assessment of scientific skills to improve educational outcomes. This requires focused efforts on teacher training, resource allocation, and continuous development of digital tools suited for diverse learning environments. Future research should focus on longitudinal studies to examine the long-term impact of these technology on student learning and explore adaptive strategies to ensure equitable access across various educational settings.

Keywords: scientific skills, technology, science process skills, manipulative skills, assessment

INTRODUCTION

Progress in science learning relies heavily on the development of two interrelated areas: conceptual understanding and procedural understanding (Gott & Duggan, 1995). Scientific skills, which includes science process skills and manipulative skills, is an important element in science education. Science process skills involve complex behaviours used by scientists in scientific investigations, enabling individuals to effectively acquire and disseminate knowledge to improve mental and psychomotor skills (Darmaji et al., 2022; Gunawan et al., 2019). Manipulative skills also refer to psychomotor skills that combine cognitive functions with corresponding physical movements (Kempa, 1986).

While many studies have been conducted on the teaching of scientific skills in schools, there is a lack of studies that scrutinise existing research through systematic literature reviews. Robinson & Lowe (2015) emphasise the importance of conducting systematic literature reviews to overcome weaknesses in regular literature reviews, such as the tendency to be incomplete, reviewer bias, and failure to consider changes in study quality from time to time.

Traditionally, scientific skills assessments have relied heavily on paper-based tests and expert assessments. Typical methods include multiple-choice questions, written examinations and practical laboratory examinations. Multiple-choice questions often assess recall of knowledge and basic understanding of scientific concepts, while written tests assess students' ability to state their understanding of scientific principles (Giner-Navarro et al., 2022). Laboratory practical tests observe students' hands-on skills in conducting experiments and using scientific methods. However, these traditional assessments often fail to assess high-level thinking skills, such as problem solving and critical thinking, instead focusing on the final product or correct answer (Reis Costa & Leoncio Netto, 2022). As a result, they may not capture the process of scientific inquiry, which is essential for a comprehensive understanding of scientific skills.

The integration of technology in assessment practice has changed the landscape of assessing scientific skills. Digital tools and platforms offer innovative ways to assess not only what students know but also how they use their knowledge in practice. For example, digital simulations and virtual labs allow students to engage in scientific inquiry in a controlled and interactive environment, allowing them to run experiments, manipulate variables and observe results without the constraints of physical lab resources (Mullis & Martin, 2017). Online assessments that use customised tests can provide personalised assessments that adjust for difficulty based on learner responses, offering a more precise measure of individual ability.

In addition, analysis of process data from digital assessments provides insight into students' problem-solving processes, revealing how they approach scientific inquiry tasks. This data can highlight areas of difficulty and inform teaching practice (Stadler et al., 2023). In addition, electronic portfolios allow students to collate and reflect on their work from term to term, showcasing the development of their scientific skills and understanding. Portfolios can include a variety of artefacts, such as term reports, project presentations and reflective journals, promoting self-assessment and deeper engagement with scientific concepts (Schwartz et al., 2023).

In conclusion, the assessment of scientific skills is evolving from traditional methods to more dynamic and technology-enhanced approaches. This trend is essential to properly measure students’ skills in a rapidly changing educational landscape. Understanding how these technologies can be effectively integrated into assessment practices is important for teachers who aim to nurture the next generation of scientifically literate individuals. Hence, this study aims to:

I. identify the latest technology used in assessing students' scientific skills.
II. identify the implications of the use of technology on the assessment of students' scientific skills.

METHODOLOGY

Literature Search Procedure

A rigorous systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to shortlist journal articles related to the use of technology in the assessment of students' scientific skills. Two databases namely SCOPUS and Web of Science (WoS) have been used in the screening of freelance journal articles to obtain quality articles and stable search results. The systematic literature highlighting procedure includes identification according to the selection criteria, screening, data collection and data analysis for the retrieved articles. A total of 21 articles were identified through established criteria such as year of publication, document type, language and field of study.

Article Search Keywords

The keywords used in the search for articles in the SCOPUS database are technolog* AND in AND assessing AND scientific AND skill* while in WoS it is technolog* in assessing scientific skill. Search techniques using truncations such as the * symbol provide variations of the base word in the search results. Search results using these keywords recoded 178 articles in the Scopus database and 5784 articles in the WoS database. The total number of articles recoded was 5962.

