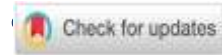




Implementing the TPACK model to enhance learning outcomes of future biology teachers for the digital era



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ABSTRACT

This research is motivated by the rapid development of technology, which has impacted learning in preparing prospective teachers for the digital era. One of the essential competencies required for this preparation is the ability to implement the TPACK model in the learning process to improve the learning outcomes of prospective biology teacher students. This study aims to analyze the effect of implementing the Technological Pedagogical Content Knowledge (TPACK) model on the learning outcomes of prospective biology teacher students in preparing them as educators in the digital era. TPACK is a framework that integrates technology, pedagogy, and content to create more effective and interactive learning experiences. The research method used is quasi-experimental, employing a non-equivalent control group design. The results show a significant improvement in the learning outcomes of students in the experimental group compared to the control group. The implementation of TPACK also enhances students' technological skills, which are crucial for their preparation as teachers in the digital era. This study concludes that the application of TPACK not only has a positive impact on cognitive learning outcomes but also fosters a positive attitude towards the use of technology and improves students' psychomotor skills.

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INTRODUCTION

The rapid advancement of technology in the digital era has brought significant changes to various aspects of life, including education. Technology not only affects how information is presented but also how learners engage with and interact with learning content. In this context, prospective teachers, including prospective biology teachers, face the challenge of integrating technology into their teaching to create relevant, effective, and meaningful learning experiences for



students. This challenge is increasingly urgent, as digital competence has become one of the essential skills in the 21st century. Advances in information and communication technology have transformed teaching and learning methods, necessitating innovation in educational approaches. Prospective teachers, especially in scientific fields such as biology, must be equipped with the ability to effectively utilize technology in the learning process. Mishra and Koehler (2006) state that to be effective teachers in the digital era, the ability to integrate Technological Pedagogical Content Knowledge (TPACK) the combination of technology, pedagogy, and content knowledge is essential and is at the core of modern education.

TPACK enables teachers to use technology in a more targeted way, not just as a teaching aid, but as an integrated tool in the learning process to deepen students' understanding of the subject matter. In the context of biology education, technology facilitates the visualization of abstract concepts, such as metabolic processes, genetics, and ecology, which are often difficult to grasp using conventional methods alone. Koehler and Mishra (2009) reveal that the application of TPACK can enhance the effectiveness of learning by combining technology with relevant pedagogical strategies and specific content.

The TPACK (Technological Pedagogical Content Knowledge) model was developed by Mishra and Koehler (2006) as an extension of the Pedagogical Content Knowledge (PCK) concept introduced by Shulman (1986). PCK is a framework that combines technological, pedagogical, and content knowledge, all of which are interconnected and play a crucial role in the learning process in the digital era. These three knowledge components cannot be separated in effective instructional design and must be used in conjunction to enhance the quality of classroom learning. Technological Knowledge (TK) encompasses the ability to use digital tools and the latest technologies to support the teaching and learning process. This involves understanding how various hardware and software work and can be integrated into education. Pedagogical Knowledge (PK) refers to the ability to understand effective teaching strategies and methods. This includes classroom management, curriculum design, and assessment of learning outcomes based on educational theories. Content Knowledge (CK) refers to mastery of the subject matter being taught, in this case, biology, which encompasses in-depth knowledge of concepts, principles, theories, and the structure of the subject material. According to Mishra and Koehler, "effective knowledge in the digital age is not just comprised of each of these components, but is the result of the dynamic interaction among them in the context of education" (Mishra & Koehler, 2006). The integration of this knowledge results in what is known as TPACK, where teachers are able to use technology appropriately to teach content effectively with relevant pedagogical approaches.

Anderson, T., & Dron, J. (2011) state that in the digital age, teachers are expected not only to master the subject matter and teaching methods but also to be capable of integrating technology into the learning process. Technology plays a crucial role in facilitating active, collaborative, and constructivist learning. According to Angeli and Valanides (2009), "TPACK enables teachers to select and use appropriate technology based on specific learning objectives, as well as understand how that technology can enrich the learning process for students" (Angeli & Valanides, 2009).

