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Effectiveness of the STEM based TPACK Learning Model on Students 21 Century Skills in Indonesia

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Abstrak

Penelitian ini bertujuan untuk mengetahui efektivitas model pembelajaran TPACK berbasis STEM terhadap keterampilan abad-21 siswa di Indonesia. Penelitian ini adalah penelitian meta-analisis dengan manganalisis 13 jurnal nasional dan internasional yang terbit 2021-2024. Kriteria inklusi dalam penelitian ini yaitu penelitian berasal dari jurnal terindeks SINTA dan Scopus, penelitian harus metode eksperimen atau kuasi eksperimen, penelitian terkait model pembelajaran TPACK berbasis STEM, Variabel terikat terkait keterampilan berpikir abad-21 terdiri dari critical thinking and problem solving, creative, calaborative dan communicative, penelitian mempunyai data yang lengkap untuk menghitung nilai effect size, dan penelitian harus open acces serta ukuran sampel > 28 siswa. Pencarian data melalui google scholar, ERIC, Taylor of francis dan Mendeley. Proses penyaringan data dengan metode PRISMA. Analisis data adalah analisis kuantitatif dengan menghitung nilai effect size dengan bantuan aplikasi SPSS. Hasil penelitian menyimpulkan bahwa model pembelaajaran TPACK berbasis STEM memberikan pengaruh positif terhafap keterampilan berpikir abad-21 siswa di Indonesia dengan nilai rata-rata effect size (ES = 1.09) kategori effect size yang tinggi. Temuan ini memberikan informasi bagi guru implementasi pembelajaran TPACK berbasis STEM efektif mengembangkan keterampilan berpikir abad-21 siswa.

Kata Kunci: *Pembelajaran TPACK, STEM, Efek Size, Berpikir abad-21*

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Abstract

This study aims to determine the effectiveness of STEM-based TPACK learning models on students' 21st century skills in Indonesia. This research is a meta-analysis research by analysing 13 national and international journals published in 2021-2024. The inclusion criteria in this study are that the research comes from SINTA and Scopus indexed journals, the research must

be experimental or quasi-experimental methods, research related to the STEM-based TPACK learning model, the dependent variable is related to 21st century thinking skills consisting of critical thinking and problem solving, creative, collaborative and communicative, the research has complete data to calculate the effect size value, and the research must be open access and sample size > 28 students. Data search through google scholar, ERIC, Taylor of francis and Mendeley. The data filtering process with the PRISMA method. Data analysis is quantitative analysis by calculating the effect size value with the help of the SPSS application. The results concluded that the STEM-based TPACK learning model had a positive effect on students' 21st century thinking skills in Indonesia with an average effect size value (ES = 1.09) in the high effect size category. The findings provide information for teachers that the implementation of STEM-based TPACK learning is effective in developing students' 21st century thinking skills.

***Keywords**: TPACK Learning, STEM, Size Effects, 21st century thinking*

Introduction

In the era of the 21st century which is spurred by technological advances in all fields, especially in the world of education (Widiawati &; Joyoatmojo, 2018; Miterianifa et al., 2021; Zulkifli et al., 2022) . Therefore, students must have 21st century skills to be able to compete in the world of education. 21st century skills include critical thinking, creativity, collaboration, and communication skills that are key to success in the work environment (Suharyat et al., 2023; Suryono et al., 2023; Tajudin et al., 2019; Judijanto et al., 2023). In addition, digital skills, information literacy, and other abilities are also important aspects that students must master in facing the 21st century (Kuloğlu &; Karabekmez, 2022; Elfira et al., 2023; Nurdiana et al., 2023). In this context, education is not only about memorizing facts or theories, but more about preparing students to apply knowledge in real situations, solve complex problems, innovate, and adapt to change (Saputri et al., 2019).

21st century skills into the education curriculum in Indonesia demand a transformation in teaching and learning methods (A. Rahman, Santosa, &; Suharyat, 2023). Teachers must play a role that goes beyond just conveying information, being facilitators who support students to think independently and work together in teams (Abda et al., 2020; Oktarina et al., 2021; Nurtamam et al., 2023). This emphasizes the importance of a project-based learning approach, which not only increases students' understanding of the subject matter, but also builds social, emotional, and self-regulation skills. Thus, education that focuses on developing 21st-century skills not only forms work-ready students, but develops the potential of students who are ready to face and contribute to global society (Higgins, 2014; Zainil et al., 2023).

The reality of students' 21st century skills in Indonesia is still low. Results can be seen from the results *Programme International for Student Assessment* (PISA) conducted by the OECD in 2018 concluded that the science literacy of Indonesian students in learning obtained a score of 397, ranked 71 out of 78 countries (Razak et al., 2022; Supriyadi et al., 2023; Utomo et al., 2023; Rahman et al., 2023). The results are supported by the results of the TIMSS study In 2015, the critical thinking skills of Indonesian students in science and mathematics were ranked 41 out of 48 member countries (Son et al., 2023). The low thinking skills of 21st century Indonesian students are also influenced by the learning system in the classroom that is not optimal. In the learning process teachers do not direct students to have 21st

century thinking skills (Solissa et al., 2023; Rizqi et al., 2019). Furthermore, the selection of inappropriate learning models and low mastery of student technology, so that students have low 21st century thinking skills in learning (Affandy et al., 2019; Bahri et al., 2021). Therefore, there is a need for a learning model that can encourage students' 21st century abilities.

