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Applying TPACK in STEM Education towards 21-st Century: Systematic Literature Review

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Abstract

To encourage students to think creatively and critically, applying Technological Pedagogical Content Knowledge (TPACK) in STEM Education (Science, Technology, Engineering, and Mathematics) is very suitable to be adapted in the teaching method or pedagogy of Science teachers. This study aims to analyze technological approaches in pedagogy based on the TPACK model that is most often used based on past studies. The next objective is to analyse the teaching and learning (T&L) approaches that utilize technology in Science education. This systematic literature review focused on empirical studies published from 2018 to 2023 using SCOPUS and Google Scholar databases. This study based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) involves four phases, namely identification, screening, eligibility and included examination. The Scopus database is used to filter 19 final articles between 2018 and 2023 according to the criteria set. The study implies strategies for enhancing the use of technology among STEM teachers, grounded in the TPACK Model.

Keywords: Integration TPACK, Implementation of TPACK, Digital Learning, STEM, Pedagogy, Teaching Method.

Introduction

The Malaysian Education Development Plan 2013 – 2025 places the need for 21st-century learning (21^{st}-CL) as a form of transformation in the country's education system. 21st-CL is one of the crucial aspects for addressing the shift towards effective teaching and learning (T&L). The existing level of education, namely an education system that is flexible, creative, challenging and more complex, becomes optimal when a transformation is created in the form of 21st-CL education (Kamal et al., 2022; Majid & Majid, 2022). This statement is supported by Idriki et al (2022), who explain that in supporting education in a world of globalization, any changes in planning need to be agile. Various changes have occurred in the country's education system, especially in curriculum, assessment and management of education by the teaching and learning (T&L) of 21st-century learning (Daud & Mahamod, 2021).

The 21st-century skills, often referred to as 21-CLS, are student-centred learning processes focused on communication, collaboration, critical thinking, creativity, and ethical values. These skills, encapsulating the essence of 21-CL, aim to equip students not only with knowledge but also with the abilities needed to thrive in the globalized era. Initially, the

Ministry of Education Malaysia (MOE) adopted the Partnership for 21-st Century Skills (P21-CLS) framework, but in 2010, they followed the National Education Association's (NEA) advice from the United States, narrowing the focus to four essential skills: communication, creativity, collaboration, and critical thinking. These four skills, representing the core of 21-CLS, were considered sufficient to encompass all other skills outlined in the 21st-century learning framework (Sahak, 2022).

In producing quality students, the quality aspect of teachers is also one of the important issues in 21-CL skills. Teachers play a significant role in ensuring students acquire the knowledge and skills necessary to succeed in an increasingly competitive world. The effectiveness of teachers in providing teaching is also a factor that affects the effectiveness of student learning. Therefore, it is crucial to improve the quality of teachers in order to ensure that students get quality education. Teacher emphasis on the level of mastery of each 21-CLS skill can change students' learning styles from conservative to more effective learning styles (Daud & Mahamod, 2021).

The Technological Pedagogical Knowledge Learning Framework (TPACK) is one of the learning models that supports the development of 21-CL skills among students. TPACK is a new learning model for teachers that combines aspects of technology, pedagogical knowledge, and content (Drajati et al., 2018). This framework is very effective in 21-CLS because it uses technology in the learning process. Therefore, integrating the TPACK learning model in Science Education (STEM) becomes a solution for teachers to improve the quality of learning. TPACK can improve students' critical thinking skills (Sheffield et al., 2015). In addition, the TPACK model can also combine Science, Technology, Engineering, and Mathematics (STEM).

TPACK stands for Technological Pedagogical Content Knowledge. TPACK is the knowledge of how important the incorporation of pedagogy and technology is in the development of content in an educational environment. TPACK consists of 3 components, namely technology, pedagogy and knowledge content.

The Technological Pedagogical Content Knowledge Framework (TPACK) describes the type of knowledge required by teachers for the successful integration of technology in teaching. It shows that teachers need to know about the intersection of technology, pedagogy, and content. Specifically, it means how these fields of knowledge interact and influence each other in unique and specific contexts. (Djulia et al., 2022).

These three components should not be separated from each other. The presence of technology is expected to enable collaboration with teacher pedagogy methods to produce effective learning content for students. These three components align with the concept of education emphasized in the 21-CLS, where teachers are required to be proficient in applying technology in learning.

The results of TPACK-related studies can be used as a reference in the effort to adjust teachers' pedagogy and professional competencies (Masrifah et al., 2018). TPACK is an integral part of 21-CL achievement and learning achievement, achieved by students in multiple domains and cannot be separated from the learning process (Juhji, 2020).

Mishra and Koehler's (2006) formulation of TPACK (technological knowledge, pedagogy, and content) expands the definition of teacher knowledge put forward by Shulman (1986) and explicitly which considers the role of knowledge about technology in effective teaching. TPACK integrates all three components and recognizes the importance of teachers' understanding of using technology in learning contexts.