Criteria of Article

The selection criteria for articles accepted from Scopus and WoS databases have been defined as in Table 1. The reviewer has set criteria such as the year of publication, which is within 2020 to 2024, i.e. within the most recent five-year period. The selection of articles is presented in the most recent five years because in this period, the search topic is still hotly discussed and covers current issues. For articles published before 2020, they have been rejected. The only document types accepted are journal articles. Other documents such as

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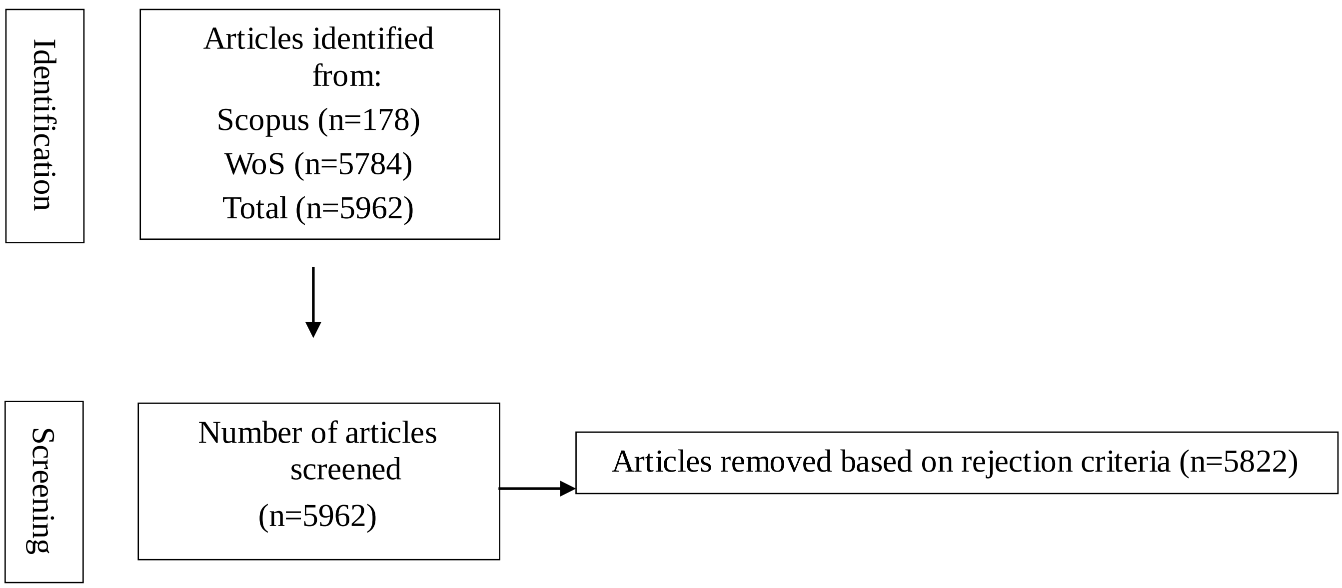
proceedings, theses, books and literature review articles are not accepted. Only journal articles were selected because journal articles are reference materials that have complete and detailed reporting. The language of the articles considered was only those published in English as most articles are published in this language. Articles published in other languages have been rejected. The field of study involved has also been presented to social sciences on Scopus. For WoS, the category along with Citation Topics Meso presented is Educational Research.

Table 1: Article selection criteria

General Criteria	**Acceptance Criteria**	**Rejection Criteria**
Year of publication	2020-2024	2019 and before
Document type	Journal article	Proceedings, theses, books, literature review articles
Language	English	Other languages
Field of study	**Scopus** Subject area: Social sciences	Other than social sciences
	WoS Categories: Education Educational Research Citation Topics Meso: Education Educational Research	Other than Education Educational Research

Article Selection Process

Figure 1 shows the flowchart of the PRISMA model used to search for articles related to the use of technology in the assessment of students' scientific skills. 5962 articles were searched at the start of the search and 21 articles were found for inclusion in the study after screening was carried out.



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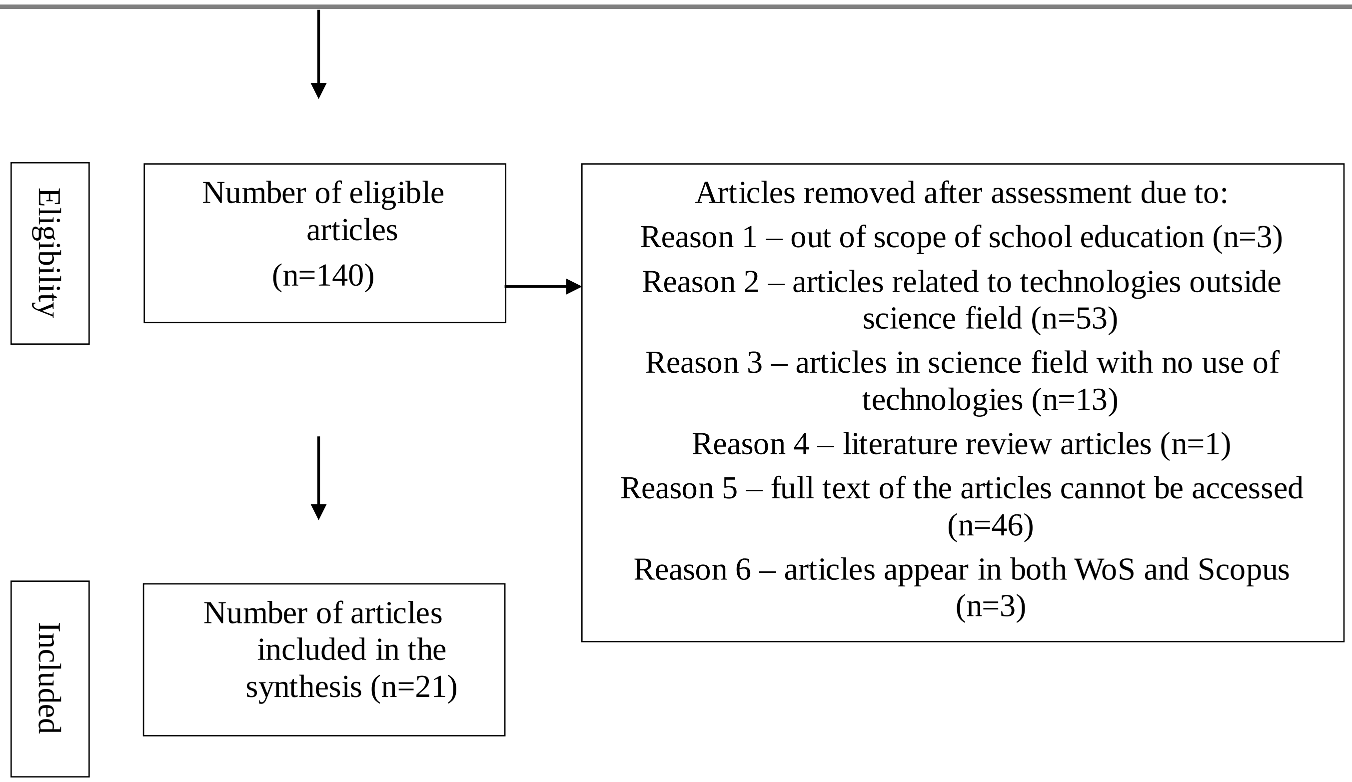

