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Trend Technological Pedagogical and Content Knowledge to Improve Biology Teacher Competency in the 21st Century: A Review

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Abstract: Biology teachers may use technology to improve learning outcomes and design engaging learning experiences for students in the digital age by becoming proficient and competent in TPACK. Previous researchers have used TPACK to improve teacher competency, namely found that fusing technology, pedagogy, and topic knowledge, significantly improves teacher proficiency. Studies have indicated that teachers gain from TPACK training, which raises their competency levels. TPACK raises teachers' competencies in teaching and learning processes by requiring them to possess a thorough understanding of technology operations, pedagogical skills, and topic knowledge The research aims to explore and highlight several research publications that examine TPACK to improve Biology teacher competency in the 21st century. A systematic literature review method was used to select relevant articles for review, with a total of 25 articles selected based on specific criteria for the literature review stage. The research results highlight the importance of integrating TPACK to improve biology teacher competency. This integration aims to equip educators with the skills necessary to effectively apply technology in biology teaching in the 21st century. The conclusion drawn is that TPACK can improve the competence of biology teachers in the 21st century to design interesting learning experiences for students.

Keywords: Teacher competency; Technology learning; TPACK; 21st-century skill

Introduction

Modern education is greatly aided by technology, which is changing traditional teaching techniques and enhancing the learning experience for students. Innovative media, hardware, and software are all included in educational technology, supporting learning (Joshi, 2023). Blended education, which combines online and face-to-face teaching to provide flexibility and accessibility to students, results from the growth of virtual interactive lectures and scientific platforms (Abbas Abbood et al., 2023). Science, art, and society have all been greatly transformed by technology, which has also made education more effective and efficient while simplifying complex procedures (Ilyas et al., 2023). Educational institutions can build interactive and engaging learning environments that improve the skills of teachers and students by integrating tools such as computers, the Internet, and audio-visual media (Boulakhsaim, 2022). Thanks to the introduction of online learning platforms such as Zoom and Google Meet, technology has brought about a dramatic transformation of traditional teaching methods (Karmakar & Chatterjee, 2022). The trend toward using technology to facilitate student-centered learning has gained prominence, highlighting the significance of pedagogical ideas unique to the use of technology in the classroom (Menrisal, 2023).

Instead of using traditional classroom setups, educational institutions are quickly implementing

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augmented, virtual, and mixed reality to engage students and improve the teaching process (Mithun R & Roopadarshini S, 2024). With an emphasis on enhancing the caliber of teaching and learning processes through contemporary technological applications, the integration of information and communication technologies (ICT) in education has become essential (Magalingam, 2022). To integrate TPACK is essential (Lestari & Rahayu, 2023; Bueno et al., 2023; Adipat et al., 2023; Haniefa & Samsudin, 2023). To improve instruction and equip educators to use information and communication technology (ICT) in the classroom, teacher preparation and support TPACK is crucial. Teachers must partake in professional development initiatives to acquire cutting-edge methods for information delivery, assessment, and documentation. This will guarantee that their TPACK skills continue to advance throughout their careers. With the use of TPACK, teachers may create learning experiences that integrate technology, pedagogy, and subject-matter expertise, which will ultimately result in more engaging and dynamic teaching methods. Biology teachers may use technology to improve learning outcomes and design engaging learning experiences for students in the digital age by becoming proficient and competent in TPACK.

Previous researchers have used TPACK to improve teacher competency, namely (Adnan & Yunisari, 2023) found that fusing technology, pedagogy, and topic knowledge, significantly improves teacher proficiency. Studies have indicated that teachers gain from TPACK training, which raises their competency levels. TPACK raises teachers' competencies in teaching and learning processes by requiring them to possess a thorough understanding of technology operations, pedagogical skills, and topic knowledge (Adji et al., 2022). According to studies, teachers tend to be more skilled in particular TPACK domains than others. For example, some teachers are more adept at pedagogy, while others are more skilled at using technology (Iskandar, 2022). Similar findings by Ortiz Colón et al. (2023) noted that teachers can improve their overall teaching quality and competency levels by incorporating TPACK into their lessons, developing digital learning materials, and making good use of a variety of resources. Furthermore, TPACK-focused customized training programs can strengthen in-service teachers' teaching competencies and remediate their weaknesses (Nithitakkharanon et al., 2023).

Based on previous findings, it seems that there has been no research that reviews and highlights TPACK to improve Biology teacher competency in the 21st century. The research aims to explore and highlight several research publications that examine TPACK to improve Biology teacher competency in the 21st century. This research answers the research questions, namely: What is the role of technology in modern education? How has technology transformed traditional teaching methods?; How does TPACK in the field of Education?; How does TPACK improve teacher competency in the 21st century?

Method

Procedure

The SLR method is used to identify, analyze, evaluate, explore, and interpret the papers obtained by the research questions. Search and harvest articles using the Publish or Perish application. We obtained articles from Google Scholar, Web of Science, and Scopus. The search for potential articles was carried out using the PRISMA diagram which consists of 3 stages, namely identification, screening, and inclusion. We searched the literature using the keywords technology learning, TPACK, teacher competency, and 21st-century skills. The time range for publishing articles is between 2017 and 2023 to produce the latest findings (Figure 1). Figure 1 shows that the number of papers published from 2017 to 2023 is 47, 58, 76, 82, 72, 85, 98. In 2023, we observed an increase in the number of papers with the CPATK theme. This means that the CPATK theme has potential for further research.