1. Pedagogical Knowledge (PK)

PK includes knowledge teachers must master in the teaching process, such as teaching methods, classroom management, learning planning, and student assessment. It is also known as pedagogical knowledge.

2. Content Knowledge (CK)

If PK is related to the series of processes that the teacher needs to master in teaching, then CK deals with the content material that the teacher needs to master in teaching.
Mastery of content by teachers will affect students' understanding of the content taught. Therefore, teachers need to understand the position of CK in teaching.

3. Technology Knowledge (TK)

TK refers to knowledge about the importance of integrating technology in teaching. Technology can be used in communication processes, processing student data, and supporting teacher productivity. In the era of a pandemic like the one that happened recently, technology has become an important factor that needs to be mastered by all parties, including teachers and students.

Within the TPACK framework, four components explain how the three types of knowledge (technology, pedagogy, and content) interact, limit, and provide opportunities to each other. That is, knowledge of technology, pedagogy, and content influence each other in the context of teaching. These four components form a complex relationship between teachers' knowledge of technology, pedagogy, and content.

1. Content Pedagogy Knowledge (PCK)

PCK focuses more on the teaching process the teacher will choose in the teaching content. PCK includes selecting teaching methods, learning planning, and teaching support facilities.

2. Content Technology Knowledge (TCK)

TCK refers to knowledge of the influence of technology in one discipline. TCK described the extent of the influence of technology on the development of a scientific discipline.

3. Knowledge of Technology Pedagogy (TPK)

TPK encompasses knowledge of the relationship between technology and the teaching process. Through TPK, teachers can understand the advantages and disadvantages of technology in teaching for assessment purposes.

4. Knowledge of Content Technology Pedagogy (TPACK)

TPACK refers to integrating the three components, namely technology, pedagogy, and teaching content. In this era of technology, teachers need to be proficient in integrating all three. Various learning platforms (e-learning) have emerged, including LMS (Learning Management System).

STEM is a learning approach that combines knowledge, technology, engineering, and mathematics in solving problems (Hacioğlu & Gülhan, 2021). Research by Lestari et al., (2018) shows that STEM approaches can improve students' critical thinking skills. In addition, STEM approaches can also improve student learning achievement (Wijayanto et al., 2020). Technology-based learning trains students to improve critical, creative, cooperative, and communication thinking skills (Pahrudin et al., 2021). Therefore, using learning models integrated with STEM is a solution to improving 21st-century student skills (Santosa et al., 2021).

Although 21-CL has been implemented for more than five years, the findings of past studies show that there are still issues and challenges in teachers' skills to apply. Some of the teacher quality issues in 21-CL teaching include lack of adaptation in the application of information technology, communication or digital technology, lack of good resources and access tools, teacher-centred teaching causing lack of implementation of the 4C concept (communication, collaborative, creative and criticize) and lack of teacher mastery in applying high-level thinking skills (HOTS).

Based on a study conducted by Ismail and Maat (2017), teacher-teaching practices that are too conventional in teaching cause students' thinking not to develop. Therefore, 21-CL is very suitable to be practised during the learning process. According to Rusdin and Ali (2019), integrating technology offers opportunities for students to master 21st-century skills such as collaboration, information, and self-access learning.

One of the ways in which researchers try to better understand how teachers can better use technology in the classroom is by focusing on the types of approaches teachers use technology more effectively. Digital technology and networking are becoming more widely available, which has the potential to dramatically change how we teach and learn. Teachers can ensure that technology integration adds value by using teaching strategies that stimulate students to engage with high-level cognitive skills and varying learning (Josua et al., 2022). Therefore, the authors aimed to analyze teaching approaches that integrate the TPACK Model, focusing on technology commonly utilized in pedagogical practices (PdPc), as evidenced by previous studies.

Research Questions of The Study

1. What is the technological approach in pedagogy based on the Model of TPACK that is most often used based on past studies?
2. What are the teaching and learning (T&L) approaches that utilize technology in Science education?

Methodology

Review Procedure

In carrying out this systematic literature spotlight (SLR), PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagrams are used to determine the selection of articles based on the stated study questions. According to McInnes et al (2018), PRISMA is a guide that can help make assessments of validity and usability and produce a more accurate and helpful literature highlight. There are several phases in selecting related articles, namely the identification, screening, eligibility, and article inclusion phases in this study. Therefore, in this study, several steps are carried out to determine the search systematically: identification, screening, eligibility, quality appraisal, data extraction and analyses.

Systematic Search Strategy

Identification Phase

The first phase is the identification phase used in systematic literature highlighting that refers to the PRISMA guidelines. The search starts by searching for keywords. The author has used websites such as thesaurus.com to get synonymous meanings based on the studies they want to carry out. Not only that, the author also gets keywords from the Scopus database keywords.