Figure 1: PRISMA model flow chart

Data Collection and Data Analysis

Data collection was carried out using 21 articles obtained from two leading databases, namely SCOPUS and WoS. Although the number of available bibliographic data sources and metrics has increased significantly over the last decade, the Web of Science (WoS) and Scopus databases remain the two most important and comprehensive sources of publication metadata and impact indicators. Therefore, they serve as main tools for a variety of tasks: from journal and literature selection or personal career tracking to large-scale bibliometric analyses and research evaluation practices at all possible levels (Pranckutė, 2021). In addition, both WoS and Scopus provide metadata about the document type and language of the texts they cover, and both are frequently used in meta-analyses (Martín-Martín et al., 2018).

Data was collected by extracting the title, author name, year, technology used in assessing scientific skills, procedures for using technology, implications of using technology and challenges or issues in using technology for each freelance review article into a table built using Microsoft Excel 365 software. Data analysis was carried out by using the built table and categorising the articles to answer the study questions. The results of the data analysis will be presented in the form of a table. Table 2 shows the list of 21 freelance research articles along with the author's name. All articles were selected based on the predetermined acceptance and rejection criteria.

Table 2: Articles based on established acceptance and rejection criteria

No	Author Name	Year	Article Title
1	Bell et al.	2024	vSEMERA: Pilot Project Assessing Health Profession Students' Experiences in an International Virtual Research Programme
2	Ingram et al.	2024	Improving Elementary Pre-Service Teachers' Science Teaching Self-Efficacy through Garden-Based Technology Integration

3	Roth & Bogner	2024	The Trade-Off Between STEM Knowledge Acquisition and Language Learning in Short-Term CLIL Implementations
4	Teig	2024	Uncovering Student Strategies for Solving Scientific Inquiry Tasks: Insights from Student Process Data in PISA
5	Wakefield et al.	2024	Filmmaking With Biology Undergraduates: Combining Digital Technology with Authentic Assessment to Develop Students' Skillset and Capabilities for Life After Graduation
6	Aktepe & Ulu	2023	A Case Study of Research Skills of Primary School Students
7	Casey et al.	2023	Motivating Youth to Learn STEM Through a Gender Inclusive Digital Forensic Science Programme
8	Coppi et al.	2023	Developing a Scientific Literacy Assessment Instrument for Portuguese 3rd Cycle Students
9	Kaldaras & Wieman	2023	Instructional Model for Teaching Blended Math-Science Sensemaking in Undergraduate Science, Technology, Engineering, And Math Courses Using Computer Simulations
10	Mora-López & Bernárdez-Vilaboa	2023	Exploratory Study on the Blended Learning of Research and Language Skills in EFL and Interinstitutional Assessment
11	Nagy & Korom	2023	Measuring Scientific Reasoning of Fourth Graders: Validation of The Science-K Inventory in Paper-Based and Computer-Based Testing Environments
12	Teo et al.	2023	Enhancing Critical Thinking in Operations Management Education: A Framework with Visual-Based Mapping for Interdisciplinary and Systems Thinking
13	Wu et al.	2023	Leveraging Computer Vision for Adaptive Learning in STEM Education: Effect of Engagement and Self-Efficacy
14	Giner-Navarro et al.	2022	Working on Critical Thinking skills using the computer lab works of an Engineering subject
15	Slim et al.	2022	Struggling or Succeeding in Science and Technology Education: Elementary School Students' Individual Differences During Inquiry- and Design-Based Learning
16	Werth et al.	2022	Assessing Student Engagement with Teamwork in an Online, Large-Enrollment Course-Based Undergraduate Research Experience in Physics
17	Bushmeleva et al.	2020	Peculiarities of Engineering Thinking Formation Using 3D Technology
18	Díez-Pascual & Díaz	2020	Audience Response Software as a Learning Tool in University Courses
19	Georgiou	2020	Characterising Communication of Scientific Concepts in Student-Generated Digital Products

