journal homepage: https://ojs3.unpatti.ac.id/index.php/biopendix

B I O P E N D I X P-ISSN: 2407-4969
Volume 12, Number 1, October 2025 E-ISSN:2684-8341
Pages: 129-136 DOI:https://doi.org/10.30598/biopendixvol12issue2page129-136

A Descriptive Study on the TPACK Knowledge of Biology Teachers in Sragen Regency, Central Java

Sendy Putra Pradana[1*], Advend Sri Rizki Sianturi[2], Muhammad Khoirul Antony[3], Ahmad Naharuddin Ramadhan[4]

[1,2] Biology Education Study Program, Faculty of Teacher Training and Education, Pattimura University, Ambon, Indonesia
*email: sendy.pradana@lecturer.unpatti.ac.id
[3]Biology Education Study Program, Faculty of Teacher Training and Education, Sriwijaya University, Palembang, Indonesia
[4]Biology Education Study Program, Faculty of Math and Science, Semarang State University, Semarang, Indonesia

Submitted: June 20, 2025; Revised: July 01, 2025; Accepted: July 04, 2025; Published: October 31, 2025

Abstract. In the context of rapid digital transformation, the integration of the TPACK (Technological Pedagogical Content Knowledge) framework has become increasingly vital for educators—especially those teaching biology—to facilitate the incorporation of technology into instruction and promote deeper student comprehension of complex topics. TPACK comprises three foundational areas: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK), as well as their interrelated domains: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK). This study investigates the extent to which high school biology teachers implement the TPACK components. Employing a descriptive research design with a test-based approach, the study targets a hypothetical population encompassing all senior high school biology teachers in Sragen Regency—past, present, and prospective. A convenience sampling technique was applied, selecting 17 currently active biology teachers from 13 senior high schools across the region. Data collection utilized a structured test instrument designed to evaluate teachers' comprehension of TPACK concepts. Results indicate that the participants generally possess a moderate level of knowledge regarding the application of TPACK in teaching.

Keywords: TPACK; Teacher Test

INTRODUCTION

Teachers play a vital role as agents of change, and as such, they are expected to continuously improve classroom learning processes and refine their skills in planning and designing instruction. One of the key approaches to achieving this is through a deep understanding of Pedagogical Content Knowledge. A strong foundation of PCK enables teachers to facilitate effective learning by aligning the characteristics of the subject matter with appropriate instructional strategies. Pedagogical Knowledge and Content Knowledge are integrated into a unified concept known as PCK.

In line with this, (Etkina, 2010) tated that the key components teachers must master in the learning process are Content Knowledge and Pedagogical Knowledge, both of which are integrated into Pedagogical Content Knowledge. CK refers to a teacher's ability to understand the subject matter, while PK encompasses knowledge about how students learn, including an understanding of cognitive psychology and how memory functions during the learning process. In teaching biology, it is not sufficient to merely master the subject matter (knowing science); teachers must also consider how to teach it effectively (Widhy, 2015). PCK involves methods of delivering content that enhance its teachability and make it more accessible to students. Therefore, as teaching experience develops over time, teachers can enhance their PCK abilities (Purwaningsih, 2015). (Eilks & Markic, 2011) also emphasized that PCK can transform teaching and learning approaches by fostering the development of competencies in instructional practice.

Entering the 21st century and the ongoing era of digitalization, teachers must continuously adapt and further develop their competencies, it is no longer sufficient to rely solely on an understanding of Pedagogical Content Knowledge. This continuous development is essential for maintaining teacher professionalism. Teacher

professionalism plays a crucial role in guiding students to build strong character values throughout their educational journey (Pratama, 2021). Teachers hold a central role in education, considering that education is a fundamental human need inherent to every individual (Priscilla & Yudhyarta, 2021). For these reasons, teachers must consistently upgrade their skills to keep pace with the times. One essential framework that should serve as a guide for teachers in navigating the digital era is Technological Pedagogical Content Knowledge (TPACK) (Akhwani & Rahayu, 2021).