However, the application of technology in the teaching and learning process has not yet been used optimally and cannot be implemented carelessly. Teachers are not only required to master technology but also need to align the use of that technology with pedagogical knowledge and the content being taught. One approach that provides a framework for integrating these three elements is the TPACK (Technological Pedagogical Content Knowledge) model. TPACK helps prospective teachers understand how to combine technology with effective pedagogy and deep content knowledge, allowing for optimal learning experiences. In the field of biology education, the application of TPACK is particularly important. Chai, Koh, and Tsai (2013) emphasize that

TPACK is not only relevant for enhancing students' conceptual understanding but also prepares prospective teachers to adapt to the ever-changing learning environments.

In the context of biology education, for example, TPACK enables prospective teachers to use digital tools such as virtual lab simulations, interactive videos, and 3D visualization applications to help students understand challenging concepts like embryology, genetics, photosynthesis, or ecology. Technology also allows for the creation of richer and more interactive learning experiences, where students can participate more actively in the learning process, both individually and collaboratively (Jonassen, Howland, Marra, & Crismond, 2008).

Biology, as a complex and abstract discipline, requires learning strategies that can facilitate the understanding of abstract concepts through visualization, simulation, and experimentation. Technology can be a very beneficial tool in facilitating this; however, prospective biology teachers must also possess adequate pedagogical skills to effectively utilize that technology. Therefore, the application of TPACK not only enhances prospective teachers' understanding of biology content but also trains them to use technology wisely in the future learning process.

Biology learning that relies on abstract concepts often requires the assistance of technology to visualize difficult material. The application of TPACK in biology education can enhance teaching effectiveness by providing visual aids, simulations, and deeper technology-based interactions. According to Hsu, Tsai, and Chang (2010), the use of technology in biology education offers a more meaningful learning experience for students, as they can explore material independently through simulations, virtual experiments, and interactive visualizations. They state that "digital technology enhances teachers' ability to explain abstract scientific concepts in a way that is easily understood by students" (Hsu, Tsai, & Chang, 2010). For example, the use of virtual reality (VR) and augmented reality (AR) can be employed to visualize human anatomy or simulate ecosystems in a highly realistic manner, thereby facilitating students' understanding of these concepts.

Additionally, the use of Learning Management System (LMS) platforms can help prospective biology teachers manage classes, organize learning resources, and provide more structured assessments. LMS allows for more flexible interaction between educators and learners, as well as supporting learning beyond the classroom. Numerous studies have shown that the application of TPACK can enhance student learning outcomes. One of the main benefits is the improvement of conceptual understanding through technology integration, where technology can help visualize concepts that are difficult to grasp through traditional methods. Koehler and Mishra (2009) state that "teachers who are able to effectively combine the three elements of TPACK are likely to improve the quality of learning and student outcomes, especially in the context of complex material" (Koehler & Mishra, 2009).

In the context of biology education, the application of TPACK enables prospective teachers to teach material in a way that is more interactive and relevant to the digital world of today's students. This can enhance student engagement, motivation to learn, and critical thinking skills. For example, by using digital experiment simulations, students can be more active in exploring and understanding biological processes that occur, rather than just studying them theoretically. According to research by Chai, Koh, and Tsai (2010), the integration of TPACK also contributes to the development of critical thinking and problem-solving skills, which are crucial in science education. They state that "the application of TPACK in science education not only enhances students' understanding of scientific concepts but also facilitates the development of analytical skills needed to evaluate technology-based information" (Chai, Koh, & Tsai, 2010).