Figure 1. The number of papers published from 2017 to 2023

Analysis

The results of the search and harvest of papers from the Google Scholar, Scopus, and Web of Science databases obtained 518 papers. Selection of potential papers using the PRISMA flow diagram.

At the identification stage, we noted 39 papers as duplicates, marked 83 articles as ineligible, and removed 47 articles for other reasons, leaving 353 papers that successfully passed the identification stage. We excluded 280 papers during the screening stage, retrieved 191 articles, and rejected another 166 reports for various reasons. During the inclusion stage, we selected a total of 25 potential articles for the literature review stage. Next, selected articles that met the

Inclusion criteria	Exclusion criteria
The research aims to improve Biology teacher competency in	The research aims is not to improve Biology teacher
the 21 st century	competency in the 21st century
Research discussing technology learning, TPACK, teacher	Research discussing technology learning, TPACK, teacher
competency, 21st-century skill	competency, 21st-century skill
	is not the main themes
The research subject studied is Biology teacher competency in	The research subject studied things other than Biology teacher
the 21 st century	competency in the 21st century
Research uses quantitative methods such as descriptive surveys,	The research did not use quantitative methods such as
experiments, or both.	descriptive surveys, experiments, or a mix of both.
Research published by international and national publishers on	Research published by international or national publishers
either one of three databases, Web of Science, Scopus, and	outside the inclusion criteria
Google Scholar, with a Digital Object Identifier (DOI) or an ISSN	
Year of publication between 2017 and 2023	Year of publication outside the range between 2017 and 2023

Research written in English or Indonesian



Figure 2. Selecting potential articles using the PRISMA flow diagram

Data Synthesis

Data synthesis was carried out on the RQ that had been designed at the beginning of the research, resulting in 25 potential papers being prepared (Figure 3). In Figure 3 the number of papers in RQ1, RQ2, RQ3, and RQ4 are 5, 7, 6, and 7. RQ1 examines the role of technology in modern education. RQ2 examines how technology transformed traditional teaching methods. RQ3 examines TPACK in the field of Education. RQ4 examines how TPACK improves teacher competency in the 21st century. This study chose a narrative synthesis approach that systematically synthesizes all findings included studies, without across conducting This research identified quantitative meta-analysis.

inclusion and exclusion criteria based on title, abstract, and full text (Table 1).

023 Research written in languages other than English and Indonesian

articles based on first author, year of publication, highlights, result, and conclusion.



Figure 3. Number of papers based on RQ

Result and Discussion

Biology teachers in the 21st century can improve their overall teaching quality, provide engaging learning environments, and make effective use of digital resources by including TPACK in their activities. The SLR on Technological Pedagogical and Content Knowledge to Improve Biology Teacher Competency in the 21st Century has been successfully analyzed to find the latest findings (Tables 2, 3, 4, and 5).

RQ1: What is the role of technology in modern education?

With the ability to provide students with individualized educational experiences based on their unique needs and talents, technology has had a huge impact on personalized learning. This highlights the necessity of ongoing improvements in educational technology to facilitate unique learning experiences (Table 2).

Based on Table 2 research has indicated that in lowand middle-income nations, technology-assisted individualized learning improves learning results, particularly when the technology adjusts to the learner's level (Major et al., 2021). Furthermore, it has been demonstrated that using adaptive testing technologies to provide individualized recommendations might enhance learning outcomes by giving students challenging material that maximizes their potential (Dai et al., 2023). For students to gain the knowledge and technical skills required for success in postsecondary education and the workforce, technology integration with personalized learning is essential. This emphasizes the significance of fundamental changes in education systems and the use of technology to improve student competencies. The trend of personalized learning has been furthered by the development of big data, artificial intelligence, learning analysis, and information technology.

Table 2. The Role of Technology in Modern Education

Author	Insights	Result	Conclusion
(Ganesan Velavutham	In the modern educational setting,	Students can now collaborate	Education has been
et al., 2022)	technology improves the quality of	and communicate in ways that	transformed by technology.
	instruction, allows for interactive	were previously unthinkable	Student cooperation and
	learning, fosters teamwork, and	because of technology. Even	communication have increased.
	gives access to a wealth of	other state kids following the	
	information sources, converting	same adventure can benefit	
	conventional teaching methods into	from what they learn in the	
	more effective and efficient	schools.	
	procedures.		
(Osman, 2022)	In today's classroom, technology	It has been discovered that	The use of technology in the
	encourages kids to learn English,	integrating technology into the	classroom encourages students
	improves their academic	classroom helps to extend	to study English.
	performance, and stimulates their	educational opportunities and	Using technology in the
	creativity. It facilitates efficient	successfully involve students in	classroom fosters greater
	learning, enhancing the course and	the learning process.	creativity in teaching
	results of education.	01	
(Kostashchuk &	Through improving teaching	To achieve the desired	Utilizing contemporary
Bilenkova, 2022)	strategies, encouraging student	outcomes, educational	instructional technology in the
	participation, and establishing a	technology is a conceptual,	classroom is essential
	supportive learning environment	methodical description of the	The part elementary school
	for autonomous decision-making	actions taken by instructors and	teachers play in putting new
	and active participation, technology	students. It is also a means of	procedures into practice
	plays a critical role in modern	streamlining and enhancing the	
	education.	learning process.	
(Ghory & Ghafory,	Technology is essential to modern	The importance of technology	The educational process is now
2021)	education because it improves	in the classroom cannot be	more enjoyable because of the
	instruction, makes it easier for	emphasized enough. In fact, the	incorporation of technology.
	students to access internet	use of computers in the	
	resources, streamlines knowledge	classroom has made it easier for	
	transfer, and makes learning more	teachers to impart knowledge	
	enjoyable and engaging for them.	and for students to access it.	
(Raja &	Technology transforms education	Education has been transformed	Education has undergone a
Nagasubramani, 2018)	by increasing the effectiveness of	by technology.	technological revolution.
	teachers, streamlining intricate	Knowledge may be imparted by	The usage of technology
	procedures, and creating an	teachers more readily and	benefits both educators and
	enjoyable learning environment. It	acquired by pupils more	learners.
	makes it simpler for professors and	readily.	
	students to share knowledge,		
	which enhances the educational		
	process overall.		