TPACK refers to a knowledge construct utilized by teachers to support the teaching process through the integration of technology. The combination of technology with pedagogical knowledge and content knowledge has become a vital component of modern education programs (Lestari, 2015). he use of technology in 21st-century learning is considered essential, as it is expected to foster more innovative teaching and learning experiences. The initial concept of TPACK was introduced by (Koehler & Mishra, 2005), who proposed it as a model that integrates technology with pedagogy and content in instructional practices. The TPACK concept was developed based on the description of Pedagogical Content Knowledge, which was then expanded to explore how the interaction between technology and PCK can lead to more effective teaching. The TPACK framework, as conceptualized by Koehler and Mishra, is typically visualized through an integrated model, as depicted in Figure 1.

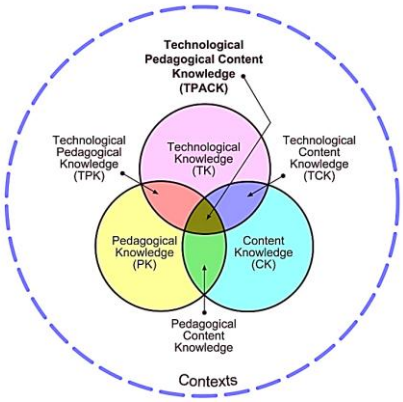

Figure 1. The TPACK framework

TPACK is a form of knowledge that teachers must possess in order to integrate technological elements into the delivery of learning materials in a holistic manner. Teachers are required to have a deep understanding of the interaction among the three core components of knowledge, there are Pedagogical Knowledge, Content Knowledge, and Technological Knowledge, and be able to apply this understanding by using appropriate pedagogical methods and technologies in instruction (Schmidt et al., 2014). eachers' competencies can be improved and enhanced through the TPACK approach, in which pedagogical skills, subject matter knowledge, and technological expertise are combined. By integrating these three elements, teachers can design more effective and innovative learning experiences, ultimately contributing to better student learning outcomes (Hayani & Sutama, 2022).

To create high-quality learning experiences, teachers need to understand and master the design of effective instructional activities. Achieving this requires a thorough understanding of the TPACK concept. This study aims to measure teachers' level of knowledge regarding TPACK, which includes their ability to integrate technology, pedagogy, and content within the teaching and learning process. The results of this study are expected to serve as a reference for teachers in continuously enhancing their TPACK competencies through various training and professional development programs, thereby enabling them to deliver more effective and innovative instruction.

MATERIALS AND METHODS

This study employs a descriptive research design using a test-based method. In this type of research, the collected data are objectively described to reflect the actual level of teachers' TPACK competencies, particularly in terms of their mastery of the core components: Technological Knowledge, Pedagogical Knowledge, and Content Knowledge. Foundational mastery of all TPACK components significantly impacts the learning process, as each component is inherently interconnected.

The research was conducted in senior high schools (SMA) located in Sragen Regency. The population of this study is hypothetical, encompassing all senior high school biology teachers in Sragen those who have taught in

the past, those currently teaching, and those who may teach in the future. A convenient sampling technique was used, involving biology teachers currently available and easily observed. The sample consisted of 17 biology teachers from 13 different senior high schools in Sragen Regency.

Data were collected using a TPACK knowledge test. For empirical validity, the test instrument yielded an infit MNSQ value of 1.00 with a standard deviation of 0.16. This indicates that all 40 test items fit well within the Rasch model, as the values fall within the acceptable range of ≥ 0.77 to ≤ 1.30. The data represent teachers' understanding of TPACK principles as assessed through the test. These data were tabulated using the developed instrument and then identified and presented in descriptive statements. This method was chosen for its practicality and simplicity.

The categorization of TPACK competency was based on the extent to which teachers demonstrated the ability to apply technology in the learning process, as measured by various test items. The collected data were then analyzed and interpreted using the scoring interpretation guidelines provided by (Hapsari et al., 2019), as follows:

Table 1. Score Interpretation Criteria

Score Range	Description
84 – 100	Very Good
68 – 83	Good
52 – 67	Fair
36 – 51	Poor
< 36	Very Poor

The use of a test-based descriptive research design in this study appropriately captures the multidimensional nature of TPACK, as it enables the objective assessment of teachers' knowledge across the three foundational domains technological, pedagogical, and content. By employing empirically validated test items and aligning the analysis with established scoring criteria, this approach ensures that the results not only reflect individual component mastery but also offer insights into how these domains interact in practice. Thus, the method employed is not only practical and efficient but also robust in representing the integrative essence of the TPACK framework within a measurable and context-relevant structure.