As a result of the search, several terms are used by the author to find keywords such as implementation of TPACK, TPACK, digital education, science teacher, STEM teacher, Biology, Chemistry and Physics and teaching approach and pedagogy. To combine identified terms, authors use search functions such as field code functions, phrase search, freecards, and even Boolean cuts and operators to get more focused articles. (refer to Table 1).

Table 1
To obtain articles in this study, the authors used a database from Scopus to search for articles in the identification phase; a total of 108 articles from Scopus were obtained.

Database	Keywords
Scopus	TITLE-ABS-KEY ((integration* OR implementation*) AND (tpack) AND (science OR stem OR steam OR biology OR physics OR chemistry) AND (TEACHING APPROACH OR TEACHING METHOD OR TEACHING OR TEACH OR PEDAGOGY))

Screening
The following study is the screening phase. The purpose of this phase is to select articles according to established standards. The year of publication, type of document, language and subject are the four criteria set by the author for this screening process. Table 2 contains the criteria used to determine whether this article should be included or excluded from the study. The author only selects articles published from 2018 to 2023 as the year of publication. Articles written before 2017 have been excluded. The second criterion is the type of document. The author only selects articles consisting of empirical data. The author has made exceptions such as reviewed articles, chapters in books, books and systematic literature highlights. In addition, for the third criterion, the author has chosen articles written in English. The author's choice of subjects are science, chemistry, biology, physics, or STEM education.

Table 2
Shows the criteria, eligibility and exceptions made by the reviewers in this study.

Criterion	Credentials/Eligibility	Exception
Year of Publication	2018 - 2023	2017 and before
Types of documents	Articles (empirical data))	Reviewed articles, chapters in books, books, systematic literature highlights and others
Language	English	Languages other than English

Subject	Social science-related subjects	Medicine, Engineering, Health Sciences and other than Social Science subjects

Table 2

Eligibility

For the qualification phase, only 50 articles are fully accessible. The authors have made a quality assessment by re-reading the article title, the abstract of the study, as the content that meets the study conducted. Based on the quality assessments carried out, only 19 articles met the specified criteria. (Refer to Figure 1 below).

