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Analysis of Technological Pedagogical Content Knowledge Competence of Biology Teachers in the Use of High School Instructional Media

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Abstract: This study aims to analyze the Technological Pedagogical Content Knowledge (TPACK) competence of biology teachers in the use of instructional media in high schools in Kuala Tungkal. This research employs a descriptive method with a quantitative approach, involving 7 biology teachers from 3 public high schools in Kuala Tungkal as subjects. Data were collected through questionnaires, interviews, and observations. The results indicate that the technology-based instructional media used by teachers vary according to the needs of the materials being taught. In terms of technological knowledge, the average percentage obtained was 77.78%, which falls under the Good category, while the pedagogical content knowledge aspect scored an average percentage of 84.4%, categorized as Very Good. The conclusion of this study suggests that biology teachers in Kuala Tungkal have good TPACK competence in the use of instructional media. Recommendations from this study include the enhancement of training for developing more advanced technology-based instructional media, such as e-modules and interactive simulations, to further improve the quality of biology education.

Keywords: Biology Teachers; Instructional Media; Technology Integration TPACK

Introduction

The rapid advancement of digital technology in the 21st century has significantly impacted various sectors, including education, by revolutionizing teaching practices and learning environments. The integration of digital technology into education is now seen as essential for enhancing learning outcomes and preparing students for future challenges. In this context, the role of educators has evolved, requiring them to possess not only pedagogical and content knowledge but also technological proficiency. This intersection of knowledge domains is encapsulated in the Technological Pedagogical Content Knowledge (TPACK) framework, which has gained prominence as a critical competency for 21st-century educators, particularly in subjects like biology that require both theoretical and practical knowledge (Putri et al., 2019). The ability to effectively merge content knowledge, pedagogy, and technology (TPACK) is a crucial factor in improving student learning outcomes and ensuring that students are equipped with the skills needed to navigate the challenges of the modern world (Rochintaniawati et al., 2019; Sutarsih & Misbah, 2021). *Technological Pedagogical Content Knowledge (TPACK)* is a framework that highlights the importance of teachers' ability to integrate technology into their teaching practices (Ratnaya et al., 2024). It extends Shulman's earlier concept of *Pedagogical Content Knowledge (PCK)* by adding a third dimension: technological knowledge. The

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TPACK framework is particularly relevant for addressing the complexities of modern education, where technology plays a vital role in delivering educational content and fostering student engagement. As noted by (Putri et al., 2019; Rahmadi, 2019), the widespread use of information and communication technology (ICT) in education requires teachers to develop competencies that allow them to effectively integrate technological tools into their teaching strategies. This is particularly true in the field of biology education, where the use of digital tools such as interactive e-modules, augmented reality (AR), and virtual simulations has been shown to significantly enhance students' understanding of complex biological concepts (Mazhitovna et al., 2022; Ratnaya et al., 2024). While TPACK has been widely studied in the context of general education, there remains a notable gap in the literature regarding its specific application to the use of instructional media in biology education. Previous studies have explored the broad implications of TPACK across different subject areas (Suyamto et al., 2020; Widiana & Septianti, 2022), but few have examined how biology teachers can apply this framework to select and utilize instructional media effectively. The connection between *TPACK* and instructional media is crucial, as appropriate media selection and usage are integral to improving the learning process, particularly in subjects that require visualization of complex processes like biology (Unaida & Fakhrah, 2022). The lack of focus on this specific aspect in the existing literature presents an opportunity to explore how *TPACK competence* in biology education can be enhanced through the effective use of instructional media.

Biology education, in particular, benefits greatly from the use of digital tools that can transform abstract concepts into tangible learning experiences. For example, (Chu, 2024) found that virtual reality (VR) dissections in biology classes significantly improved students' retention of knowledge and understanding of biological mechanisms. Similarly, (Puspita, 2024) emphasized that interactive e-modules aligned with the *STEM* approach can foster creative thinking and collaboration skills, which are essential for students in the 21st century. These findings highlight the importance of integrating digital technologies into biology education, not only to improve student engagement but also to enhance teachers' pedagogical effectiveness.