RESULTS AND DISCUSSION

This study yielded data in the form of percentages representing teachers' mastery of TPACK principles, as obtained through test results. The TPACK components identified in this research consist of seven key elements: Technological Knowledge, Pedagogical Knowledge, Content Knowledge, Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge, and the integrated TPACK.

Teachers' mastery of these components was measured using a test instrument administered to the participants. Descriptive data on teachers' TPACK proficiency are presented in Table 2. Based on Table 1, it can be seen that the biology teachers' PK competency falls into the "Good" category (69.6%), CK is "Good" (82.4%), TK is "Fair" (57.4%), PCK is "Fair" (52.9%), TCK is "Fair" (64.7%), TPK is "Fair" (59.4%), and the overall TPACK competency is "Fair" (54.1%). Thus, among all components, teachers' overall TPACK competency ranks the lowest.

Table 2. Summary of TPACK Principle Mastery Based on Test Results

TPACK Component	Score	Description
PK	69,6	Good
CK	82,4	Good
TK	57,4	Fair
PCK	52,9	Fair
TCK	64,7	Fair
TPK	59,4	Fair
TPACK	54,1	Fair
Mean	**62,92**	**Fair**

Table 2 presents a summary of teachers' mastery levels across the seven components of the TPACK framework, namely Pedagogical Knowledge, Content Knowledge, Technological Knowledge, Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge, and the integrated TPACK. The scores are presented alongside their corresponding qualitative categories. Additionally,

the overall mean score across all components is provided. A more detailed discussion and interpretation of these findings will be presented in the subsequent section.

To further enhance the interpretation of the results, the descriptive data derived from the TPACK test were also transformed into graphical representations (Figure 2). These visualizations serve to illustrate patterns and distributions of teachers' competencies across the core components of TPACK more clearly and intuitively. Graphical displays not only facilitate comparative analysis between individual and group performance but also support better identification of areas that require pedagogical or technological reinforcement. Thus, incorporating visual elements strengthens the communicative aspect of the findings and contributes to a more comprehensive understanding of the data.

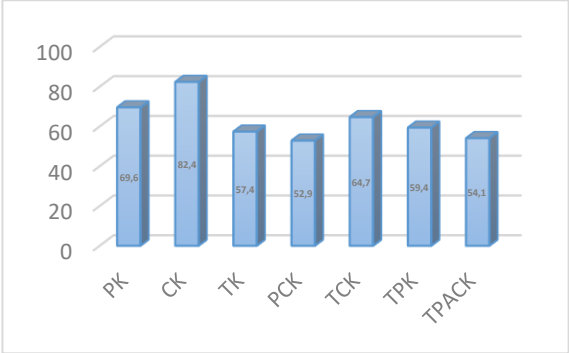

Figure 2. Summary of TPACK Principle Mastery Based on Test Results

To further enrich the presentation of findings, the descriptive statistics obtained from the TPACK test were visualized through a bar graph, as presented in Figure 2. This graphical depiction offers a clearer overview of the distribution of teacher competencies across each domain of the TPACK framework. Visual representations like this are instrumental in capturing variations in knowledge domains, allowing for intuitive comparisons and highlighting disparities that may not be immediately evident from numerical data alone. The inclusion of such figures enhances the interpretability of the research outcomes by providing a more accessible format for both academic and practitioner audiences. A detailed discussion of the trends and implications shown in the figure will be elaborated in the subsequent section.