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20	Prastiwi et al.	2020	Assessing Using Technology: Is Electronic Portfolio Effective to Assess the Scientific Literacy on Evolution Theory
21	Soboleva & Karavaev	2020	Characteristics of the Project-Based Teamwork in the Case of Developing a Smart Application in a Digital Educational Environment

STUDY FINDINGS

Articles on the Use of Emerging Technologies in Assessing Student Scientific Skills

As a result of data extraction and synthesis, the 21 articles on the use of current technology in assessing scientific skills have been classified into four categories based on the theme of technology brought. Based on Table 3.1, the four categories are:

a. Digital Technology for Student Engagement and Assessment
b. Visual and Interactive Technologies to Enhance Learning and Critical Thinking
c. Blended and Adaptive Learning Environments
d. Assessment Instruments and Tools

Table 3.1: Technologies Used in Assessing Scientific Skills

No	**Category**	**Technology Used in Assessing Scientific Skills**	**Researcher**
1	Digital Technology for Student Engagement and Assessment	Filmmaking with digital technology	Wakefield et al. (2024)
		Computer labour	Giner-Navarro et al. (2022)
		Digital products	Georgiou (2020)
		The digital education environment	Soboleva & Karavaev (2020)
		Audience response software	Díez-Pascual & Díaz (2020)
		Digital Forensic Science Programme	Casey et al. (2023)
		Online course-based research	Werth et al. (2022)
2	Visual and Interactive Technologies to Enhance Learning and Critical Thinking	Visual-based mapping	Teo et al. (2023)
		Process data in PISA	Teig (2024)
		3D Technology	Bushmeleva et al. (2020)
		Garden-based technology integration	Ingram et al. (2024)
		Short-term CLIL implementation	Roth & Bogner (2024)
		Computer simulation	Kaldaras & Wieman (2023)
		Condensed learning	Mora-López & Bernárdez-Vilaboa (2023)

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		Learning based on inquiry and design	Slim et al. (2022)
3	Blended and Adaptive Learning Environments	Cyber investigation programme	Bell et al. (2024)
		Computer vision for adaptive learning	Wu et al. (2023)
		Computer-based exams	Nagy & Korom (2023)
		Scientific literacy assessment instrument	Coppi et al. (2023)
4	Assessment Instruments and Tools	Investigation Skills Assessment	Aktepe & Ulu (2023)
		Electronic portfolio	Prastiwi et al. (2020)