Through its revolutionary effect on the traditional classroom setting and its enhancement of student communication and collaboration, technology has brought tremendous modernization to teaching methods. With the use of tools like Zoom, Google Meet, wikis, and Google Docs, students can participate in group discussions and collaborative projects that have been made more productive and fun by modern 905 technology like computers, the Internet, and audiovisual media. Furthermore, language teaching has changed as a result of the incorporation of technology such as the Internet, YouTube, Skype, and social media platforms. This has overcome the drawbacks of conventional rote learning techniques and made language learning more dynamic and interesting for students (Sinha, 2022). Additionally, students now have greater freedom in accessing educational materials and evaluations because of the advent of virtual interactive lectures and blended learning methodologies, which ultimately improve the entire learning experience and encourage self-education.

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RQ2: How has technology transformed traditional teaching methods?

For students to acquire the information and technical skills necessary for success in postsecondary education and the world of work, the integration of technology with individual learning is critical, underscoring the importance of significant systemic change in education. Additionally, big data, learning analytics, artificial intelligence, and advances in information technology have made personalized learning popular and highlighted the role of technology in enhancing Biology Teacher Competency in the 21st century (Table 3).

Author	Insights	Result	Conclusion
(Sangtani et al., 2022)	Through the introduction of	The outdated teaching and	Globally, digital education
	digital technologies such as	learning techniques were quickly	has significantly changed.
	augmented, virtual, and mixed	replaced by digital versions of the	Changes in teaching
	reality, technology has	textual facts.	approaches are being
	transformed traditional teaching		implemented by educational
	techniques, resulting in a		institutions.
	transition from traditional to		
	interactive and engaging modes		
	of education.		
(Yarychev & Mentsiev,	By facilitating faster information	Advanced inventions in	Traditional teaching methods
2020)	dissemination, increasing	technology made education more	have been supplanted by
	accessibility to education, and	accessible to people. Information	digital education.
	fostering a knowledge-based	reaches with the speed of light	Access to information has
	culture, technology has	from one place to another.	increased thanks to digital
	supplanted conventional teaching		schooling.
	techniques in education. Students		
	now benefit from knowing		
	current events in the globe.		
(Misra, 2021)	By providing educators with a	To integrate technology into	One tool that can improve
	variety of ways to incorporate	traditional classrooms (face-to-	education is technology.
	technology into the classroom,	face), teachers need to be well-	For teachers to use technology
	encouraging students to use it,	versed in its nature and	effectively, they need to be
	and resolving implementation-	prospective applications. They	clear and have the necessary
	related issues, technology has	also need to possess the necessary	skills.
	improved traditional teaching.	attitudes and tool-using skills.	
(Wang, 2018)	By bringing intelligent	The test findings show that the	An intelligent information
	information processing,	suggested method achieves a	technology-based teaching
	streamlining resource allocation,	better level of intelligence in	optimization strategy has
	and improving information	teaching methods compared to	been proposed.
	management in colleges and	traditional approaches, improves	better information
	universities, technology has	the dispatch and balance of	management and resource
	revolutionized traditional	teaching resource information,	allocation for instruction in
	teaching methods and increased	and improves the design of	colleges
	teaching intelligence and	teaching methods in higher	
	efficiency.	education institutions.	
(Hadžiomerović et al.,	According to the study, students'	Using technology-based tools or	Students' performance in
2023)	memory retention improves	other alternative teaching	Neuroanatomy is improved
	while learning neuroanatomy	methods can be more successful	by using technology-based
	with the use of technology, such	in helping students learn and	learning approaches such as
	as 3D models and video lectures,	retain difficult anatomy	3D printed specimens, 3D
		information	models, and video lectures

Table 3. Technology Transformed Traditional Teaching Methods

Author	Insights	Result	Conclusion
	as compared to traditional		Different strategies make it
	techniques.		easier to memorize anatomical
	-		words and structures.
(Raut, 2021)	According to the article,	Every possible subject is affected	Technology's effects on
	technology has completely	by innovation, and education is	conventional teaching
	changed the way that education is	one of them.	methods
	delivered by enabling online		It's significance in the
	learning, improving learning		educational field
	outcomes through ICT, and		
	supporting contemporary		
	teaching methods.		
(López-Belmonte et al.,	According to the study findings,	Teachers noted that the STEM	The STEM teaching strategy
2022)	technology has revolutionized	teaching approach had a	was important in every aspect
	traditional teaching techniques by	significant effect on student	of the research. It also had a
	bringing STEM education and	motivation and grades. The	greater impact on students'
	improving student motivation,	greatest impact was seen in	grades and motivation.
	grades, interactions, autonomy,	raising students' credentials and	
	cooperation, problem-solving,	motivation.	
	and overall learning experience.		