The mastery of TPACK principles consists of seven main components: Pedagogical Knowledge, Content Knowledge, Technological Knowledge, Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge, and the integrated TPACK. The TPACK competency test was conducted to assess how well teachers understand the fundamental aspects of TPACK-related knowledge. Based on Table 2, the pedagogical knowledge of biology teachers falls into the "Good" category, with a score percentage of 69.9%. According to Government Regulation No. 74 of 2008, pedagogical competence refers to a teacher's ability to manage the student learning process, which includes educational insight, understanding of learners, curriculum development, instructional planning, media usage, learning assessment, and student development. PK encompasses teachers' knowledge related to classroom management, lesson planning, and instructional delivery. In this context, biology teachers demonstrate strong pedagogical knowledge, as reflected in their ability to understand student characteristics and apply various instructional models, methods, and media.

The Content Knowledge of biology teachers is categorized as "Good," with a score percentage of 82.4%. This indicates that biology teachers are expected to have strong mastery of subject matter related to the field of biology. Mastery of content is essential, as teachers must thoroughly understand the topics they are going to teach before delivering them to students. According to (Etkina, 2010), CK refers to knowledge of the subject matter being taught as well as the ability to develop new knowledge. CK competence can be evaluated by assessing the depth and comprehensiveness of a teacher's understanding of the material. Nevertheless, content mastery should be continuously improved, considering that classroom material plays a crucial role in the learning process and in achieving educational objectives aligned with the established Basic Competencies. A lack of content mastery may negatively impact the effectiveness of instruction and diminish the teacher's authority in the eyes of students (M.S.Tuerah, 2015). To enhance their subject knowledge, teachers need to invest time in reading, studying, and deepening their understanding through textbooks and other reliable sources.

The level of Technological Knowledge among teachers is categorized as "Fair," with a percentage of 57.4%. Given the rapid pace of technological advancement, teachers are expected to continuously develop their technological skills. Mastery of technology is essential in today's digital era to support the learning process, as various aspects of life, such as the economy, transportation, technology, communication, and information are

experiencing swift and often unpredictable changes. These rapid changes can offer valuable opportunities if properly utilized; however, without systematic, structured, and measurable anticipation, such developments may pose negative consequences (Rosnaeni, 2021). Teachers' knowledge of technological advancements can be observed through their effective use of digital media that integrates advanced technologies as part of popular instructional strategies in 21st-century learning (Peña-Ayala, 2021).

Teachers' Pedagogical Content Knowledge is categorized as "Fair," with a percentage of 52.9%. In this study, PCK is defined as the balance between pedagogical knowledge and content knowledge in biology. PCK reflects a teacher's ability to deliver subject matter effectively so that it is well understood by students (teachability and accessibility), and it can be developed by every teacher over time (Purwaningsih, 2015). PCK represents the integration of content knowledge and pedagogical strategies to present specific topics, taking into account the organization of material, students' interests, and varying abilities (Koçoğlu, 2009), The evaluation of PCK involves assessing the teacher's ability to align appropriate instructional models, methods, media, and assessment strategies with the content being taught. However, teachers' PCK still needs improvement, as many are not yet fully capable of optimally integrating pedagogical and content knowledge.

Biology teachers' understanding of Technological Content Knowledge remains suboptimal and is categorized as "Fair," with a score percentage of 64.7%. TCK is defined as the combination of technological knowledge and subject matter content (Koehler & Mishra, 2005). The level of TCK can be assessed based on how well teachers integrate information and communication technology with the subject matter—such as utilizing ICT to strengthen conceptual understanding, guiding students to find relevant information through digital platforms, and using technological tools to collect teaching materials. However, the findings indicate that many teachers still struggle to effectively integrate technology with content. Currently, their use of technology is often limited to downloading materials from certain websites. Therefore, enhancing teachers' understanding of TCK is crucial. With strong ICT proficiency, teachers can utilize technology more effectively in delivering instructional content. According to (Mairisiska et al., 2014), the use of ICT can transform abstract concepts into more concrete representations. Teachers are expected not only to have deep subject knowledge but also to possess a broad understanding that allows them to communicate new information in ways that help students grasp complex concepts more easily. To deliver up-to-date content, teachers must master ICT skills that enable them to continuously update and enrich learning materials in line with the latest developments available online.