Although the application of TPACK has many benefits, there are several challenges that must be faced in integrating this model into education. One of them is the limited technological infrastructure in many schools, particularly in remote areas. According to Voogt and McKenney



(2017), "limited access to technology and inadequate training often pose major barriers to the implementation of TPACK in many schools" (Voogt & McKenney, 2017). Furthermore, not all prospective teacher students possess sufficient technological skills, necessitating additional training in the use of educational technology. Another challenge is the resistance to change in teaching methods. The application of TPACK requires a shift in mindset from traditional teaching methods to more dynamic, technology-based, and student-centered learning. This transition process often demands time and strong support from educational institutions. The TPACK model provides a holistic framework for integrating technological, pedagogical, and content knowledge, particularly in biology education in the digital age. The application of TPACK enables prospective biology teachers to utilize technology in a relevant, interactive, and effective manner to enhance student learning outcomes. Hwang and Chang (2011) state that technology not only enriches conceptual understanding but also promotes the development of critical thinking skills and student engagement in learning. Despite the challenges in implementation, support in the form of technology training and adequate infrastructure is essential for TPACK to yield optimal results. However, the application of TPACK in the education of prospective teachers still faces various challenges, including students' technological skills, infrastructure availability, and the readiness of educational institutions. Therefore, research on the application of TPACK to the learning outcomes of prospective biology teachers is essential. This study aims not only to evaluate the effectiveness of TPACK in improving learning outcomes but also to understand how prospective biology teachers can be optimally prepared to meet the demands of learning in the digital age.

RESEARCH METHODS

Research Design

This study employs a quasi-experimental research method with a nonequivalent control group design. In this design, two groups are being studied: the experimental group, which will receive treatment through the implementation of the TPACK model in learning, and the control group, which will use conventional teaching methods without the application of TPACK. This design is chosen because it allows the researcher to compare learning outcomes between the two groups and evaluate the effectiveness of TPACK implementation (Table 1).

Table 1. Nonequivalent Control Group Design.

Group	Pre Test	Treatment	Post Test
Experiment	O1	X1	O3
Control	O2	X2	O4

Information :

O1 and O2 : Pre Test

O3 and O4 : Post Test

X1 and X2 : Treatment

Population and Samples

The population in this study consists of seventh-semester students from the Biology Education Program at the Faculty of Teacher Training and Education (FKIP) Universitas Pasundan Bandung, who are currently taking the Embryology course and have previously completed a course on biology teaching strategies. The choice of this semester is based on the assumption that students at this stage have a sufficient understanding of biology content and basic pedagogy, as well as an introduction to the use of technology in education. The research sample was selected using purposive sampling techniques, where two classes were chosen as samples: one class served as the experimental group, and the other as the control group. The number of students



participating in each group consisted of 80 individuals. Consisting of 40 people in the experimental class and 40 people in the control class.

Instruments

The instruments used in this study include: 1. Learning Outcomes Test: This test is designed to measure the cognitive abilities of students. It consists of 40 multiple-choice and 10 essay questions that cover biology content and technology-based pedagogical applications. The test is administered at the beginning and end of the study (pre-test and post-test) to assess changes in students' understanding. 2. Questionnaire: This instrument is utilized to measure the affective aspects of students regarding their attitudes toward the use of technology in learning and the application of the TPACK model. The questionnaire contains 10 statements rated on a 1-5 Likert scale (from strongly disagree to strongly agree). 3. Observation: 10 observation instruments are used to assess students' psychomotor skills, such as their involvement in technology-based simulations or experiments. Observations are conducted during the learning process in the experimental class to evaluate student engagement and participation. 4. Interviews: Semi-structured interviews are conducted with selected students from both groups to gather in-depth information about their perceptions of the learning process and the application of technology in the classroom. This qualitative data provides valuable insights into the students' experiences and attitudes toward the TPACK model.

Procedures

The steps in conducting this research are as follows: a. Preparation: Develop TPACK-based learning materials, including teaching materials, the technology media to be used, and student worksheets, as well as developing research instruments (learning outcome tests, questionnaires, observations, and interviews). b. Pre-test Implementation: Before the treatment is given, a pre-test is conducted in both groups (experimental and control) to assess the initial understanding of students regarding biology material and their mastery of technology. c. TPACK Implementation in the Experimental Group: a). The experimental group receives TPACK-based learning, where technology is explicitly integrated into the biology teaching process. For example, the use of virtual laboratory simulations, interactive videos, and applications for visualizing biological concepts. b). Learning takes place over several sessions according to the planned topics. d. Conventional Learning in the Control Group: The control group is taught using traditional learning methods without the integrated application of technology. This method focuses on lectures, discussions, and the use of textbooks as the primary learning source. e. Post-test Implementation: After the learning is completed, a post-test is administered to both groups to evaluate the improvement in student learning outcomes. f. Affective and Psychomotor Data Collection: a). Affective questionnaires are administered after the post-test to measure students' attitudes toward the use of technology in learning. b). Observations are conducted during the learning process in the experimental class to measure students' psychomotor skills in using technology. c). Interviews are conducted after the learning to obtain qualitative data about students' perceptions related to TPACK-based learning.