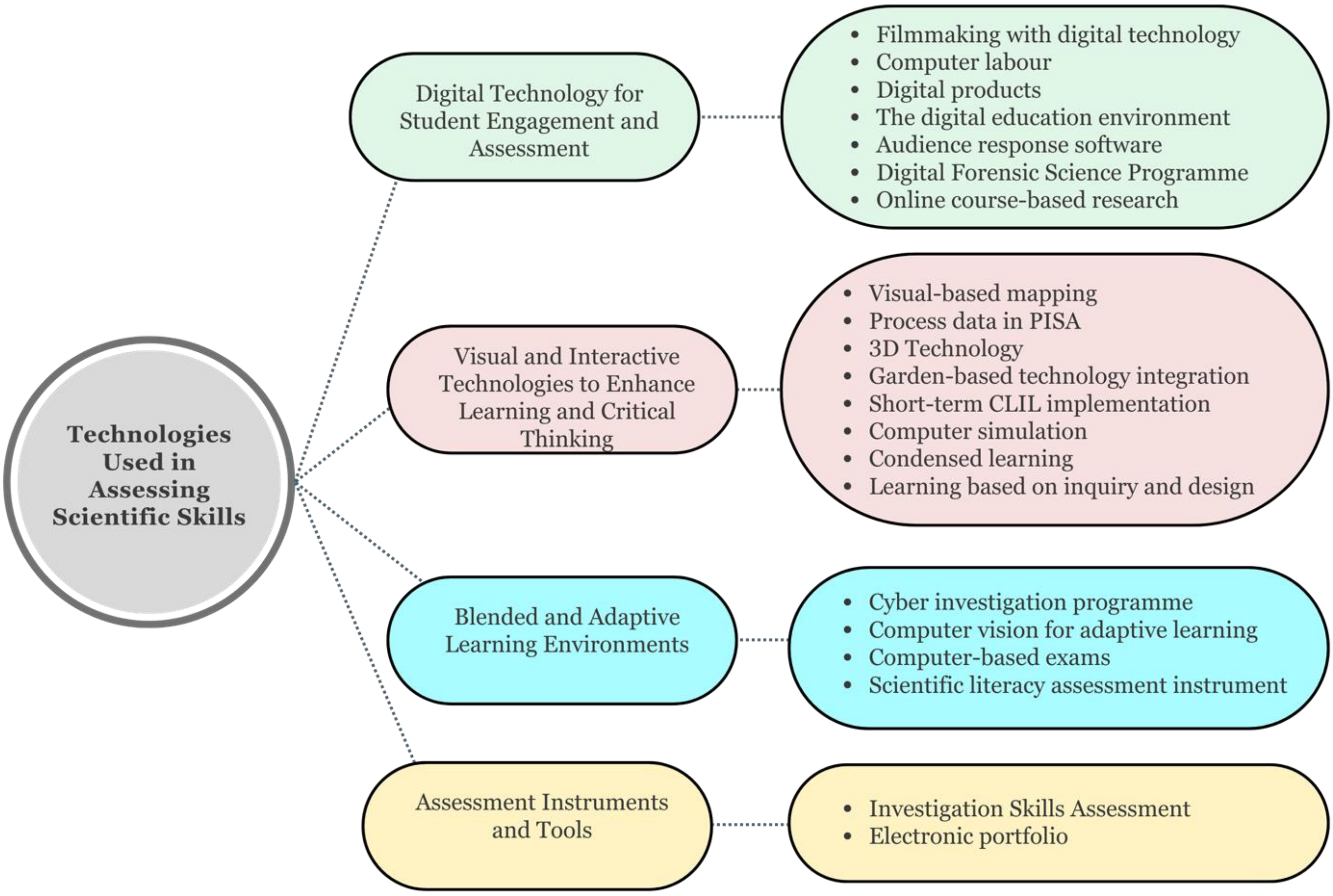

Figure 2: Technologies Used in Assessing Scientific Skills

Articles on the Implications of Technology Use on the Assessment of Students' Scientific Skills

The articles found relating to the implications of using technology on the assessment of students' scientific skills are included in Table 3.2. The implications found are classified into six types:

a. improving critical thinking and skills
b. increasing engagement and motivation
c. providing a comprehensive assessment
d. developing practical skills for real-world applications
e. supporting personalised and adaptive learning
f. handling technical challenges and sources

Table 3.2: Implications of Technology Use on the Assessment of Students' Scientific Skills

No	Type of implication	Explanation
1	Improving Critical Thinking and Skills	Enhance creative thinking and practical skill and prepare for real-world applications (Wakefield et al., 2024)
		Improve critical thinking and technical skills (Giner-Navarro et al., 2022)
		Promote critical thinking and interdisciplinary learning (Teo et al., 2023)
		Support personalised learning and recognise individual differences in learning (Slim et al. ,2022)
		Provide insight into problem-solving strategies and inform teaching practice (Teig, 2024)
2	Increasing Engagement and Motivation	Increase engagement and self-efficacy in STEM education (Wu et al., 2023)
		Motivate youth in STEM and promote inclusivity (Casey et al., 2023)
		Activate the learner and provide immediate feedback (Díez-Pascual & Díaz, 2020)
		Provide global enquiry experiences and foster international co-operation (Bell et al., 2024)
		Activate students in enquiry and is applicable to large classes (Werth et al., 2022)
3	Providing a Comprehensive Assessment	Provide a comprehensive assessment of scientific literacy (Prastiwi et al., 2020)
		Improve both research and language skills through inter-institutional assessment (Mora-López & Bernárdez-Vilaboa, 2023)
		Provide a reliable measure of scientific judgement (Nagy & Korom, 2023)
		Provide a standardised measure of scientific literacy (Coppi et al., 2023)
4	Developing Practical Skills for Real-World Applications	Improve spatial thinking and engineering skills (Bushmeleva et al., 2020)
		Foster teamwork and app development skills (Soboleva & Karavaev, 2020)
		Improve communication of scientific concepts; promote digital literacy (Georgiou, 2020)
		Improve understanding of complex concepts through simulation

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		(Kaldaras & Wieman, 2023)
5	Supporting Personalised and Adaptive Learning	Increase engagement and self-efficacy through adaptive learning systems (Wu et al., 2023)
		Provide insight into problem-solving strategies and inform teaching practice (Teig, 2024)
		Support personalised learning and recognise individual differences in learning (Slim et al., 2022)
		Improve both research and language skills through inter-institutional assessment (Mora-López & Bernárdez-Vilaboa, 2023)
6	Handling Technical Challenges and Sources	Access to park resources and variation in learner engagement (Ingram et al., 2024). Technical issues and variations in students' knowledge of software (Giner-Navarro et al., 2022). Require access to technology in which may not be suitable for all learning styles (Kaldaras & Wieman, 2023). Technical challenges and sourcing requirements (Bushmeleva et al., 2020). Harmonisation challenges and technical difficulties (Soboleva & Karavaev, 2020). Technical issues with software and different levels of learner engagement (Díez-Pascual & Díaz, 2020). Technical issues and time zone differences (Bell et al., 2024).