Teachers' understanding of Technological Pedagogical Knowledge is considered fair, with a score percentage of only 59.4%. TPK refers to teachers' ability to align the use of technology with various instructional activities (Puspitarini et al., 2013). The assessment of TPK includes how teachers utilize information and communication technology (ICT) to support the implementation of various teaching models and methods, how technology is adapted to meet students' characteristics, and how ICT is used as a medium to create interactive learning experiences. The analysis shows that teachers' TPK knowledge remains limited, as many are not yet familiar with a variety of tools and devices that can serve as interactive instructional media. This indicates that teachers' skills in leveraging technology to support the teaching and learning process are still underdeveloped.

Table 2 indicates that teachers' understanding of TPACK remains relatively low, with a score percentage of 54.1%. TPACK is a crucial component that integrates three fundamental domains of knowledge: Pedagogical Knowledge, Content Knowledge, and Technological Knowledge. This weakness in TPACK mastery suggests that teachers are not yet fully capable of effectively combining technology, pedagogy, and subject content. The lack of teachers' understanding of TPACK is concerning, especially given the importance of this concept in navigating technological advancements in the 21st century. A solid understanding of TPACK enables teachers to find appropriate solutions to classroom challenges and supports the development of their professional competencies within the educational environment (Chai et al., 2013).

The mastery of all components within the TPACK framework is a critical concern for educators. The integration of technology in education cannot rely solely on proficiency with digital tools; rather, it requires comprehensive competence that encompasses pedagogical, content, and technological dimensions in a cohesive manner as outlined in the TPACK model (Akram et al., 2021). In the context of online learning during the COVID-19 pandemic, teachers' ability to apply TPACK has proven essential in maintaining instructional quality. Educators who demonstrate technological proficiency, a positive disposition toward innovation, and adaptable pedagogical knowledge tend to be more effective in designing technology-integrated learning strategies (Seufert et al., 2021).

The implementation of TPACK in educational settings is closely tied to teachers' readiness to integrate its three core components: pedagogical knowledge, content knowledge, and technological knowledge. This readiness involves the ability to design instructional strategies that are contextually relevant, while also taking into account students' characteristics and the intended learning outcomes. However, limited access to digital tools and resources in many public schools poses a significant challenge to effective integration. Therefore, the

successful application of TPACK largely depends on teachers' creativity in utilizing available resources and the extent to which institutional policies support the provision of adequate technological infrastructure (Santos & Castro, 2021).

Therefore, the development of TPACK must be supported by institutional commitment, comprehensive competency assessments, and reflective approaches that are grounded in authentic classroom practice (Loi, 2021). To enhance teachers' TPACK, professional development programs should be designed based on the TPACK framework, particularly by incorporating argumentation-based strategies and hands-on practice, which have been shown to significantly improve teachers' self-efficacy in meaningfully integrating technology into instruction (Joshi, 2023). Improving TPACK also requires that teachers thoroughly understand their classroom environment (micro-context), the broader school culture and conditions (meso-context), as well as the prevailing educational policies and systemic structures (macro-context). In addition, teachers should adopt caring and empathetic pedagogical approaches that prioritize students' needs, emotions, and well-being throughout the learning process (Gozali, 2022).

To address these challenges, professional development approaches must go beyond theoretical understanding and incorporate practical, context-based lesson planning (Schmid et al., 2021). Training programs that emphasize Technological Pedagogical Knowledge and Technological Content Knowledge have been shown to be the most effective in improving the quality of TPACK implementation among teachers (Santos & Castro, 2021). Moreover, fostering a positive attitude toward the use of technology serves as a significant predictor in encouraging teachers' sustained intention to adopt the TPACK framework (Seufert et al., 2021). In today's educational landscape, curriculum-based training grounded in TPACK principles is also essential to ensure alignment between technological advancements and pedagogical competencies (Akram et al., 2021). Therefore, the development of TPACK must be supported by institutional backing, holistic competency assessments, and reflective practices that are firmly rooted in real classroom experiences.