Data Analysis

The data obtained from this research will be analyzed using quantitative and qualitative analysis techniques, detailed as follows: a. Quantitative Analysis: A t-test is conducted to examine the mean differences in learning outcomes (pre-test and post-test) between the experimental and control groups. Descriptive statistical tests are then used to analyze the results of the students' attitude questionnaires. b. Qualitative Analysis: Data from observations and interviews are qualitatively analyzed using content analysis techniques to identify themes related to the implementation of TPACK and students' perceptions. The results of the prerequisite tests. I. Normality Test Using tests such as Kolmogorov-Smirnov or Shapiro-Wilk to determine whether the learning outcome



data is normally distributed. Result Indicates the significance value (p-value). If $p > 0.05$, the data is considered normal. 2. Homogeneity Test Use Levene's test or Bartlett's test to check for equal variances between groups (experimental group and control group). Result: If $p > 0.05$, the variances between groups are considered homogeneous.

RESULTS

a. Results of Pre-test and Post-test

The research results indicate that the implementation of the TPACK-based learning model has a positive impact on the learning outcomes of prospective biology teachers. Learning outcomes were measured through pre-tests and post-tests in the experimental group (with TPACK implementation) and the control group (conventional learning). The pre-test results show that the experimental group had an average pre-test score of 62.5, while the control group had an average pre-test score of 60.2. Both groups had a relatively equivalent level of initial understanding before the treatment.

After the treatment, a significant increase was observed in the experimental group compared to the control group. The post-test results showed that the experimental group had an average post-test score of 86.2, while the control group had an average score of 76.9.

Statistical analysis using the t-test indicated a significant difference between the two groups, with a p-value < 0.05 . This means that the application of TPACK is significantly more effective in improving student learning outcomes compared to conventional teaching methods.

b. Results of Student Attitude Questionnaire toward TPACK

After the learning session, a questionnaire was administered to the experimental group students to evaluate their attitudes toward the implementation of the TPACK model. The results indicated that the majority of students had a positive attitude toward TPACK-based learning: a) Understanding Biological Concepts: 88% of students stated that the use of technology helped them understand biological concepts better. b) Interactivity and Enjoyment: 95% of students felt that learning became more interactive and enjoyable with the integration of technology. c) Confidence in Using Technology: 85% of students reported feeling more confident in using technology after participating in TPACK-based learning.

This positive attitude among students indicates that TPACK not only enhances learning outcomes but also boosts their motivation and confidence in utilizing technology in the classroom.

c. Results of Psychomotor Skills Observation

The observation of psychomotor skills was conducted to assess students' abilities in using technology during TPACK-based learning. The results of the observation indicate that: Effective Use of Technology: 80% of students were able to effectively utilize technology in completing biology-related tasks. Active Engagement: 92% of students demonstrated active involvement in technology-based simulation and experimental activities.

These findings suggest that the implementation of TPACK not only aids in enhancing conceptual understanding but also improves students' practical skills in using technology to support their learning. This is crucial for preparing future teachers in the digital era.

d. Interview Results

Interviews with several students from the experimental group revealed that they found it easier to understand biological concepts with the help of technology. One student stated, "With technology, I can visualize complex concepts, like the fertilization process, which I previously



struggled to imagine just from theoretical explanations." Students also expressed that technology-based learning made the classroom more dynamic and engaging.