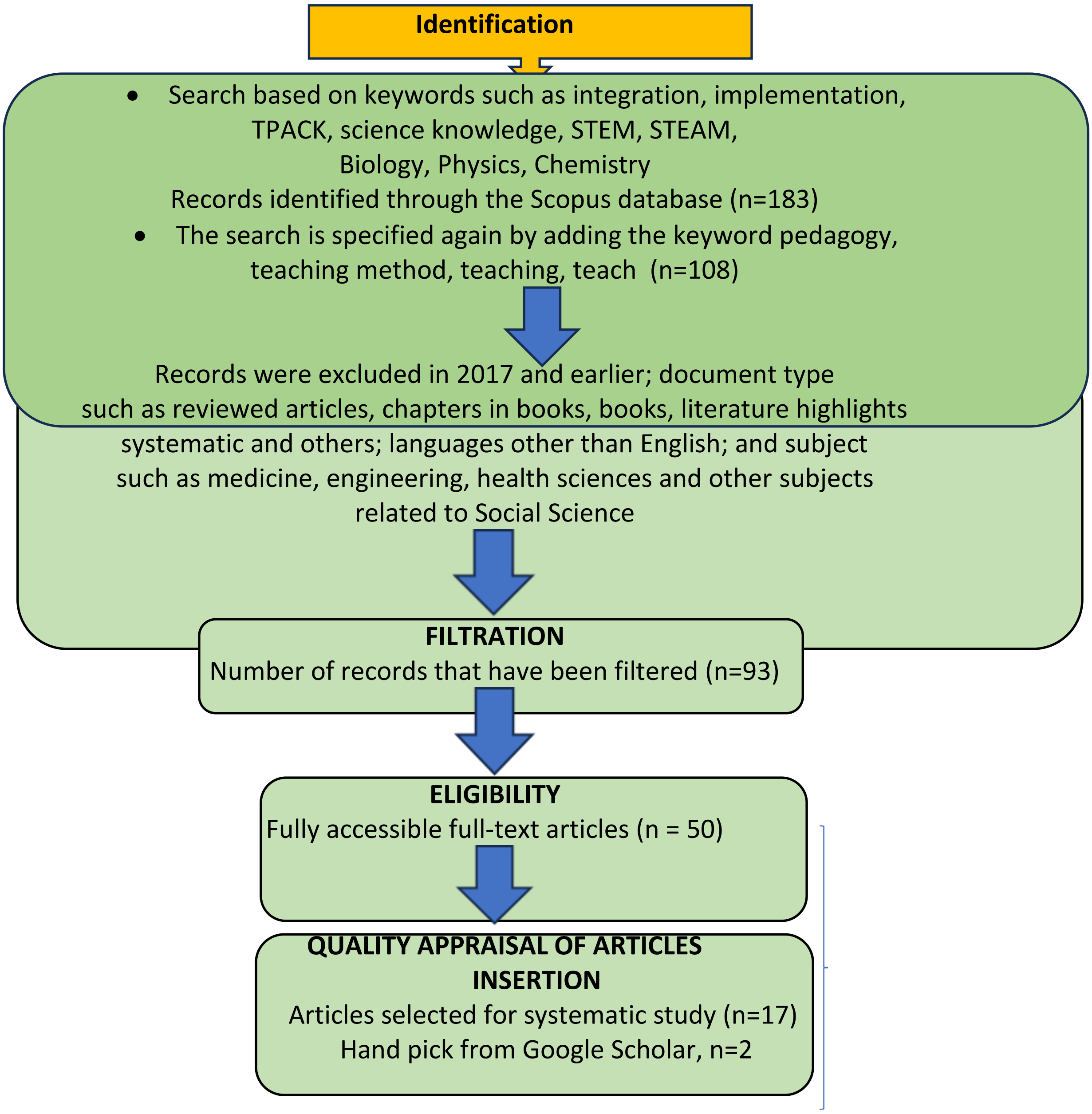

Figure 1: Overview of PRISMA flow

Quality Appraisal

Quality assessment is focused on ensuring that the methodology and analysis of the selected article meet satisfactory criteria. The Mixed-Method Appraisal Tool (MMAT) provided by Hong et al (2018) was used at the quality evaluation stage. MMAT provides a systematic framework to help researchers assess the quality of studies and the advantages and disadvantages of the studies they review.

The MMAT table focuses on several study methods, namely qualitative, clustered randomized control tests (quantitative randomized controlled trials), non-randomized quantitative tests (quantitative non-randomized), quantitative descriptive (quantitative descriptive) and mixed methods (mixed-method).

There are screening questions that the authors need to state before making a quality assessment or appraisal of each research method. Once the screening questions are answered, and the criteria are met, the author can begin to evaluate the study method and analyze the article data. To ensure that the selected articles meet the criteria, MMAT has provided the necessary guidance on each research method by referring to Hong et al. (2018) (See Table 4).

Each article made a quality assessment; the author has received a referral from an expert to survey to avoid bias in the selection of the article.

Table 4
Hong et. al (2018) resource

CATEGORY OF STUDY DESIGN	METHODOLOGICAL QUALITY CRITERIA
Qualitative	• Is a qualitative approach suitable for answering the question of the study? (QA1) • Are qualitative data collection methods sufficient to solve the question of the study? (QA2) • Are the resulting conclusions sufficient from the data? (QA3) • Is the interpretation of the results sufficiently supported by the data? (QA4) • Is there coherence between qualitative data sources, collection, analysis and interpretation?? (QA5)
Quantitative randomized controlled trials	• Is randomization appropriately performed? (QA1) • Are the groups comparable to the baseline? (QA2) • Is there complete results data? (QA3) • Are outcome checkers obscured of the interventions given? (QA4) • Do participants comply with the intervention given? (QA5)

Quantitative non-randomized	• Are participants representatives of the target population? (QA1) • Do measurements match outcomes and interventions (or exposure)? (QA2) • Is the result data complete? (QA3) • Are nuisance factors taken into account in the design and analysis? (QA4) • During the study period, was the intervention implemented (or did the exposure occur) as required? (QA5)
Quantitative descriptive	• Are sampling strategies relevant to answer research questions? (QA1) • Does the sample represent the target population? (QA2) • Is the measurement appropriate? (QA3) • Is the risk of bias not answering low? (QA4) • Is statistical analysis appropriate to answer research questions? (QA5)
Mixed-method	• Is there sufficient justification for using mixed-method design to answer the study question? (QA1) • Whether the different components of the study were effectively integrated to answer the question of the study? (QA2) • Are the results from the integration of qualitative and quantitative components adequately interpreted? (QA3) • Are the differences and inconsistencies between quantitative and qualitative outcomes adequately addressed? (QA4) • Whether the different components of the study comply with the quality criteria of each of the traditions involved? (QA5)

Article Study Design Analysis

A summary of the designs used in the research of 19 articles is shown in Table 5. From the studies conducted, six articles used quantitative methods, six articles used qualitative methods, and seven articles used mixed methods. For future research, it is recommended that researchers use qualitative methods as researchers will be able to gather information by focusing on exploring insights, meanings, experiences, and deep attitudes by using methods such as interviews, observations, text analysis, and case studies collected, studied, and interpreted.