Through the use of digital technologies and the development of fresh educational strategies, it has completely transformed conventional teaching techniques. Experiences in education have been improved by online resources like Moodle, Open edX, and NEO LMS. Technology transformed traditional teaching methods into modern ones (Table 4). Teachers have modified conventional teaching strategies by adding technology to improve learning in several ways. With an emphasis on behavioral, emotional, and cognitive involvement, the use of educational technologies in higher education has become essential. This change is notably noticeable in the use of clicker technology, which encourages engagement and active participation from students and helps to keep them, especially in big classes. Furthermore, the pandemic caused teaching methods to change more quickly than they had previously, causing instructors of technologybased courses to go through several stages of metamorphosis before becoming resilient and adaptable to the ways that academia was changing through visioning, learning, rationalizing, and modernizing. With an emphasis on effective engagement tactics in digital pedagogy, these modifications seek to optimize students' potential in the "new normal" of education.

Teachers must have access to pertinent technologies, the requisite knowledge, and the requisite abilities to successfully integrate technology into the classroom. They should take on the role of technology leaders, guiding and modeling the incorporation of educational technology (ed-tech) and enabling students to use it for their studies (Santos, 2023). Before implementing technology, educators must evaluate it, comprehend the possible advantages and disadvantages of doing so, develop the requisite technological competencies, and match their methods of instruction to the latest standards and specifications. Furthermore, employing digital platforms and technical resources can improve student learning, teacher expertise, and motivation which contribute to the development of an atmosphere that is favorable to actual learning (Mourya & Singh, 2022). Teachers may make sure that the use of technology in the classroom improves student development and education quality by remaining up-todate on technological advancements and preparedness.

RQ3: How does TPACK in the field of Education?

Teachers frequently display differing degrees of ability in various TPACK domains; some are more skilled in pedagogy, while others are more adept with technology. Effective teaching and learning processes depend on using TPACK in lesson design and classroom activities (Table 4). By combining technology, pedagogy, and subject knowledge, TPACK, or Technological Pedagogical subject Knowledge, plays a significant role in the field of education. Studies have demonstrated that TPACK competency has a major impact on teachers' efficacy and quality of instruction (Shambare & Jita, 2024). To use TPACK and provide students with creative and interesting learning experiences, educators must possess a thorough understanding of technological operations, pedagogical methodologies, and topic expertise. Moreover, TPACK model training can improve teaching methods and address instructors' inadequacies to further support their initial and continuing professional growth. Teachers may build a dynamic learning environment that encourages student involvement and knowledge acquisition by integrating different technologies, pedagogical approaches, and

appropriate content. This will ultimately improve the quality of education for all students.

Table 4. TPACK in the Field of Education

Author	Insights	Result	Conclusion
(Harris & Hofer,	For professional development, K-	The study emphasized how	Context and professional
2017)	12 schools and districts use TPACK.	educational leaders' views about	culture are crucial when
	TPACK serves as a link between	professional development impacted	implementing TPACK.
	different professional development	the comprehension and	TPACK is a tool used to link
	programs in educational	implementation of TPACK in schools	several efforts in professional
	institutions.	and districts, as well as the	development.
		significance of context and	
		professional culture in how TPACK	
		was appropriated.	
(Salas-Rueda,	Using technology, content, and	The TPACK paradigm, which	The TPACK approach makes it
2019)	pedagogy, TPACK arranges and	emphasizes the value of integrating	easier to build virtual learning
	applies instructional resources.	technology, pedagogy, and content	environments and use
	The teaching-learning environment	knowledge in educational contexts,	technology tools.
	in the educational profession is	improved the effectiveness of the use	The identification and
	improved by TPACK.	of technological tools and virtual	assessment of the linear
		learning environments.	function are positively
			impacted by the contents of
			WALF.
(Castéra et al.,	Teacher educators' perceptions and	The study produced 3 main findings:	The six nations validated the
2020)	training are influenced by TPACK.	1) the seven-factor model structure is	seven-tactor TPACK model.
	The perception of TPACK differs	relatively stable across nations; 2)	It was discovered that age had
	among six European and Asian	university professors' opinions of	an impact on how TPACK was
	nations.	TPACK vary across six European and	perceived.
		Asian countries; 3) age and TPACK	
		factors are dependent upon each	
		other.	
(Rodriguez Solis	IPACK dynamically combines	The integration of mobile	Digital teaching aids speed up
& Acurio	content knowledge, pedagogy, and	applications such as PAM	learning and increase problem-
Maldonado, 2021)	technology.	(Plataforma Adaptativa para	solving efficacy by facilitating
	the office mode mothematics	Matematica) is nignighted as an	the development of new
	the efficacy of mathematics	important tool for adaptive learning,	When pacesent a variate of
	instruction.	allowing students to learn at their	digital tools can be used both
		in mathematics aducation	inside and outside of the
		in matientatics education	classroom
(Rahmatiah et al	For more effective instruction	Teachers should be able to develop a	For more effective instruction
(Rannatian et al., 2022)	TPACK combines pedagogy	creative relationship between what is	TPACK combines pedagogy
2022)	content knowledge and	learned (content) what is taught	content knowledge and
	technology By integrating	(pedagogy) and the right	technology
	technology, pedagogy, and content.	instruments (technology)	By integrating technology.
	the TPACK framework improves		pedagogy, and content. the
	instruction.		TPACK framework improves
			instruction.