Despite the availability of these technological tools, many teachers, particularly in biology, have not yet fully mastered the competencies required to integrate TPACK into their teaching. This issue is particularly evident in schools in *Kuala Tungkal*, where the availability of technology-based instructional media is often underutilized due to teachers' limited understanding of how to connect TPACK competence with instructional media (Nevrita et al., 2020). Teachers in this region have access to various forms of technology, such as *PowerPoint presentations (PPT)*, *videos*, and *animations*, yet the use of more advanced tools such as *multimedia* and *e-modules* remains limited. This highlights a significant gap in teachers' ability to design and implement effective technology-based learning materials that align with the needs of the subject matter.

Furthermore, the connection between *TPACK competence* and instructional media use in biology education is not only about the availability of tools but also about how these tools are selected and applied in the classroom. Quality instructional media is essential for facilitating the teaching and learning process. For instance, videos and animations have been shown to make complex biological processes more understandable and engaging for students (Harfian & Hendra, 2022). However, without a strong foundation in TPACK, teachers may struggle to choose the most appropriate media for their lessons, thereby limiting the effectiveness of their teaching practices.

In response to this gap, this study aims to analyze the *TPACK competence* of biology teachers in *Kuala Tungkal* high schools, with a specific focus on their use of instructional media. By examining how teachers integrate technological, pedagogical, and content knowledge in their teaching practices, this research seeks to provide insights into the current state of TPACK competence in biology education and identify areas for improvement. The novelty of this research lies in its focus on the specific application of TPACK to the selection and use of instructional media, which has received limited attention in previous studies. By focusing on biology education, this study contributes to the growing body of literature on TPACK by providing new insights into how this framework can be applied to improve teaching practices in specific subject areas.

The research also seeks to explore the factors that influence teachers' ability to integrate technology into their teaching practices. Indicators of TPACK competence include teachers' ability to select and design appropriate instructional media, as well as their capacity to evaluate the effectiveness of these tools in improving student learning outcomes (Koh et al., 2010; Lee & Tsai, 2008). The findings of this study will provide a comprehensive overview of the current state of TPACK competence among biology teachers and offer recommendations for professional development programs aimed at enhancing teachers' skills in this area.

Moreover, the study will examine how teachers' TPACK competence impacts student outcomes in biology education. Research by (Osman & Kaur, 2014) has demonstrated that the integration of ICT with problem-based learning (PBL) in biology significantly

improved students' retention of biological concepts, suggesting that when teachers possess strong TPACK competence, they are more likely to implement teaching strategies that enhance student learning. Similarly, (Incantalupo et al., 2013) found that positive student attitudes towards technology in biology classrooms are correlated with improved learning outcomes, underscoring the importance of effective technology integration in fostering student engagement and achievement.

The integration of digital technology into biology education through the *TPACK* framework is essential for improving both teaching practices and student outcomes. This research aims to fill the existing gap in the literature by providing a detailed analysis of how biology teachers in *Kuala Tungkal* high schools utilize instructional media within the context of their TPACK competence. By identifying the factors that influence teachers' ability to integrate technology into their teaching, this study will provide valuable insights for educators and policymakers seeking to enhance the quality of biology education through the effective use of instructional media. The findings will also contribute to the development of targeted professional development programs that address the specific needs of biology teachers in integrating technology into their classrooms, thereby improving the overall quality of education.

Method

This study was conducted at three public high schools (*SMA Negeri*) in the city of Kuala Tungkal, West Tanjung Jabung Regency. The subjects were seven biology teachers from these schools, selected through purposive sampling based on their involvement in integrating Technological Pedagogical Content Knowledge (TPACK) in biology teaching. The purposive selection aimed to ensure that the subjects had sufficient experience with TPACK to provide relevant insights.

This descriptive study utilized a phenomenological approach to capture the lived experiences of teachers in integrating TPACK into biology instruction. The phenomenological approach was chosen because the primary objective was to explore how teachers incorporate technology into pedagogical practices and content delivery, emphasizing their personal experiences and challenges.