DISCUSSION

Development of the Use of Technology in Assessing Students' Scientific Skills

The assessment of scientific skills has been significantly enhanced through the integration of various technologies, which has transformed traditional assessment methods to a more dynamic and interactive experience. These technologies not only facilitate knowledge assessment but also provide insights into learner cognitive processes, problem-solving strategies and collaborative skills. This talk explores some of the key technologies used in assessing scientific skills, including digital simulations, online assessment, electronic portfolios and data analysis.

Digital simulations and virtual labs have emerged as powerful tools for assessing scientific skills. These platforms allow students to engage in realistic scientific experiments in a controlled environment, where they can manipulate variables, observe results and draw conclusions without the constraints of physical laboratory settings (Mullis & Martin, 2017). For example, platforms such as Labster provide immersive simulations that cover a range of scientific disciplines, allowing students to practise their inquiry skills and apply theoretical knowledge in practical scenarios. Research has shown that students who engage with digital simulations demonstrate a better understanding of scientific concepts and improved problem-solving skills (Schwartz et al., 2023). Additionally, these simulations can assess not only the final decision of the experiment but also the process used by the learner to reach that decision, offering a more comprehensive assessment of their scientific skills.

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Online assessment has also revolutionised the way scientific skills is assessed. Adaptive testing technology, which ranks question difficulty based on learner responses, provides a personalised assessment experience that can reflect individual abilities more precisely. This approach allows teachers to identify specific areas of strength and weakness in students' scientific understanding and thus facilitate targeted teaching. In addition, online assessment can incorporate multimedia elements, such as videos and interactive graphics, which can capture students' interest and provide a richer context for assessing their scientific judgement and critical thinking skills (Reis Costa & Leoncio Netto, 2022). The use of technology in assessment also allows for immediate feedback, allowing students to reflect on their performance and make the necessary alignments in real time.

Electronic portfolios represent another innovative technology for assessing scientific skills. This digital collection of student work allows the documentation of learning progress from term to term and can showcase different types of student work such as laboratory reports, project presentations and reflective essays (Giner-Navarro et al., 2022). Electronic portfolios also encourage students to engage in self-assessment and reflection, fostering a deeper understanding of their learning process and scientific skills. In addition, portfolios provide teachers with a holistic view of learner development and allow teachers to more deeply improve the quality of teaching. Research suggests that the use of electronic portfolios can improve students' metacognitive skills and promote a sense of ownership over their learning (Schwartz et al., 2023).

Data analytics is another critical technology that has transformed the assessment of scientific skills. Analysis of process data from digital assessments can reveal patterns in learner behaviour, such as frequency of specific actions, response times and accuracy of answers (Stadler et al., 2023). This data is particularly valuable for understanding how students approach scientific inquiry tasks and identifying misconceptions or difficulties that learners commonly encounter. By utilising data analysis, teachers can adapt their teaching strategies to better meet the needs of their various learners, ultimately improving learning outcomes.

In summary, the integration of technology into the assessment of scientific skills has opened up new avenues for assessment that go beyond traditional methods by introducing diverse tools that allow for more comprehensive, interactive, and process-oriented assessments. These tools, which include digital simulations, online assessments, electronic portfolios and data analytics, could improve the assessment process overall by providing a more comprehensive and nuanced view of student learning. For example, digital simulations and online assessments can track a student's every action, such as how long they take to complete a task, what strategies they use and what mistakes they make, providing insight into their thinking patterns and not just their final answers. Given that educational practices are constantly evolving, it is important for teachers to embrace these technologies by integrating digital tools into their teaching and assessment practices to foster the development of scientific skills in the next generation of students. Professional development programs can equip teachers with the knowledge and skills to use digital platforms, simulations, and data analytics in assessments.

Implications of the Use of Technology on the Assessment of Students' Scientific Skills

The integration of technology in education assessment has changed the landscape of teaching and learning, particularly in the field of science education. Given that teachers are increasingly using digital tools and platforms, the implications of the use of technology on scientific skills are becoming clear. This section explores the various implications of using technology in assessing scientific skills, focusing on enhanced engagement, personalised learning, the development of critical thinking and problem-solving skills, and the enhancement of collaborative learning.

One of the most notable implications of using technology in assessment is increased learner engagement. Digital tools, such as electronic portfolios and multimedia presentations, allow learners to showcase their understanding in creative and interactive ways. For example, Prastiwi et al. (2020) highlighted the efficacy of electronic portfolios in assessing scientific literacy, stating that it provides a holistic view of learner progress and fosters reflective practice. By engaging learners in authentic assessments that require them to use their knowledge in real-world contexts, teachers can foster a deeper interest in inquiry and scientific learning. This

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engagement is important, as it not only motivates learners but also encourages them to take charge of their learning process.

In addition, technology facilitates personalised learning experiences and allows teachers to customise assessments to meet various learner needs. With the use of data analytics and adaptive learning platforms, teachers can gain insight into learner performance and individual learning styles. This allows for targeted interventions that address specific areas of difficulty, ultimately leading to better learning outcomes (Giner-Navarro et al., 2022). For example, a study by Teig (2024) showed how processing data from digital assessments can shed light on the best teaching practices and help teachers identify students' strengths and weaknesses in scientific research. By utilising technology, teachers can create a more inclusive and supportive learning environment that promotes scientific literacy for all learners.