CONCLUSION

The findings of this study indicate that while biology teachers in Sragen Regency demonstrate adequate mastery in Pedagogical Knowledge and Content Knowledge, their competencies in Technological Knowledge , as well as the integrative domains of TPACK (particularly PCK, TCK, and TPK) remain at a moderate level. This reflects a pressing need to strengthen teachers' capacity to integrate technology meaningfully into pedagogical and content domains. Therefore, it is recommended that targeted professional development programs be implemented, focusing on hands-on training, reflective teaching practices, and school-based support systems that are aligned with the TPACK framework. Additionally, educational institutions should ensure equitable access to technological resources and foster a school culture that encourages innovation and continuous learning among teachers.

REFERENCES

Akhwani, A., & Rahayu, D. W. (2021). Analisis Komponen TPACK Guru SD sebagai Kerangka Kompetensi Guru Profesional di Abad 21. *Jurnal Basicedu*, *5*(4), 1918 - 1925. https://doi.org/10.31004/basicedu.v5i4.1119

Akram, H., Yingxiu, Y., Al-Adwan, A. S., & Alkhalifah, A. (2021). Technology Integration in Higher Education During COVID-19: An Assessment of Online Teaching Competencies Through Technological Pedagogical Content Knowledge Model. *Frontiers in Psychology*, *12*, 736522. https://doi.org/10.3389/fpsyg.2021.736522

Chai, C. S., Koh, J. H. L., & Tsai, C. C. (2013). A review of technological pedagogical content knowledge. *Educational Technology and Society*, *16*(2), 31–51.

Eilks, I., & Markic, S. (2011). Effects of a long-term participatory action research project on science teachers' professional development. *Eurasia Journal of Mathematics, Science and Technology Education*, *7*(3), 149–160. https://doi.org/10.12973/ejmste/75196

Etkina, E. (2010). Pedagogical content knowledge and preparation of high school physics teachers. *Physical Review Special Topics-Physics Education Research*, *6*(2), 1–26. https://doi.org/10.1103/PhysRevSTPER.6.020110

Gozali, I. (2022). Students' Perspective on the Importance of EFL Teachers' TPACK (Technological Pedagogical Content Knowledge) and XK (Contextual Knowledge) for learning English during the Pandemic. *PASAA*, *64*(1), 244–277. https://doi.org/10.58837/CHULA.PASAA.64.1.11

Hapsari, N., Paidi, Subali, B., Astuti, F. E. C., Pradana, S. P., & Antony, M. K. (2019). The TPACK Profile of Biology Teacher Based on Certification Status: A Case Study in Bantul Regency. *Journal of Physics: Conference Series*, *1397*(1). https://doi.org/10.1088/1742-6596/1397/1/012055

Hayani, S. N., & Sutama, S. (2022). Pengembangan Perangkat dan Model Pembelajaran Berbasis TPACK Terhadap Kualitas Pembelajaran Daring. *Jurnal Basicedu*, *6*(2), 2871–2882. https://doi.org/10.31004/basicedu.v6i2.2512

Joshi, S. (2023). TPACK and Teachers' Self-Efficacy: A Systematic Review. *Canadian Journal of Learning and Technology*, *49*(2), 1–23. https://doi.org/10.21432/cjlt28280

Koçoğlu, Z. (2009). Exploring the technological pedagogical content knowledge of pre-service teachers in language education. *Procedia - Social and Behavioral Sciences*, *1*(1), 2734–2737. https://doi.org/10.1016/j.sbspro.2009.01.485

Koehler, M. J., & Mishra, P. (2005). What happens when teachers design educational technology? *Journal of Educational Computing Research Environmental Science and Technology*, *32*(2), 131–152.

Lestari, S. (2015). Analisis Kemampuan Technological Pedagogical Content Knowledge (TPACK) Pada Guru Biologi Sma Dalam Materi Sistem Saraf. *Proceeding Biology Education Conference: Biology, Science, Enviromental, and Learning*, *12*(1), 557–564.

Loi, N. V. (2021). VIETNAMESE HIGH-SCHOOL TEACHERS' PERCEPTIONS OF TPACK IN TEACHING ENGLISH AS A FOREIGN LANGUAGE. *European Journal of Education Studies*, *8*(4). https://doi.org/10.46827/ejes.v8i4.3693

Mairisiska, T., Sutrisno, & Asrial. (2014). Pengembangan Perangkat Pembelajaran Berbasis TPACK pada Materi Sifat Koligatif Larutan untuk Meningkatkan Keterampilan Berpikir Kritis Siswa Development TPACK Based Learning Devices on Colligative Properties to Improve Critical Thinking Skill Students. *Jurnal Pendidikan Matematika Dan Ilmu Pengetahuan Alam*, *3*(1), 28–37.