Data Collection

The data were collected through a combination of questionnaires, interviews, and classroom observations. The questionnaire assessed teachers' self-reported TPACK competence in using biology teaching media, while the interviews delved deeper into their experiences with technology integration. Observations provided additional context to verify the self-reported data. Data sources included the biology teachers as primary subjects and the school principals, who contributed insights into school-level policies supporting TPACK integration.

The researcher served as the main instrument in this study, facilitating data collection and analysis. This required immersion in the study context and subject matter to ensure comprehensive understanding and accurate data interpretation.

Data Analysis

The data were analyzed descriptively, focusing on portraying the TPACK competence of the biology teachers without generalizing findings beyond the study participants. The analysis was conducted in stages, beginning with organizing the data and categorizing it according to the teachers' use of technological, pedagogical, and content knowledge. Descriptive statistics were applied to the questionnaire results, while thematic analysis was used for the interview and observation data. Table 1 outlines the criteria used to interpret teachers' TPACK competence based on their utilization of technology-based media in teaching.

Table 1. Criteria for Interpreting Media Usage Scores

Score	Category
81-100	Excellent
61-80	Good
41-60	Averange
21-40	Not Good
0-20	Very Poor

This scoring system facilitated the interpretation of TPACK competence and helped identify areas where teachers excelled or required further development.

Result and Discussion

This research focuses on the analysis of the technological pedagogical content knowledge (TPACK) competence of biology teachers in using learning media in high schools. Based on the data obtained from the questionnaire, the data related to the use of biology learning media are described as follows:

Integration of TPACK in the Utilization of Biology Learning Media

a. Utilization of technology-based learning media

Based on the questionnaire results, data were obtained from 7 biology teachers who were respondents regarding the utilization of technology-based learning media as follow (Table 2). Based on **Table 2**, it is evident that the most commonly used technology-based learning media by teachers are PowerPoint (PPT),

videos, and animations. The frequent use of PPT in the learning process can be attributed to its ease of creation and design, making it highly accessible for educators. Furthermore, schools providing devices such as laptops and projectors greatly support the implementation of PPT in classrooms. The versatility of PowerPoint is well-documented, as it enables teachers to incorporate various multimedia elements, such as text, graphics, videos, and sounds, enhancing both the structure and engagement of lessons (Konstantinidis et al., 2017). This interactive nature fosters an engaging learning environment, encouraging active student participation (Ghimire, 2023).

Table 2. Utilization of Technology-Based Media

Based Media Technology	Utilizing Teachers (%)
PPT	100
Video	100
Animation	71.4
Audiovisual	100
Multimedia	28.6
E-module	0
Audio	57.1

Additionally, research has shown that students prefer PowerPoint-based instruction over traditional methods, such as chalk-and-talk, leading to better learning outcomes and higher test scores (Oommen, 2012). The use of PowerPoint aligns with contemporary educational practices that emphasize student-centered learning, where the focus is on increasing student engagement and motivation (Ratu & Komara, 2021). PowerPoint also caters to diverse learning styles visual, auditory, and kinesthetic making it a highly adaptable tool in various instructional contexts (Lari, 2014).

In addition to PPT, teachers frequently utilize instructional videos, supported by easy access to the internet and platforms like YouTube. The availability of a wide range of video resources allows teachers to select materials that are tailored to specific lesson content, thus enhancing student comprehension and engagement. Audiovisual media, including sound slides and teacher-recorded videos, further enrich the learning experience by combining auditory and visual stimuli, which are particularly effective for topics requiring detailed explanation.

Another technology-based medium commonly used is animation. Teachers often acquire animations from the internet to visually represent complex biological processes that are difficult to explain verbally. Animations help in transforming abstract concepts into concrete visualizations, thereby improving students' understanding and retention of material (Budiyono et al., 2019).

Moreover, teachers also use audio recordings, particularly in online or asynchronous learning environments where direct face-to-face instruction is not feasible. Audio media can provide explanations or supplementary content at specific points in the learning process, further aiding student understanding.