Study Design Findings

Table 5

Design for 19 articles reviewed

STUDY	DESIGN STUDY	QA1	QA2	QA3	QA4	QA5	FULFILLING BILLS CRITERIA	INSERTED ARTICLES
Arpaci et al., (2023)	Quantitative	√	√	√	X	√	4/5	√
Villamin et al., (2022)	Mixed-method	√	√	√	√	√	5/5	√
Kier & Johnson (2022)	Qualitative	√	√	√	√	√	5/5	√
Yapici & Karakoyun (2021)	Qualitative	√	√	√	√	√	5/5	√
Kim & Kwon (2023)	Mixed-method	√	√	√	√	√	5/5	√
Ekawati & Prastyo (2022)	Mixed-method	√	√	√	√	√	5/5	√
Nilsson P. (2022)	Mixed-method	√	√	√	√	√	5/5	√
Bakri et al., (2021)	Qualitative	√	√	√	√	√	5/5	√
Bakri et al., (2019)	Qualitative	√	X	√	X	√	5/3	√
Ilmi et al., (2020)	Quantitative	X	√	X	√	X	5/2	√
Paristiowati et al., (2019)	Quantitative Not Random	√	√	√	√	√	5/5	√
Nurdiani et al., (2019)	Qualitative	X	X	√	X	√	5/5	√
Dorfman et al., (2019)	Quantitative Descriptive	√	√	√	√	√	5/5	√
Fan et al., (2018)	Mixed-method	√	√	√	√	√	5/5	√
Agustin et al., (2018)	Mixed-method	√	X	√	X	√	5/3	√
Tanjung et al., (2022)	Quantitative	√	√	√	X	X	5/5	√
Walan (2020)	Random Quantitative	√	√	√	√	√	5/5	√
Mallik et al., (2018)	Qualitatitive	√	√	√	√	√	5/5	√

Tombak & Ateşkan (2019)	Mixed-method	√	√	√	√	√	5/5	√

Results and Discussion of Studies

The highlight of this Systematic Literature is that it aims to identify technological approaches in TPACK based pedagogy under the TPK construct used by teachers. In addition, the objective of this study is also to analyse the teaching and learning (T&L) approaches that utilize technology in Science education as a guide and reference for STEM teachers. The results of the research from the article, there are 19 articles that meet almost all the criteria that have been set based on MMAT. In the TPACK based technological approach, the main focus is to produce active student teacher learning and teaching that meets the characteristics of 21st-century learning.

According to the Ministry of Education Malaysia (2013), the STEM teaching approach is based on multi-mode teaching integrating face-to-face teaching with technology-assisted teaching. In addition, through this STEM teaching approach, the knowledge and skills aspects of a subject are also emphasized in detail through inquiry-based teaching, project-based teaching and problem-based teaching in real-world contexts (Ministry of Education Malaysia, 2017b). In addition, according to Aziz & Andin (2018), to obtain interactive processes between students in enhancing their ability to analyze and generate new ideas, cooperative teaching is also used in this STEM approach. Therefore, the results of the analysis from this study found that in the process of PdPc, there are several technologies that can be used to help pupils improve their understanding of Science (STEM) subjects.

Table 6
Theme of 19 articles

RESEARCH	RESEARCH DESIGN	COUNTRY	THEME								
			GBT	R	ML	AR	AI	IWB	PVA	PJBL	PBL
Arpaci et al., (2023)	Quantitative	Turkey	√								
Villamin et al., (2022)	Mixed-method	Philipines			√						
Kier & Johnson (2022)	Qualitative	USA								√	
Yapıcı & Karakoyun (2021)	Qualitative	Turkey				√					
Kim & Kwon (2023)	Mixed-method	Korea					√				
Ekawati & Prastyo (2022)	Mixed-method	Indonesia								√	
Nilsson P. (2022)	Mixed Method	Sweden				√					
Bakri et al., (2021)	Qualitative	Indonesia				√					

Bakri et al., (2019)	Qualitative	Indonesia			√			
Ilmi et al., (2020)	Quantitative	Indonesia			√			
Paristiowati et al., (2019)	Quantitative-Not random	Indonesia		√				
Nurdiani et al., (2019)	Qualitative	Indonesia		√				
Dorfman et al., (2019)	Descriptive Quantitative	Australia					√	
Fan et al., (2018)	Mixed-method	Brunei					√	
Agustin et al., (2018)	Mixed-method	Indonesia		√				
Tanjung et al., (2022)	Quantitative	Indonesia						√
Walan (2020)	Random Quantitative	Sweden				√		
Mallik et al., (2018)	Qualitative	USA	√					
Anatürk Tombak & Ateşkan (2019)	Mixed-method	Turkey				√		

Note: GBT: Game-Based Technology, R; Robotic, ML: Mobile Learning, AR: Augmented Reality, AI: Artificial Intelligence, IWB: Interactive White Board, VA: Editing Video and Animation Editing Technology, PJBL: Project Based Learning, PBL: Problem Based Learning

1. What is the technological approach in pedagogy based on the TPACK Model that is most often used based on past studies?