M.S.Tuerah, R. (2015). Penguasaan Materi Pembelajaran, Manajemen Dan Komitmen Menjalankan Tugas Berkorelasi Pada Kinerja Guru SD DI KOTA TOMOHON. *Jurnal Inovasi Dan Teknologi Pembelajaran*, *1*(2), 137–154.

Peña-Ayala, A. (2021). A learning design cooperative framework to instill 21st century education. *Telematics and Informatics*, *62*(May). https://doi.org/10.1016/j.tele.2021.101632

Pratama, D. (2021). Profesionalitas Guru Melalui Pendekatan Empat Pilar Pendidikan Dalam Mengembangkan Nilai - Nilai Karakter Siswa. *Jurnal Paris Langkis*, *1*(2), 126 - 139. https://doi.org/10.37304/paris.v1i2.2482

Priscilla, C., & Yudhyarta, D. Y. (2021). Implementasi Pilar-Pilar Pendidikan UNESCO. *Asatiza: Jurnal Pendidikan*, *2*(1), 64–76. https://doi.org/10.46963/asatiza.v2i1.258

Purwaningsih, E. (2015). Potret Representasi Pedagogical Content Knowledge (PCK) Guru dalam Mengajarkan Materi Getaran dan Gelombang pada Siswa Smp. *Indonesian Journal of Applied Physics*, *5*(01), 9. https://doi.org/10.13057/ijap.v5i01.252

Puspitarini, E. W., Sunaryo, S., & Suryani, E. (2013). Pemodelan Technological Pedagogical Content Knowledge (TPACK) Berbasis Teknologi Informasi Dan Komunikasi (TIK) Dengan Pendekatan Structural Equation Modeling (SEM). *Seminar Nasional Manajemen Teknologi XVIII*, 1–8.

Rosnaeni, R. (2021). Karakteristik dan Asesmen Pembelajaran Abad 21. *Jurnal Basicedu*, *5*(5), 4341–4350. https://doi.org/10.31004/basicedu.v5i5.1548

Santos, J. M., & Castro, R. D. R. (2021). Technological Pedagogical content knowledge (TPACK) in action: Application of learning in the classroom by pre-service teachers (PST). *Social Sciences & Humanities Open*, *3*(1), 100110. https://doi.org/10.1016/j.ssaho.2021.100110

Schmid, M., Brianza, E., & Petko, D. (2021). Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. *Computers in Human Behavior*, *115*, 106586. https://doi.org/10.1016/j.chb.2020.106586

Schmidt, D. A., Thompson, A. D., Koehler, M. J., & Shin, T. S. (2014). CIE 2014—44th International Conference on Computers and Industrial Engineering and IMSS 2014—9th International Symposium on Intelligent Manufacturing and Service Systems, Joint International Symposium on "The Social Impacts of Developments in Informat. *CIE 2014 - 44th International Conference on Computers and Industrial Engineering and IMSS 2014 - 9th International Symposium on Intelligent Manufacturing and Service Systems, Joint International Symposium on "The Social Impacts of Developments in Informat*, *42*(2), 2531p.

Seufert, S., Guggemos, J., & Sailer, M. (2021). Technology-related knowledge, skills, and attitudes of pre- and in-service teachers: The current situation and emerging trends. *Computers in Human Behavior*, *115*, 106552. https://doi.org/10.1016/j.chb.2020.106552

Widhy, P. H. (2015). Analisis Pedagogical Content Knowledge Guru Ipa Smp Kelas Viii Dalam Implementasi Kurikulum 2013 Analysis of Pedagogical Content Knowledge Junior High School 8Th Grade Science Teacher on Curriculum 2013 Implementation. *Jurnal Pendidikan Matematika Dan Sains Tahun III*, *1*, 72–78.