Lastly, multimedia applications—accessed via the internet—are also employed by some teachers. Although their use is less widespread compared to PPT and videos, multimedia tools offer an interactive platform that integrates various types of media, which can lead to more engaging and effective teaching practices. However, the successful application of these tools relies heavily on the teachers' ability to design creative and interactive content. Poorly designed presentations or overly simplistic slides can negatively impact the learning experience, highlighting the importance of teacher competence in multimedia creation (Gjersvik, 2014).

The widespread use of PPT, videos, and animations in biology teaching reflects the growing trend towards multimedia-enhanced instruction, which not only improves content delivery but also supports diverse learning styles. However, the effectiveness of these media depends largely on how creatively and interactively they are used by teachers, emphasizing the need for professional development in multimedia skills.

b. Utilization of Conventional Learning Media

In addition to the use of technology-based media, conventional media is still utilized in the biology learning process. Some of the media used are as follows (Table 3).

Table 3. Utilization of Conventional Learning

Media Conventional	Media Utilizing Teachers (%)
Pictures	100
Models	85.7
Landscape	0
Miniatures	42.9
Direct Media	100
Environment	85.7

The most commonly used conventional media in the learning process is pictures. According to teachers, the use of this media is easy to create and access. Additionally, pictures are readily available in the textbooks used by students, meaning that teachers only need to supplement them with additional relevant images. For instance, when teaching about viruses, pictures are the easiest choice for visualizing the concept. Research supports the idea that visual representations, such as pictures, enhance students' understanding of complex ideas more effectively than text alone (Ghimire, 2023).

Teachers also frequently utilize direct media, which includes real objects or live demonstrations. They find that direct media is not only simple to use but also provides students with contextual experiences, which are particularly valuable when facing challenges like power outages or network issues. This type of contextual learning helps students link theoretical knowledge to real-world applications, thereby enhancing comprehension and retention (Konstantinidis et al., 2017). Moreover, such experiences encourage critical thinking and problem-solving skills, which are vital for academic success and lifelong learning (Ghimire, 2023).

In addition to pictures, teachers also use models and the surrounding environment as learning media, with a usage rate of 85.7%. Models are particularly helpful for topics that cannot be demonstrated through direct experience or real objects, such as the human body's organs. These models, which are replicas of real objects, allow students to see and understand the physical form of biological structures. This approach is especially effective in conveying complex biological phenomena (Hamida, 2024).

Teachers also integrate the local environment into the learning process, using it as a medium for topics or materials that are readily available in students' surroundings. The local environment provides a contextual learning experience that offers students meaningful and hands-on opportunities to engage with biological concepts. For instance, studying local ecosystems allows students to grasp ecological principles and biodiversity more deeply through direct observation (Ratu & Komara, 2021). Learning in such environments can also increase student engagement and motivation, making the learning process more dynamic and interactive (Hamida, 2024).

Another conventional medium used by teachers is miniatures. These are often employed to represent objects that are difficult for students to access or observe directly. A common example is the use of a miniature virus model, which enables students to visualize the structure of a virus that is otherwise invisible to the naked eye. Miniatures provide a concrete representation of abstract biological concepts, making them more understandable for students (Konstantinidis et al., 2017).

On the other hand, landscape media is rarely used by teachers. Teachers report that this type of media is unsuitable for teaching core biological topics. For example, landscape media, which emphasizes spatial relationships, is not effective for representing detailed biological processes, such as cellular structures or molecular interactions, which are fundamental in biology (Hamida, 2024). Instead, teachers prefer using more conventional tools like diagrams, PowerPoint presentations, videos, and interactive simulations, which they find to be more effective for conveying complex biological information. These forms of media allow for the integration of text, images, and animations, which break down difficult concepts into more digestible segments, enhancing students' comprehension (Oommen, 2012).

In the context of environmental learning, research has shown that using the environment as a learning medium can improve students' critical thinking skills and foster a sense of environmental responsibility. By engaging directly with their surroundings, students not only gain a deeper understanding of biological concepts but also develop an awareness of environmental stewardship, which is crucial for addressing global challenges (Ratu & Komara, 2021).

c. Utilization of Laboratory Media Biology

The learning activities in the three schools used as data sources are supported by laboratories. However, the use of laboratory resources is similar to that of conventional teaching aids, such as pictures and models. The results of the analysis are presented below.