Teaching Using Technology
Game Technology

Based on Table 6 above, in the study of Arpaci et al (2023), the development and implementation of educational games based on Arduino have been used to teach the topic of Genetics (Biology) to high school students. The results showed that the game had a positive impact on the effectiveness of students' understanding of the topic of Biological genetics.

In other words, this study has shown that the use of Arduino-based educational games in genetic teaching can be an effective tool to increase student engagement and understanding in science. It also emphasizes changes in teaching materials and the need to adapt new technologies in education.

Robotic-Based Learning

A study by Mallik et al (2018) states that the robotic-assisted Technology, Pedagogy, and Content Knowledge (TPACK) framework can improve the effectiveness of STEM teaching and learning. This study shows that skills and knowledge in the TPACK domain are critical for teachers in effectively integrating robotic technology into their teaching. It includes a deep understanding of how technology can enrich content and pedagogical strategies in STEM learning.

In addition, the study also highlights the need for more focused teacher teaching in the TPACK domain, especially in the context of teaching that uses robotics. By training teachers specifically in aspects of TPACK, they will be better prepared to face various levels of difficulty in teaching and be able to improve students' learning outcomes. In conclusion, this study affirms that the development and improvement of TPACK skills for teachers is an essential factor in ensuring the success of robotic-assisted STEM learning.

Mobile Learning

The mobile learning approach in the teaching of secondary school Biology involves the use of a developed mobile learning modular application (MoLMA) that can be accessed through mobile devices to deliver learning materials and activities to students. Studies have found that mobile learning promotes a ubiquitous and personalized learning experience (according to students' suitability), increases students' interest and motivation, as well as provides cost and time efficiency in teaching Biology subjects compared to printed modules (Villamin et al., 2022).

"Mobile learning" refers to the use of mobile technologies, such as smartphones, tablets, or other mobile devices, in the context of learning and education. It involves the use of applications, software, and digital learning resources accessible through mobile devices to deliver learning materials, interactions, and learning activities to students. "Mobile learning" allows access to learning materials anywhere and at any time, allowing learning to be mobile and tailored to individual (personal) needs. It also leverages the capabilities of mobile devices such as cameras, microphones, and network setups to enrich the learning experience.

The study conducted by Nurdiani et al (2019) highlighted two main points, namely "IM" and "LMS Moodle". IM refers to "Instant Messaging" or an online instant messaging service that allows students and teachers to communicate directly through digital platforms. Famous examples of IM include WhatsApp, Telegram, and other instant messaging platforms. The results of this study are in line with previous research showing the potential of IM and LMS Moodle in improving students' learning outcomes in a variety of subjects, including Biology (Kurniawan et al., 2019; Al-Fraihat et al., 2020). It is seen as a technological aid in Biology education.

LMS Moodle refers to a "Learning Management System", which is an online learning platform that helps teachers manage and deliver learning materials to students. Moodle is one of the popular LMS and is often used in educational institutions.

In this study, both IM and LMS Moodle were used to enrich students' learning experiences in the subject of Biological Embryology. IM allows for direct interaction between students and teachers, while LMS Moodle provides a platform to access and share learning materials online. Using IM and LMS Moodle, students can interact with teachers and classmates for additional support, ask questions, and share information. Additionally, students can also access learning materials, assignments, and tests through LMS Moodle.

The Paristiowati et al (2019) study showed that Chemistry teachers can use different learning methods each session according to the characteristics of acid-base substances. Teachers also use information and communication technology-based learning media (ICT) to moderate and explain the delivery of materials. It can be concluded that teachers know pedagogical content (PCK) and knowledge of technological content (TCK). The use of ICT media such as interactive power presentations, video, and mobile phones to support the chosen learning method shows that teachers are also competent in technological pedagogical knowledge (TPK). The results of the study concluded that the teachers had integrated all the components of TPACK into acid-base learning so that they fell into the action category (Action/An Level) at the TPACK competency level (Paristiowati et. al., 2019).

In a study conducted by Agustin et al (2018), digital technologies such as Google Classroom software, digital study materials, and other online resources have been used to assist science teachers in integrating digital technology into science teaching.

Use of Reality/AR Media Technology

The use of augmented reality media technology, AR (Augmented Reality), additionally developed in physics textbooks, can improve the experience and engagement of students' learning in the process of learning Physics for mechanical wave topics. The implementation of TPACK in high school physics textbook products is suitable for improving 4C skills in preparation for 21st -century learning skills (Bakri et al., 2019).

The implementation of TPACK in physics textbooks is effective in training the problem-solving skills of high-level students. Developed physics textbooks integrate technological knowledge, pedagogical knowledge, and knowledge of the content of physics in various forms of representation, as well as providing students with a comprehensive learning experience. In addition to AR in textbooks, the study of kinematic practical modules equipped with AR technology developed using the TPACK approach is also effective in developing high-level thinking skills (HOTS) among Physics students (Bakri et al., 2021).