Technological Knowledge, Pedagogical Knowledge, Content Knowledge, Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge, and Technological Pedagogical Content Knowledge are the seven main components that make up the TPACK framework. Together, these elements improve teachers' capacity to successfully incorporate technology into lesson plans. Teachers using TPACK must possess a thorough understanding of pedagogy, technology, and the material they are teaching (Rahmatiah et al., 2022). Studies highlight how important TPACK is for improving teachers' abilities, and there is a direct link between TPACK components and effective classroom technology integration. Geospatial technologies can be effectively incorporated into classes by teachers who are skilled at aligning TPACK components with curriculum goals. This emphasizes the significance of a balanced integration of geography content, pedagogy, and technology within the TPACK framework. Furthermore, 908 customized training plans built around the dimensions of the TPACK model can help teachers improve their teaching proficiency and address their areas of weakness, which will ultimately help educational settings successfully integrate technology.

RQ4: How does TPACK improve biology teacher competency in the 21st century?

Biology teachers may use technology to improve learning outcomes and design engaging learning experiences for students in the digital age by becoming proficient and competent in TPACK (Table 5).

Table 5. TPACK Improve Biology Teacher Competency in the 21st Century

Author	Insights	Result	Conclusion
(Suganda et al.,	In the twenty-first century, TPACK	The TPACK analysis concentrated on	Understanding teachers
2021)	improves the use of technology in	the perspectives of instructors	opinions of TPACK is
	biology education.	regarding their TPACK	essential
	enhances educators'	competencies, the significance of	Teachers' opinions on the
	comprehension of the challenges of	21st-century learning, and the factors	features of 21st-century
	21st-century learning.	they take into account to attain it.	learning are not constant.
(Nuruzzakiah et al.,	TPACK improves technology	The statistical analysis revealed that	Qualification standards for
2022)	integration for efficient distribution	there were no appreciable variations	biology instructors in Aceh
	of content.	in the TPACK proficiency of biology	Province
	Teachers can better organize and	instructors according to their	Based on certification and
	execute technology-based learning	teaching experience or qualification.	teaching experience, there is
	with the support of TPACK.		no discernible difference in
			TPACK competency.
(Ratnawulan, 2022)	With the provision of technical	By incorporating 21st-century	Teacher proficiency rising
	guidance on 21st-century learning,	learning abilities into the Student	from mediocre to excellent.
	TPACK enhances the competency	Worksheets, teachers were able to	Orientation, planning, group
	of biology teachers.	improve their ability to make	projects, observation, and
	Including 21st-century abilities in	meaningful connections across	assessment were all part of
	student worksheets improves the	biology, chemistry, and physics,	the mentoring process.
	competency of teachers.	leading to the desired curriculum	
		integration.	
(Rissanen, 2018)	TPACK's active teaching strategies	To increase interest in biology among	Active learning decreased
	help raise student engagement.	students enrolled in big first-year	absenteeism and raised
	Active teaching strategies increase	introductory biology classrooms,	biology scores.
	biology students' interest and	active learning and engaging	Students cited the benefits of
	participation.	teaching are used to reduce	learning and chose engaging
		absenteeism to improve grades.	approaches
(Thohir et al., 2022)	improves the incorporation of	The findings highlighted the	One new skill that pre-service
	technology into biology education	necessity of providing in-service	science teachers are learning
	strategies.	science teachers with chances for	is TPACK.
	increases the proficiency of science	ongoing professional development to	The Indonesian setting is
	instructors in using technology.	enhance their TPACK competencies	ignorant about the use of
		and remain current with the most	technology in education.
		recent technological developments in	
		education.	
(Muthmainnah &	TPACK improves the ability to do	Teachers of biology typically exhibit	TPACK improves the ability
Nurkamilah, 2022)	practical tasks while learning	higher levels of self-efficacy in their	to do practical tasks while
	remotely.	content knowledge than in their	learning remotely.
	Instructors of biology have	technological competence.	Instructors of biology have
	confidence in their ability to carry		confidence in their ability to
	out practical work well.		carry out practical work well.
(Aguilera et al.,	TPACK can improve participation	The examination results indicate that	Exam performance and
2017)	by imitating scientific research and	the iterative group's pupils	critical thinking are improved
	findings.	outperformed the control group on	by iterative group
	TPACK stimulates curiosity in	questions, and the presentations	presentations
	biology and critical thinking	raised both groups' general interest	Both presentation approaches
	abilities.	in biology.	raised interest in biology.

By fusing pedagogy, content knowledge, and technology, which stands for Technological Pedagogical

Content Knowledge biology teacher competency in the twenty-first century. Studies show that implementing

TPACK in science instruction improves teacher performance significantly, particularly in higher-order thinking skills, which in turn enhances students' educational experiences (Selly, 2022). Pre-service science teachers can improve their learning design skills and TPACK proficiency by using TPACK frameworks such as the Project-Based Scaffolding TPACK model. This will help them meet the expectations of 21st-century education, which places a strong emphasis on technology integration. Moreover, TPACK gives educators the ability to successfully design, carry out, and evaluate their instructional strategies, preparing them for the quickly changing 21st-century educational environment.