Table 4. Utilization of Laboratory Media

Laboratory Media	Utilizing Teachers (%)
Pictures	100
Models	100
Preserved specimens	71.4
Not yet used	0
Other media	28.6

The data in Table 4 illustrates the utilization of laboratory media in the schools under study. The laboratory media used include pictures, models, preserved specimens, and other media. Interestingly, the data shows that all teachers (100%) utilize pictures and models as part of their laboratory teaching tools. This indicates a strong preference for conventional, visual aids that likely serve to simplify abstract concepts and provide concrete examples for students. The high percentage also suggests that these tools are readily available and considered effective in enhancing students' understanding of the subject matter.

However, the use of preserved specimens is lower, with only 71.4% of teachers utilizing them. This could be due to several factors, such as the limited availability of specimens, the potential cost of acquiring and maintaining them, or even the difficulty of integrating them into the regular curriculum. Preserved specimens, while offering valuable hands-on learning experiences, might also require specialized knowledge or additional preparation time for effective use, which could explain the relatively lower usage.

Notably, none of the teachers reported that they have yet to utilize any laboratory media, indicating that all teachers in the sample are making an effort to

incorporate some form of laboratory tool in their instruction. This is a positive indication of the importance placed on active and experiential learning, even if the tools used may vary in sophistication.

Additionally, 28.6% of teachers reported using other types of media beyond those listed. This suggests a degree of innovation or adaptability, with some educators possibly introducing more modern or digital tools such as interactive simulations, multimedia, or virtual labs. These tools could provide alternative methods for students to engage with the material, particularly when access to physical specimens or models is limited.

The data shows that while traditional tools like pictures and models dominate laboratory media usage, there is room for more diverse and innovative tools, especially those that could facilitate hands-on learning. Schools may benefit from increasing access to preserved specimens or other specialized media to provide more comprehensive learning experiences.

d. Design of Biology Learning Media Designed by Teachers

Learning media designed by teachers themselves are media created or developed by teachers according to their needs in delivering biology material messages to students. From the questionnaire given, data on the types of media designed or created by teachers themselves as follows (Table 5).

Table 5. Technology-based Learning Media Designed by Teachers

Media Type	Teachers who design (%)
PPT	85.7
Video	42.9
Animation	14.3
Audiovisual	42.9
Multimedia	0
E-Module	0
Audio	14.3
Others	0
Never	14.3

The most commonly designed technology-based learning media by teachers themselves is PPT with a percentage of 85.7%. According to teachers, PPT is easier to create according to the material and does not require special skills. PPT is also supported by the facilities provided by the school, making it highly feasible to use this type of media in learning. Furthermore, other technology-based media designed by teachers themselves are videos and audiovisuals, each with a percentage of 42.9%. Videos are created directly, such as those related to environmental pollution or ecosystems. As for audiovisuals, teachers combine several photos that are turned into videos and add sound to them. The next technology-based media developed by teachers are animations and audio, each with a percentage of 14.3%. Animations are created in a simple form due to the limitations of teachers' abilities and the lengthy process involved in creating them. Meanwhile, audio media is usually created by teachers in the form of voice recordings to provide explanations or reinforcement for certain materials. Based on Table 5.4, it can also be seen that there are still teachers who are unable to design technology-based learning on their own. This is due to a lack of understanding and skills, as well as the time constraints involved.

e. Initial Profile of TPACK Competence of Teachers through the Use of Biology Learning Media

The initial profile of TPACK competence represents the initial overview of teachers' competence in using biology learning media. In this study, the initial profile of TPACK competence focused on technological knowledge (Technological Knowledge) and pedagogical content knowledge. The results of the questionnaire given to teachers revealed the initial profile of TPACK competence through the use of biology learning media as follows (Table 6).

Table 6. Initial TPACK Profile in terms of Technological Knowledge (TK)

Indicator	Percentage (%)	Score Interpretation
Utilizing technology-based media	81.5	Very Good
Considering the utilization of technology-based media	85.2	Very Good
Designing technology-based media	66.67	Good
Average Percentage	77.78	Good

Table 6 shows the initial profile of TPACK competence of teachers in using biology learning media in terms of technological knowledge, with an average percentage of 77.78, indicating a good level of competence. As for the aspect of pedagogical content knowledge, the data obtained are as follows (Table 7).