In addition to increasing engagement and personalisation, the use of technology in assessment fosters the development of critical thinking and problem-solving skills. Digital tools encourage students to engage in higher order thinking by requiring them to analyse, assess and synthesise information. For example, Wakefield et al. (2024) suggest filmmaking as a learning method can enhance students' critical thinking skills by allowing them to construct narratives that reflect their understanding of scientific concepts. This is in line with the study by Teo et al. (2023) which advocates an interdisciplinary approach that promotes systematic thinking. By integrating technology into assessment, teachers can challenge students to think critically and creatively, preparing them for the complexities of the modern scientific landscape.

Additionally, the collaborative nature of most digital assessment tools can promote teamwork and communication skills among students. A study by Werth et al. (2022) that assessed student engagement with teamwork based on online courses found that collaborative online platforms can increase student engagement and foster community spirit. This collaborative approach not only reflects real-world scientific practices but also equips students with essential skills for future careers in science and technology. The ability to work effectively in teams is increasingly recognised as a critical skill of the 21st century, making the integration of collaborative technologies in assessment particularly valuable.

Moreover, the use of technology in assessment can provide immediate feedback to students, which is essential for learning and improvement. Digital platforms can facilitate real-time assessment and feedback, thereby allowing learners to understand their performance and areas for growth immediately. This immediacy can enhance the learning experience by allowing learners to adjust (Bushmeleva, 2020). The ability to receive and act on feedback information quickly is important in scientific education, where iterative processes and continuous improvement are fundamental to the scientific approach.

In conclusion, the implications of using technology in assessing scientific skills are widespread. By increasing learner engagement, facilitating personalised learning, promoting critical thinking and collaboration, and providing immediate feedback, technology serves as a powerful tool for teachers looking to improve scientific literacy. Given that educational practices are constantly evolving, it is important for teachers to embrace these technological advances to create meaningful and memorable assessment experiences that prepare students to succeed in an increasingly complex world.

Best Technology in the Malaysian Education Context

Among the various technologies used in assessing scientific skills, electronic portfolios stand out as one of the most effective tools. An electronic portfolio, or e-portfolio, is a digital collection of student work that showcases their learning progress, achievements and reflections over time. This technology not only facilitates the assessment of scientific skills but also promotes deeper learning and critical thinking. Among the advantages of e-portfolios in assessing scientific skills is that they allow for the assessment of multiple dimensions of student learning which allows teachers to assess not only the end product but also the learning process, including the ability of students to carry out scientific inquiry, analyse data, and make inferences (Prastiwi et al., 2020). In addition, e-portfolios offer continuous learning and reflection where students can document their learning journey, reflect on their experiences and set goals for improvement.

Furthermore, e-portfolios empower learners to take charge of their learning. By collating their work, learners become active participants in the assessment process, which can increase their motivation and engagement. This ownership is particularly important in scientific education, where curiosity and intrinsic motivation drive exploration and discovery (Werth et al. 2022). Electronic portfolios also provide a platform for feedback from peers and teachers. This collaborative aspect fosters a learning community where students can share views, critique each other's work and learn from multiple perspectives.

While electronic portfolios offer many benefits, there are challenges to consider. The digital divide can limit access for some students, which can lead to unequal assessment opportunities. Not all students have equal access to computers, tablets, or reliable internet connections, which can limit their ability to participate in assignments that require the use of electronic portfolios. Prastiwi et al. (2020) reported that 76% of students were categorized at beginner level in creating electronic portfolios, with content less supported by artifacts and different media formats. Only 10% of students reached the proficient level, meaning their portfolios contained diverse media formats and were managed attractively, while 0% of students were categorized as advanced. Furthermore, the impact of access to technology goes beyond mere availability, it also includes the quality of resources. Students may not have access to the same software or platform for creating and managing electronic portfolios, which can affect the quality and presentation of their work. This disparity in resource availability can lead to an uneven playing field as some students are better equipped to present their learning experiences than others.

Additionally, teachers must be trained to effectively implement and assess e-portfolios, ensuring that they are utilised to their full potential. Many teachers may not have experience with the specific platforms used for electronic portfolios, which may prevent them from effectively guiding their students in the use of these tools (Prastiwi et al., 2020). Without proper training, teachers may find it difficult to integrate electronic portfolios into their teaching practice, resulting in inconsistent implementation and reduced effectiveness. This lack of familiarity can also lead to teachers feeling overwhelmed, especially when they have to learn new technologies alongside their existing teaching responsibilities. The subjective nature of portfolio assessments can lead to inconsistencies in grading and evaluation, making it difficult for teachers to provide fair and objective feedback. Without clearly defined criteria, it can be difficult for teachers to effectively assess student work, which undermines the purpose of using electronic portfolios as a tool to measure learning outcomes. This lack of clarity can also lead to confusion among students who are unclear about what is expected of their portfolios. Therefore, clear guidelines and rubrics are important to ensure consistency and fairness in assessment.