TPACK is a key component in raising student interest in biology courses. Teachers can effectively use technology to increase students' science process skills, encourage positive behavioral orientations toward technology exploitation (Stinken-Rösner et al., 2023), and improve students' performance and involvement in class activities (Lai et al., 2022) by incorporating TPACK into their teaching techniques. Teachers' TPACK skills have improved significantly as a result of training programs that emphasize TPACK, such as biology teachers' training in numerical taxonomy, which has improved the way students learn about living things and boosted the use of technology in the classroom. It has also been discovered that TPACK and student engagement in science education are improved by integrating ICT into pre-service teacher courses and demonstrating optimal teaching techniques with learning technologies. In general, the incorporation of TPACK enables educators to design dynamic and captivating learning spaces that encourage student involvement and comprehension of biology subject.

Conclusion

The research paper utilized a systematic approach to identify and select relevant articles for review, focusing on technological pedagogical and content knowledge (TPACK) to improve biology teacher competency. Through a rigorous screening process, a total of 25 articles were selected for the literature review stage based on specific inclusion and exclusion criteria. The findings suggest that a deep understanding and integration of technology, pedagogy, and content can enhance biology teachers' competence in the 21st century. The study highlights the importance of incorporating the TPACK framework into teacher training programs to equip educators with the necessary skills to effectively utilize technology in teaching biology. It was evident from the review that using TPACK can lead to improved teaching practices, student engagement, and overall learning outcomes in biology education. The paper's conclusions emphasize the significance of enhancing biology teachers' competencies by integrating TPACK seamlessly with pedagogical approaches and subject-specific knowledge.

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Author Contributions

Conceptualization; methodology; validation; formal analysis.; investigation; resources; data curation: writing – original draft preparation; writing – review and editing.: visualization: T.

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Conflicts of Interest

The authors declare no conflict of interest.

References

- Abbas-Abbood, A., Qassim Gadhban, A., & Hasan Rhaif AL-Sahlanee, M. (2023). The Role of Modern Technologies in Improving the Quality of Education. In *Technology in Learning*. IntechOpen. https://doi.org/10.5772/intechopen.109801
- Adipat, S., Chotikapanich, R., Laksana, K., Busayanon, K., Piatanom, P., Ausawasowan, A., & Elbasouni, I. (2023). Technological Pedagogical Content Knowledge for Professional Teacher Development. *Academic Journal of Interdisciplinary Studies*, 12(1), 173. https://doi.org/10.36941/ajis-2023-0015
- Adji, S. S., Kismiati, D. A., Safitri, H., Hartinawati, H., Sugilar, S., Novianti, I., & Zakirman, Z. (2022). Pelatihan Technological Pedagogical Content Knowledge (TPACK) Sebagai Kerangka Pengetahuan untuk Meningkatkan Kompetensi Guru. Jurnal Pengabdian UNDIKMA, 3(3), 401. https://doi.org/10.33394/jpu.v3i3.5897
- Adnan, A., & Yunisari, C. (2023). TPACK: Teachers' Needs. *Ta'dib*, 26(1), 143. https://doi.org/10.31958/jt.v26i1.9072
- Aguilera, A., Schreier, J., & Saitow, C. (2017). Using Iterative Group Presentations in an Introductory Biology Course to Enhance Student Engagement and Critical Thinking. *The American Biology Teacher*, 79(6), 450–454. https://doi.org/10.1525/abt.2017.79.6.450
- Boulakhsaim, T. (2022). Modern technologies and their role in the educational process. *Mathematical Linguistics*, 2(1), 15–43. https://doi.org/10.58205/ml.v2i1.150

- Bueno, R., Niess, M. L., Aldemir Engin, R., Ballejo, C. C., & Lieban, D. (2023). Technological pedagogical content knowledge: Exploring new perspectives. *Australasian Journal of Educational Technology*, 88– 105. https://doi.org/10.14742/ajet.7970
- Castéra, J., Marre, C. C., Yok, M. C. K., Sherab, K., Impedovo, M. A., Sarapuu, T., Pedregosa, A. D., Malik, S. K., & Armand, H. (2020). Self-reported TPACK of teacher educators across six countries in Asia and Europe. *Education and Information Technologies*, 25(4), 3003–3019. https://doi.org/10.1007/s10639-020-10106-6
- Dai, J., Gu, X., & Zhu, J. (2023). Personalized Recommendation in the Adaptive Learning System: The Role of Adaptive Testing Technology. *Journal of Educational Computing Research*, 61(3), 523–545. https://doi.org/10.1177/07356331221127303
- Ganesan Velayutham, A. Raja, & Daniel Felix Joseph Chalke. (2022). Impact of New Technologies In Education. Journal of Pharmaceutical Negative Results, 1393–1396. https://doi.org/10.47750/pnr.2022.13.S09.167
- Ghory, S., & Ghafory, H. (2021). The impact of modern technology in the teaching and learning process. *International Journal of Innovative Research and Scientific Studies*, 4(3), 168–173. https://doi.org/10.53894/ijirss.v4i3.73
- Hadžiomerović, N., Hadžiomerović, A. I., Avdić, R., Muminović, A., Tandir, F., Bejdić, P., & Pandžić, A. (2023). Students' performance in teaching neuroanatomy using traditional and technologybased methods. *Anatomia, Histologia, Embryologia*, 52(1), 115–122. https://doi.org/10.1111/ahe.12876
- Haniefa, R., & Samsudin, M. (2023). Penerapan Technological Pedagogical and Content Knowledge (TPACK) dalam Pengajaran Keterampilan Berbahasa Arab. *Ta'limi Journal of Arabic Education and Arabic Studies*, 2(1), 61–72. https://doi.org/10.53038/tlmi.v2i1.62
- Harris, J. B., & Hofer, M. J. (2017). "TPACK Stories": Schools and School Districts Repurposing a Theoretical Construct for Technology-Related Professional Development. *Journal of Research on Technology in Education*, 49(1-2), 1-15. https://doi.org/10.1080/15391523.2017.1295408
- Ilyas, A., Akbar, S. S., Hamza Wajid, S., Joghee, S., Fatima, A., & Mago, B. (2023). The Growing Importance of Modern Technology in Education. 2023 International Conference on Business Analytics for Technology and Security (ICBATS), 1–4. https://doi.org/10.1109/ICBATS57792.2023.101 11128