Table 7. Initial Profile of TPACK in terms of Pedagogical Content Knowledge (PCK)

Indicator	Percentage (%)	Score Interpretation
Utilizing varied and relevant learning media	85.2	Very Good
Considering the suitability of content and media	92.6	Very Good
Designing and using media according to the taught content	81.5	Very Good

Indicator	Percentage (%)	Score Interpretation
Utilizing available learning media in the laboratory	85.2	Very Good
Conducting student evaluations to assess the effectiveness of the learning media used	77.8	Good
Average Percentage	84.4	Very Good

The Initial TPACK Profile in terms of Pedagogical Content Knowledge (PCK), obtained through the given questionnaire, shows an average percentage of 84.4, which falls under the category of "Very Good." In the biology teaching process, it is evident that the teacher possesses technological knowledge, as seen from the use of technology-based media.

Based on the presented results, it can be concluded that teachers possess Technological Pedagogical Content Knowledge (TPACK) competencies in utilizing biology learning media. This is evident from the diversity of technology-based media used by teachers in the learning process. One of the most commonly used media is video. Teachers believe that the variety of videos makes it easier for them to select those most suitable for the material they will teach. These instructional videos boost students' enthusiasm for learning and prevent boredom, making biology more engaging for students (Asy'ari et al., 2023; Gazali & Nahdatain, 2019; Harefa, 2022; Pramana et al., 2020).

In addition to videos, animation is another widely used medium among teachers. According to the teachers, animation media in the learning process presents material in a realistic manner and is accompanied by processes that are easily understood by students. Animations help transform abstract concepts into concrete forms, effectively capturing students' attention and interest in face-to-face learning, thereby improving learning outcomes (Afrilia et al., 2022; Budiyono et al., 2019; Tiwow et al., 2022). The use of animation, combined with interactive elements, allows students to engage more actively in the learning process, ultimately enhancing educational results (Monica, 2022; Wulandari et al., 2018).

The presence of multimedia in learning activities not only increases interaction but also improves the quality of education by providing flexibility in learning time. This flexibility, in turn, helps improve learning outcomes by adapting to students' individual needs (Monica, 2022; Wulandari et al., 2018). However, according to Table 1, one of the least used technology-based media by teachers is E-Module. This lack of use is attributed to the limited availability of suitable E-Modules for biology content, along with teachers' limited understanding and time to create such materials. Not all teachers have the capability to develop E-Modules, and they lack the time to independently learn how to create them. However, E-Modules are essential as one of the teaching resources that apply technological tools to improve learning (Budyastuti & Fauziati, 2021; Yunus et al., 2021). Conventional media, in comparison, tend to be formal and structured, often making it difficult for students to fully understand without careful attention (Putra et al., 2019; Siahaan & Pane, 2021).

Teachers must be able to design and develop learning media. The rapid technological advancements of today's globalized era have significant implications, especially for teachers, who are expected to keep pace with these changes to improve the quality of teaching and learning (Myori et al., 2019; Sijabat et al., 2022). TPACK represents the integration of content knowledge, pedagogical knowledge, and technological knowledge, focusing on how technology can be tailored to meet pedagogical needs in specific teaching contexts (Hanik et al., 2022; Schmid & Petko, 2019). In the learning process, content knowledge is essential for teachers, as it defines the distinct ways of thinking in each subject area. Therefore, analyzing TPACK competencies is an important foundation in school management (Suyamto et al., 2020; Uningal, 2020).

Before the learning process begins, teachers consider the use of technology-based learning media to deliver their materials. This is evident in the various technology-based media that teachers use, as well as the media designed or developed by the teachers themselves. This aligns with the view of (Suyamto et al., 2020), which explains that TPACK is a framework that seeks to understand the relationship between pedagogical knowledge and technology use. In TPACK, a teacher's ability to integrate technology into teaching makes the learning process more effective and efficient.