DISCUSSION

The research findings indicate that the implementation of TPACK has a significant impact on improving the learning outcomes of prospective biology teachers. This improvement is clearly evident from the post-test results, which show a significant difference between the experimental group and the control group. This suggests that the integration of technology in education not only enriches the learning process but also enhances deeper conceptual understanding, as supported by Zhang, Zhao, Zhou, Fan, and Yang (2016), as well as Miller and Hohenstein (2016). These results support the research conducted by Koehler & Mishra (2009), which states that the integration of technology, pedagogy, and content in education can enhance overall learning effectiveness.

This study also found that students' positive attitudes toward the use of technology in learning contribute to the effectiveness of the TPACK model. These positive attitudes enhance motivation for learning and foster more active engagement in the classroom. These findings align with previous research by Chai, Koh, and Tsai (2010), which states that the implementation of TPACK can increase student engagement and motivation in the learning process are essential competencies that teachers must possess in the digital age (Khan, 2014; Irlbeck et al., 2013; Griffin et al., 2012). Through this experience, prospective biology teachers can be better prepared to face the challenges of teaching in an increasingly digital environment. The use of technological tools in integrated learning allows students to practice using modern instruments relevant to the field of biology, such as digital microscopes, simulation software, and biological measuring devices (Baker, 2017). Practical activities within TPACK-based learning encourage students to engage in hands-on tasks that require psychomotor skills, such as conducting experiments, demonstrating procedures, or using digital applications in data analysis (Harris & Hofer, 2011). This finding aligns with the research by Herring et al. (2016), which emphasizes that the TPACK approach creates a more immersive learning experience and enables better comprehension of complex scientific concepts.

Improvement of Learning Outcomes Through TPACK

The implementation of TPACK has been shown to enhance the learning outcomes of prospective biology teachers. This is evidenced by the significant increase in post-test scores within the experimental group. The integration of technology with pedagogy and content provides better visualization and interactivity, which can aid students in understanding the material more clearly and in-depth. Koehler & Mishra (2009) argue that TPACK enables teachers to leverage the strengths of technology to support more effective teaching strategies, particularly for complex and abstract concepts such as biological content.

a. Positive Attitude Towards the Use of Technology

The positive attitude of students towards the implementation of TPACK also plays a significant role in the success of the learning process. The high motivation and engagement levels among students, as indicated by the survey results, support the theory that technology can make learning more engaging and interactive. Chai, Koh, and Tsai (2013) also found that the use of technology in education enhances students' interest in learning and boosts their confidence to participate actively in the classroom.

b. Technology Skills as Competencies for the Digital Era

The implementation of TPACK also enhances students' technology skills, which are essential competencies for future teachers in the digital era. These skills are not only crucial for facilitating



more effective learning but also aid students in their preparation as educators who can integrate technology into the curriculum. Mishra and Koehler (2006) assert that future teachers must possess the ability to combine content, pedagogy, and technology in their teaching to maximize student learning outcomes.

d. Students' Readiness to Face Educational Challenges in the Digital Era

This research illustrates that the implementation of TPACK can help prepare prospective biology teachers to confront educational challenges in the digital era. In addition to enhancing cognitive learning outcomes, the technology skills acquired during the learning process will also be highly beneficial when they become teachers in the future. According to Koehler and Mishra (2009), teachers who understand the TPACK framework possess a competitive advantage in leveraging technology to optimize the teaching and learning process in the classroom.

The implementation of TPACK not only impacts the improvement of cognitive learning outcomes but also develops essential technology skills for prospective teachers. Observation results indicate that students become more proficient in using various software and digital tools relevant to biology learning, such as virtual lab simulations, biological process-visualizations, and technology-based assessment tools. This is particularly relevant to the demands of education in the digital era, where technology has become an integral part of the teaching and learning process.

CONCLUSION

Based on the research findings, it can be concluded that the implementation of TPACK has a significant positive impact on the learning outcomes of prospective biology teachers. The application of TPACK not only enhances the understanding of biological concepts but also fosters a positive attitude towards the use of technology and improves students' skills in utilizing technology for learning. Therefore, TPACK can be regarded as an effective approach in preparing competent biology teacher candidates who are ready to face the challenges of education in the digital era.

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