Iskandar, D. (2022). Integration of Technological Pedagogical Content Knowledge (TPACK) Learning Methods in The Learning Management System as An Effort to Improve Educator Competence. *JTP - Jurnal Teknologi Pendidikan*, 24(3), 389–399.

https://doi.org/10.21009/jtp.v24i3.31773

- Joshi, S. (2023). Technology in Education. *Vidya A Journal of Gujarat University*, 2(2), 3–5. https://doi.org/10.47413/vidya.v2i2.197
- Karmakar, S., & Chatterjee, R. P. (2022). A Relook on Impact of Digitization for Education: An Overview. In Advances in Educational Technologies and Instructional Design (pp. 1–12). IGI Global. https://doi.org/10.4018/978-1-6684-5914-0.ch001
- Kostashchuk, O., & Bilenkova, L. (2022). The Use Of Modern Educational Technologies In The Professional Activities Of Primary School Teacher. Problems of Modern Teacher Training, 2(26), 96–102. https://doi.org/10.31499/2307-4914.2(26).2022.267722
- Lai, D., Lew, S. L., & Ooi, S. Y. (2022). Modified TPACK Framework for Teachers' Efficiency, Students' Performance and Students' Engagement. In Proceedings of Sixth International Congress on Information and Communication Technology (Vol. 235, pp. 827–835). Springer Singapore. https://doi.org/10.1007/978-981-16-2377-6_76
- Lestari, A., & Rahayu, D. S. (2023). Technological Pedagogical Content Knowledge (TPACK): Survey Persepsi pada Mahasiswa Calon Guru IPA. *PENDIPA Journal of Science Education*, 7(1), 33-42. https://doi.org/10.33369/pendipa.7.1.33-42
- López-Belmonte, J., Segura-Robles, A., Moreno-Guerrero, A.-J., & Parra-González, M. E. (2022). Comparative analysis between a STEM-based learning process and traditional teaching. *South African Journal of Education*, 42(1), S1–S10. https://doi.org/10.15700/saje.v42ns1a2057
- Magalingam, A. (2022). Technology of Teaching. *Shanlax International Journal of Arts, Science and Humanities,* 10(S1), 140–143. https://doi.org/10.34293/sijash.v10iS1.5225
- Major, L., Francis, G. A., & Tsapali, M. (2021). The effectiveness of technology-supported personalised learning in low- and middle-income countries: A meta-analysis. *British Journal of Educational Technology*, 52(5), 1935–1964. https://doi.org/10.1111/bjet.13116
- Menrisal. (2023). Analyze Variable TPACK (Technological, Pedagogical, and Content Knowledge) in Digital Learning: A Review.

Journal of Digital Learning And Distance Education, 2(5), 637-641. https://doi.org/10.56778/jdlde.v2i5.267

- Misra, P. K. (2021). Technology and Teaching. In Learning and Teaching for Teachers (pp. 181–198). Springer Singapore. https://doi.org/10.1007/978-981-16-3077-4_11
- Mithun, R., & Roopadarshini, S. (2024). Study on Distance Learning: A Developmental Leap towards Smart Education in Smart Cities. *Journal* of Digital Learning And Distance Education, 2(7), 645–651. https://doi.org/10.56778/jdlde.v2i7.175
- Mourya, S. K., & Singh, T. (2022). Effective ways of using Technology in Teaching. *Gyan Management Journal*, 16(2), 20–25. https://doi.org/10.48165/gmj.2022.16.2.3
- Muthmainnah, R., & Nurkamilah, S. (2022). Biology Teachers' TPACK Self-Efficacy in Practical Work During Distance Learning. *Lentera Pendidikan*: *Jurnal Ilmu Tarbiyah Dan Keguruan*, 25(1), 157–171. https://doi.org/10.24252/lp.2022v25n1i14
- Nithitakkharanon, P., Vetsawat, C., Sawasdee, V., & Nuangchalerm, P. (2023). Fostering TPACK for Pre-service Teachers about Learning Management Competency into Professional Experiences. *Journal of Curriculum and Teaching*, 12(1), 220.

https://doi.org/10.5430/jct.v12n1p220

- Nuruzzakiah, N., Hasanuddin, H., Artika, W., S., Supriatno, & Rahmatan, H. (2022). Competency Analysis of Technological Pedagogical and Content Knowledge (TPACK) Biology Teachers. Jurnal Penelitian Pendidikan IPA, 8(1), 325-335. https://doi.org/10.29303/jppipa.v8i1.1166
- Ortiz Colón, A. M., Izquierdo Rus, T., Rodríguez Moreno, J., & Agreda Montoro, M. (2023). TPACK model as a framework for in-service teacher training. *Contemporary Educational Technology*, 15(3), ep439. https://doi.org/10.30935/cedtech/13279
- Osman, W. A. E. A. E. (2022). Utilizing Modern Technology to Motivate University Students to Study English Language. *Journal of Language and Cultural Education*, 10(3), 43–53. https://doi.org/10.2478/jolace-2022-0016
- Rahmatiah, R., Sarjan, M., Muliadi, A., Azizi, A., Hamidi, H., Fauzi, I., Yamin, M., Muttaqin, Muh.
 Z. H., Ardiansyah, B., Rasyidi, M., Sudirman, S., & Khery, Y. (2022). Kerangka Kerja TPACK (Technological Pedagogical Content Knowledge) dalam Perspektif Filsafat Ilmu Untuk Menyongsong Pendidikan Masa Depan. Jurnal