Additionally, in terms of Pedagogical Content Knowledge (PCK) in biology, the technology-based media used by teachers align with the material being taught. The media used are also appropriately matched to their instructional use. For example, videos and multimedia are used by teachers to teach complex processes, such as viral reproduction. The use of videos and other multimedia makes it easier for students to grasp the concepts being taught (Manurung, 2021). Pedagogical Content Knowledge (PCK) is a blend of pedagogical knowledge specifically related to certain content, meaning that teachers need to understand the content being taught and ensure that it is adapted to the technology used (Erlina & Ulfah, 2022; Rahmadi, 2019).

Furthermore, in terms of developing technology-based media, teachers are also capable of designing media suitable for the taught material, although the developed media are still limited. The integration of

technology in learning offers many benefits, such as improving learning quality, expanding access to education, helping to visualize abstract concepts, facilitating the understanding of complex topics, presenting learning material more attractively, and enabling interactions between students and the material being studied (Paidi et al., 2021; Wangge, 2020)

In addition to widely used media such as videos and animations, more advanced technology-based tools like Augmented Reality (AR) and Virtual Reality (VR) are being explored for biology education. These tools provide immersive learning experiences, allowing students to interact with complex biological processes like mitosis or photosynthesis in ways that enhance understanding (Arbuzova, 2023; Hunaepi et al., 2023; Nguyen et al., 2022). The integration of such advanced tools aligns with efforts to improve TPACK competencies among biology teachers, which have been shown to increase student engagement and learning outcomes.

In conclusion, while biology teachers have made considerable progress in developing TPACK competencies, there is still room for improvement, particularly in the creation and use of more advanced tools like E-Modules and interactive simulations. Ongoing professional development is essential to equip teachers with the skills needed to design and implement these tools effectively. As technology continues to evolve, so too must the pedagogical approaches employed by educators to ensure that students receive a comprehensive and engaging biology education.

Conclusion

This study demonstrates that biology teachers in Kuala Tungkal high schools possess good competence in integrating *Technological Pedagogical Content Knowledge* (TPACK) into their teaching practices. The use of technology-based instructional media, such as PowerPoint, videos, and animations, significantly aids in enhancing students' understanding of complex biological concepts. The findings reveal that teachers exhibit strong TPACK competence, with good scores in technological knowledge and very good scores in pedagogical content knowledge. Despite these positive results, there remains a gap in the utilization of more advanced technological tools, such as e-modules and interactive simulations. These tools have not been fully leveraged, highlighting the need for further improvement in teachers' ability to integrate more sophisticated technology into their lessons. This study underscores the importance of continuously enhancing technological competence among teachers to ensure the effectiveness of digital tools in enriching student learning experiences. Overall, the integration of TPACK in biology teaching has proven effective in facilitating more interactive and efficient learning, leading to improved student outcomes.

For future research, it is recommended to focus on exploring the development and application of more advanced instructional technologies, such as e-modules, Augmented Reality (AR), and Virtual Reality (VR), in biology education. These technologies offer great potential for providing immersive and interactive learning experiences, which can significantly enhance students' understanding of abstract biological concepts. Moreover, future studies should investigate the challenges teachers face in adopting and utilizing these advanced technologies, such as limitations in resources, time, and technological expertise. To address these challenges, further research should emphasize the importance of ongoing professional development programs that equip teachers with the necessary skills to create and implement advanced instructional media. Additionally, studies examining the impact of these technologies on student learning outcomes will provide valuable empirical evidence regarding their effectiveness in biology education, offering insights for educators and policymakers to improve the overall quality of teaching and learning.

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Author Contributions

All authors contributed significantly to this research. Harlis conceptualized and designed the study, oversaw data collection, and contributed to the interpretation of the results. Retni Sulistiyoning Budiarti assisted with data analysis and provided critical revisions to the manuscript. Dara Mutiara Aswan was responsible for administering the questionnaires and conducting interviews with the participants. Hendra Budiono contributed to the literature review and assisted in the drafting of the manuscript. All authors reviewed and approved the final version of the manuscript, ensuring accuracy and integrity throughout the research process.

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The authors declare no conflict of interest.

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