In summary, electronic portfolios represent a powerful technology for assessing scientific skills. They provide a comprehensive, reflective and engaging method of assessment that is aligned with the goals of science education. By fostering ownership, collaboration and the development of technological skills, e-portfolios not only assess student learning but also enhance the educational experience and prepare students for future challenges in scientific investigations and beyond.

IMPLICATIONS

Given that the use of technology in education is constantly evolving, understanding its impact on assessment practices and student learning outcomes is important for improving the quality of science education. One important area for future research is the need for longitudinal studies that measure the impact of the use of technology in assessment on students' scientific skills from time to time. Such studies can provide valuable insights into how these technologies affect learning trajectories, development of critical thinking and problem-solving skills in scientific contexts (Teig 2024). By examining the long-term effects of technology on student learning, researchers can better understand the sustainability of these assessment methods and their effectiveness in fostering deep learning.

In addition, comparative studies across different scientific disciplines are natural. Studies investigating the efficacy of various technology assessment tools in different contexts could be undertaken as this could help identify the best practices and customise assessments for specific subject areas (Giner-Navarro et al., 2022). Understanding the performance of different technologies in various scientific fields will increase their relevance and effectiveness, ultimately benefiting the learner's learning experience.

Another critical area for research is the efficacy of technology-based assessments among diverse student populations. Future studies should focus on how these assessments can be customised to meet the needs of students from different cultural, linguistic and socioeconomic backgrounds. Investigating the impact of technology on equity in science education is important to ensure all students have access to high-quality assessment practices (Giner-Navarro et al., 2022). This focus on diversity will help teachers create inclusive learning environments that support the success of all learners. In addition, future studies examining the integration of artificial intelligence (AI) and data analytics into educational assessment could also be undertaken. Given the proliferation of these technologies, studies should explore how AI can be used to provide personalised feedback and customised assessments that respond to student needs and individual learning styles (Teig, 2024). Understanding the potential of AI in improving assessment practices can lead to more effective and customised educational experiences for learners.

Studies can also be conducted to explore the impact of the use of technology in assessment on teacher practice and the professional development needed to support this change. Understanding the challenges and successes faced by teachers when integrating technology into assessment strategies can help in shaping effective training programmes (Giner-Navarro et al., 2022). By equipping teachers with the necessary skills and knowledge, educational institutions can foster more effective implementation of technology in assessment. Finally, given that technology is playing a more important role in education, reviewers should focus on ethics and data privacy as it relates to the use of digital assessment tools. Understanding how to protect student data while utilising technology for assessment purposes is important to maintain trust and integrity in educational practices (Teig, 2024). Future research should explore best practices to ensure data privacy and ethical considerations in the use of technology in assessment.

The integration of technology in the assessment of academic skills not only affects pedagogical practice, but also has significant theoretical implications for the field of education. Traditional theories of assessment that focus primarily on summative assessments and content knowledge are being challenged by the shift toward more dynamic, process-oriented, and formative assessment methods facilitated by technology. As technology enables more personalized, adaptive, and inquiry-based learning experiences, the theoretical frameworks that underlie the assessment of education must evolve to accommodate these changes. For example, the theory of cognitive load is becoming increasingly relevant in the context of digital assessments. Cognitive load theory suggests that instructional materials must be designed in such a way that students are not overwhelmed with too much information at once (Sweller, 1988). The inclusion of complex simulations, multimedia and interactive elements in digital assessments can either support or hinder learning, depending on how they are designed (Paas & Van Merriënboer, 1994). Future research should explore how the rich, immersive nature of digital assessments can be balanced with the need to minimize cognitive overload to ensure that these tools remain effective and accessible in different learning contexts.

CONCLUSION

The integration of technology into scientific skills assessment has revolutionised educational practice, offering innovative ways to assess student learning and engagement. Given that teachers are increasingly using digital tools, the implications of this technology extend beyond mere assessment where it is able to reshape pedagogical approaches, enhance student learning experiences, and foster the development of critical skills necessary for success in the 21st century. The use of technology in assessment provides many advantages, including the ability to collect and analyse data efficiently, facilitate personalised learning experiences, and promote learner engagement.

Despite these benefits, the implementation of technology in assessing scientific skills presents some challenges that teachers must navigate. One important issue is the digital divide which can further exacerbate existing inequalities in education. Students from less privileged backgrounds may lack access to the necessary technology and resources, hindering their ability to fully participate in technology-based assessment. This disparity raises concerns about equity and fairness in assessment practices, as not all students have equal opportunities to demonstrate their scientific skills. Data interpretation also poses challenges in technology-based assessment. While digital tools can generate extensive data on student performance, teachers may

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struggle to analyse and use this information effectively. The complexity of interpreting assessment data requires teachers to have data literacy skills and requires additional training and support.

In conclusion, the use of technology in assessing scientific skills offers transformative potential for education, enhancing the student learning experience and providing valuable insights into student progress. However, challenges relating to skills, interpersonal interactions, data interpretation and academic integrity must be addressed to ensure technology-based assessment is thorough and effective. Continued professional development and support will be essential in harnessing the full potential of technology to assess scientific skills and nurture a generation of students who can compete globally.

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