Ilmiah Profesi Pendidikan, 7(4). https://doi.org/10.29303/jipp.v7i4.1069

- Raja, R., & Nagasubramani, P. C. (2018). Impact of modern technology in education. *Journal of Applied and Advanced Research*, S33–S35. https://doi.org/10.21839/jaar.2018.v3iS1.165
- Ratnawulan, R. (2022). Increasing The Competence of Science Teachers in The Batusangkar City through Technical Guidance on 21st Century Learning Implementation in Integrated Science student worksheet. *Pelita Eksakta*, 5(1), 28. https://doi.org/10.24036/pelitaeksakta/vol5iss1/169
- Raut, B. N. (2021). Impact of Technology on Traditional Teaching—Learning Measures in The Era of Covid-19 Pandemic. SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, 13(1), 92–96.

https://doi.org/10.18090/samriddhi.v13iS1.21

- Rissanen, A. (2018). Student Engagement in Large Classroom: The Effect on Grades, Attendance and Student Experiences in an Undergraduate Biology Course. *Canadian Journal of Science, Mathematics and Technology Education*, 18(2), 136–153. https://doi.org/10.1007/s42330-018-0015-2
- Rodríguez Solís, M. F., & Acurio Maldonado, S. A. (2021). Modelo TPACK y metodología activa, aplicaciones en el área de matemática. Un enfoque teórico. *Revista Científica UISRAEL*, 8(2), 49–64. https://doi.org/10.35290/rcui.v8n2.2021.394
- Salas-Rueda, R.-A. (2019). TPACK: Technological, Pedagogical and Content Model Necessary to Improve the Educational Process on Mathematics through a Web Application? International Electronic Journal of Mathematics Education, 1(1). https://doi.org/10.29333/iejme/5887
- Sangtani, R. B., Samnani, L., Sarasambi, A. B., Kumar, R. M., & Pawar, S. R. (2022). Digital Innovations in Education: In Advances in Higher Education and Professional Development (pp. 218–238). IGI Global. https://doi.org/10.4018/978-1-6684-4083-4.ch011
- Santos, R. A. H. (2023). Rethinking Technology Literacy for Effective Technology Integration of Secondary Teachers. 729–741.

https://doi.org/10.22492/issn.2435-5240.2023.60

Selly, A. (2022). Training to Improve the Competence of 21st Century Teachers With A Tecnological Pedagogical And Content Knowledge (TPACK) Approach Through The Google Sites Application and Mentimter for Christian High School Teachers 2 Kalabahi: Pelatihan Peningkatan Kompetensi Guru Abad 21 dengan Pendekatan Tecnological Pedagogical and Content Cnowledge (TPACK) Melalui Aplikasi Sites Google Dan Mentimter Bagi Guru SMA Kristen 2 Kalabahi. Indonesian Journal of Engagement, Community Services, Empowerment and Development, 2(2), 200–209. https://doi.org/10.53067/ijecsed.v2i2.59

- Shambare, B., & Jita, T. (2024). TPACK: A descriptive study of science teachers' integration of the virtual laboratory in rural school teaching. *Cogent Education*, 11(1), 2365110. https://doi.org/10.1080/2331186X.2024.2365110
- Sinha, K. K. (2022). Role of Modern Technology in Teaching and Learning the English Language in Indian Educational Institutions. *Indonesian Journal of English Language Studies (IJELS), 8*(2), 19–30. https://doi.org/10.24071/ijels.v8i2.4713
- Stinken-Rösner, L., Hofer, E., Rodenhauser, A., & Abels,
 S. (2023). Technology Implementation in Pre-Service Science Teacher Education Based on the Transformative View of TPACK: Effects on Pre-Service Teachers' TPACK, Behavioral Orientations and Actions in Practice. *Education Sciences*, 13(7), 732. https://doi.org/10.3390/educsci13070732
- Suganda, H., Riandi, R., & Purwianingsih, W. (2021). TPACK perception analysis of teachers in facing 21st-century learning. *Jurnal Bioedukatika*, 9(2), 93. https://doi.org/10.26555/bioedukatika.v9i2.177 88
- Thohir, M. A., Jumadi, J., & Warsono, W. (2022). Technological pedagogical content knowledge (TPACK) of pre-service science teachers: A Delphi study. *Journal of Research on Technology in Education*, 54(1), 127–142. https://doi.org/10.1080/15391523.2020.1814908
- Wang, M. (2018). Teaching Methods of Colleges and Universities Based on Intelligent Information Technology. 2018 International Conference on Virtual Reality and Intelligent Systems (ICVRIS), 318–323.

https://doi.org/10.1109/ICVRIS.2018.00084

Yarychev, N. U., & Mentsiev, A. U. (2020). Impact of digital education on traditional education. *Journal* of Physics: Conference Series, 1691(1), 012132. https://doi.org/10.1088/1742-6596/1691/1/012132