Future studies can focus on the effectiveness of physics textbooks developed to improve students' problem-solving skills and the integration of TPACK in other subjects. They also suggest that future studies explore the use of augmented reality media in other subjects and its effectiveness in improving the learning experience of students.

The author's justification for taking the study of this article is to show that STEM teachers in primary and secondary schools can add or diversify the pedagogical way of teaching in schools in terms of the use of technologies such as reality media technology in PdPc. If seen, in the subjects of Form 2 Science and Form 4 Biology, there are already technological mechanisms based on reality media technology but less expanded and used. It is supported by Ilmi et al (2020) who state that the technology used as a specially designed TPACK-based learning material can improve HOTS and scientific attitudes among students. Nelson (2022), in her study, also highlighted the importance of digital technology integration in science teaching and the need for student teachers to build a knowledge base in the use of digital technology in teacher teaching.

In this study by Yapici and Karakoyun (2021), it was found that prospective biology teachers have a mostly positive view of the use of AR in the teaching of biology. These teachers see many advantages of AR activities, including subject concretion, information retention, exciting and fun departures, repetition capabilities, and multimedia support.

Subject concrete refers to the use of AR technology to help students understand the subject more clearly and easily. Information retention refers to the ability of AR technology to store information that has been displayed in visual form. Exciting and fun departure refers to the use of AR technology to make learning more exciting and enjoyable. Repetition ability refers to the ability of AR technology to allow students to repeat learning more easily.

Multimedia support refers to the use of AR technology to support learning with multimedia elements such as video and audio.

Nevertheless, there are also some disadvantages that are observed, such as the need for an internet connection, the need to keep the phone stable, the boredom of students from time to time, high costs, and incompatibility with each subject. Prospective teachers propose to expand AR activities in schools, ensure equality in accessing technological tools, use these activities in various subjects, and develop a wide range of applications.

AI Applications

In South Korea, primary school teachers are least confident in content knowledge, followed by technological knowledge and pedagogical knowledge related to artificial intelligence (AI) (Kim & Kwon, 2023). Five themes pertaining to AI education: (1) emphasizing the importance of teaching design in AI education; (2) readjusting the learning environment to enhance the learning experience; (3) reducing teaching concerns by acknowledging the weakness of content knowledge; (4) expanding AI education based on Computer Science (CS) principles; and (5) acquire literacy in code, data, AI technology, and ethical issues. Based on these findings, 22 AI competencies for primary school teachers have been generated and categorized based on the TPACK Framework.

Interactive White Board (IWB)

The Anatürk Tombak and Ateşkan (2019) 's study stated the use of Interactive Whiteboards (IWB) showed that Biology and Chemistry teachers use IWB more often in showing visual, video, and animation materials than Physics teachers. It may be due to differences in the curriculum and teaching methods applied in the subjects. These teachers report that the use of IWB can improve the effectiveness of their teaching and help improve students' understanding of complex scientific concepts.

However, this study in Turkey also shows that most teachers still face challenges in using IWB (Tombak & Ateşkan, 2019). They need help in integrating this technology into their day-to-day teaching, mainly due to inadequate in-service training. Teachers feel less confident and uncomfortable with the use of this technology in the classroom.

A study by Walan (2020) in Sweden found that teachers showed competence in using digital technology (TK) and had no problems operating laptops, projectors, or interactive white boards (IWBs) in science learning.

Nevertheless, some students need help in using technology, and some students need printed text because they have difficulties reading digital texts. Teachers use a variety of teaching strategies even when based on the use of digital technology (DT). Teaching consists of short presentations using various digital tools, digitally-based individual work by students, group discussions and practical investigations. During the observation session, all students are active in working on various tasks related to the learning of science. In individual work, students are able to carry out tasks at various levels of difficulty because digital learning materials provide different training. Tasks in teaching materials are sometimes presented in the form of games, which give students points and the opportunity to challenge themselves at a higher level (TPACK). Students are motivated to find information about Science issues related to in-game challenges and visit other websites to get this information. Despite this, some students face difficulties in moving between sites.

Video vs Animation Editing Technology

In the study by Dorfman et al., (2019), it was found that teachers showed improvements in their video editing skills and knowledge of the effective use of this technology in biochemistry lessons. Differences in the ability of the two media to convey information. The video has an advantage in conveying information in a way that is easier for the viewer to understand because it has audio and visual elements that can help the viewer better understand the information (Fauziyah et al., 2020). In addition, videos also have an advantage in conveying emotions and moods better than animation (Mardiansyah et al., 2023).

Nevertheless, animation has the advantage of presenting complex and abstract information better because it can more clearly describe elusive concepts. Animation also has an advantage in creating a more creative picture and attracting the attention of the audience (Mardiansyah et al., 2023).

Fan et al (2018) emphasized the need for teachers to gain access to high-quality digital videos and animations that are scientifically accurate and pedagogically relevant. Second, the importance of giving teachers the opportunity to tailor digital video based on their pedagogical experience and the teacher's classroom needs, as well as the importance of teacher knowledge technology (TPACK) in the effective implementation of digital video in the classroom. In other words, this video technology can be used effectively in the teaching and learning process

What are the teaching and learning (T&L) approaches that utilize technology in Science education?

Project-Based Learning Model

The Project-Based Learning Model using digital technology has also been found to enhance TPACK's capabilities among students of physics education programs during the pandemic era (Ekawati & Prastyo (2022). Data collected through observations, interviews, and questionnaires show that students are capable of integrating physics learning with appropriate technologies but need more confidence in inferring assessment results because such learning is not applied in actual classes. Students are able to use learning technologies well and master the content of learning but are less proficient in demonstrating pedagogical capabilities. This conclusion underscores the importance of developing online learning strategies that use technology and the need for teachers to be more creative in leveraging distance learning.

This study suggests that future studies should focus on the development of project-based learning strategies that provide more stimulation to improve pedagogical capabilities.

Kier and Johnson (2022) argue that digital technology needs to be used to teach science, technology, and engineering (STEM) to students. Examples of technologies used include the use of digital tools such as robotics and water transport systems, as well as the use of collaborative tools in learning.

This collaborative approach gives learners the opportunity to demonstrate their learning by creating products, such as robotic hands, water transport systems, or songs. This approach also reinforces understanding of the importance of mentorship or collaborative relationships in STEM fields, inspiring many students to pursue future STEM opportunities.

Project Based Learning (PBL)

The Problem-Based Learning (PBL) Model with a Technological, Pedagogical, and Content Knowledge (TPACK) approach is an effective method to improve the Science learning achievement of secondary school students (Tanjung et al., 2022). The PBL Model with the TPACK approach was found to be more effective than the Discovery Learning Model in increasing student engagement and understanding. Therefore, it is recommended that educators take into account the use of the PBL Model with the TPACK approach in their teaching practices to improve student learning achievement.

From the SLR that was carried out, the authors found that the most frequently studied technological approaches six years back were related to the approach of Reality Media/AR technology (5 articles) and "Mobile Learning' (4 articles). Based on a search in Google Trending, the authors also found that the 'Artificial Intelligence' technology is no less impressive even than the article findings of only one article.

Augmented Reality Media (AR) has shown great potential in helping to enrich the learning experience. In the four articles studied, it was explained that AR technology has been widely used in various fields, including education and health. Through the use of AR applications, students can access additional information and interact directly with 3D objects, simulation models, and virtual environments that improve their understanding. This approach promotes deeper understanding, creativity, and student engagement in the STEM learning process.

Mobile Learning has also been the main focus of the four articles studied. In an increasingly digital society, the use of mobile devices such as smartphones and tablets has become prevalent. Mobile Learning leverages the capabilities of this mobile device to provide learning access to individuals anywhere and at any time. This approach provides advantages such as mobile learning, location-based learning, easy access to online learning materials, as well as the use of interactive educational applications and games. Mobile Learning helps develop digital skills and knowledge, increases accessibility to education, and promotes lifelong learning.

Conclusion

The findings of the above studies show that the technological approach in teacher pedagogy based on the TPACK Model is very important and effective in improving students' high-level thinking skills and scientific attitudes, thus cultivating PAK21. The development of learning materials that combine the technology and pedagogical knowledge of the teacher can help teachers and students in promoting active learning.

Therefore, the authors suggest that teachers be trained in using technological tools while being provided with relevant content knowledge and TPACK. Depending on existing knowledge of pedagogical content, teachers can develop their TPACK and TPACK beliefs.

With appropriate training and support, teachers can acquire the necessary skills and understanding to use technology in an effective way in the process of teaching and learning. This will help increase student engagement, foster high-level thinking skills (HOTS), and promote positive scientific attitudes.

Overall, technological approaches based on the TPACK Framework in teaching and learning play an important role in preparing students for an increasingly digital future. Teachers need to continue to develop their TPACK through practice and experience, while integrating technology with relevant pedagogical and content knowledge. Thus, teachers will be able to create engaging and meaningful learning experiences for students, as well as help them reach their full potential in facing the challenges of an increasingly technologically advanced world.

This research offers significant theoretical and contextual contributions to the field of technology integration in science education through the TPACK framework. It provides empirical evidence on effective technological approaches within science pedagogy, for enhancing student engagement and understanding. The study underscores the importance of aligning technological tools with pedagogical strategies and content knowledge, advancing our understanding of their interaction in fostering an environment conducive to 21st-century learning skills. Contextually, it offers practical insights for educators and policymakers in designing and implementing engaging, relevant, and effective science teaching and learning experiences. This research not only enriches the academic discourse on technology integration in education but also serves as a catalyst for educational transformation, highlighting the need for holistic teacher education encompassing technological, pedagogical, and content knowledge.

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