The TPACK (Technological Pedagogical Content Knowledge) model is a comprehensive framework designed to help teachers integrate technology in their teaching effectively (Zhang & Tang, 2021; Moreno et al., 2019). The framework recognizes that mastery of content alone is not sufficient for effective teaching; Teachers also need to understand how to teach such content (pedagogy) and how technology can support these two aspects. TPACK emphasizes synergy between three main domains: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). The harmonious integration of these three domains enables teachers to design and execute learning that is not only content immersive, but also innovative and engaging with the support of technology (Asamoah, 2019).

In practice, the TPACK model encourages teachers to consider how technology can improve teaching and learning in the context of the specific content being taught (Chaidam &; Poonputta, 2022; Rahman , et al., 2023). For example, math teachers could use specialized software to help students understand geometry concepts more visually and interactively, or history teachers could use virtual reality to take students on immersive exploration of historical events. Thus, TPACK helps teachers identify and utilize the most effective technology to achieve learning objectives, while ensuring that the use of such technology increases students' understanding of the subject matter (Fazilla et al., 2023; Irmita &; Atun, 2018). In this era of education 4.0, mastery of the TPACK model by teachers is an essential key to prepare students with relevant and adaptive skills in the future (Handayani et al., 2023; Bwalya et al., 2023).

TPACK learning can be linked to Science Technology Engineering and Mathematics (STEM). STEM is an interdisciplinary approach that is vital in preparing future generations for the complex challenges of this digital age (Morales et al., 2019); . Through the synergistic integration of the four disciplines, STEM education not only enhances students' conceptual understanding in their respective fields, but also develops critical skills such as problem-solving, analytical thinking, and innovation. In practice, STEM encourages project- and exploration-based learning, enabling students to apply theory in real contexts, thus paving the way for them to become creative thinkers and innovators of the future (English, 2016; Kennedy, 2014). Thus, STEM education is considered key to advancing technological and economic progress, preparing students who are prepared for ever-evolving global challenges (Asghar & Prime, 2012; Putra et al., 2023).

Previous research into TPACK learning can boost students' 21st-century thinking skills in learning (Valtonen et al., 2017; Santosa et al., 2022; Teknowijoyo, 2024). Furthermore, research by Fazilla et al., (2024) TPACK learning can encourage teacher professional competence in teaching in class so that students more easily understand the learning material. However, many TPACK learning studies have not found the effect of the size of STEM-based TPACK learning, so meta-analysis is needed to get accurate

conclusions about students' STEM-based TPACK learning in Indonesia. Therefore, this study aims to determine the effectiveness of the STEM-based TPACK learning model on the 21st century skills of students in Indonesia.

Methods

This research is a type of meta-analysis research. Meta-analysis is a type of research collecting and analyzing primary data quantitatively to obtain an accurate conclusion (Ramdani, 2016; Tamur et al., 2020; Santosa et al., 2021; Çevik &; Bakioğlu, 2022). The meta-analysis study aims to determine the effect of STEM-based TPACK learning size on students' 21st century thinking skills. According to Borenstein & Hedges (2009) The steps in meta-analysis research consist of 1) formulating the research problem, 2) collecting data and coding the data and 3) data analysis and interpretation can be seen in Figure 1.

Figure 1. Meta-analysis research procedure

Furthermore, the inclusion criteria in this study are research derived from SINTA and Scopus indexed journals, research must be experimental or quasi-experimental methods, research related to STEM-based TPACK learning models, Dependent variables related to 21st century thinking skills consist of critical thinking and problem solving, creative, calaborative and communicative, research has complete data to calculate the value of effect size, And the study had to be open access and the sample size > 28 students. Search data through google scholar, ERIC, Taylor of francis and Mendeley. Data filtering process using PRISMA method (Figure 2). Data analysis is quantitative analysis by calculating the effect size value with the help of SPSS applications. In addition, the effect size criteria can be seen in Table 1.

Table 1. Effect Size Value Criteria

Effect Size	Criterion
0.00≤ ES ≤0.20	Low
0.20≤ ES ≤0.80	Moderate
ES≥ 0.80	High

Source:(Cohen et al., 2007)

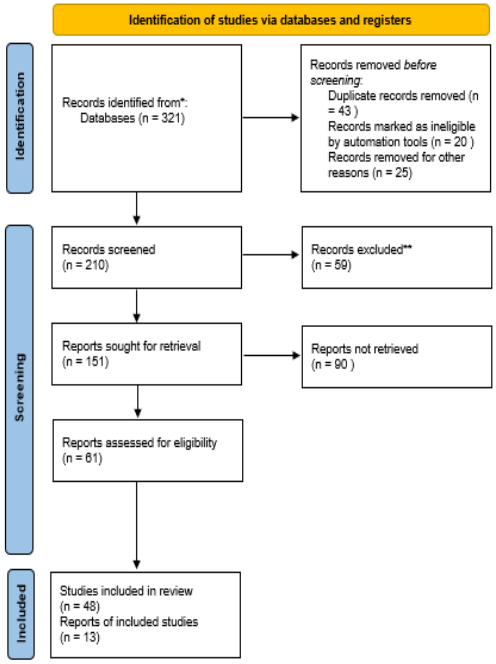

Figure 2. Data Selection Through PRISMA Method

Result and Discussion

In the process of searching data through the google scholar google scholar database, ERIC, Taylor of Francis and Mendeley related to the STEM-based TPACK learning model for 21st century skills of students in Indonesia obtained 321 studies. Furthermore, relevant research was selected based on the inclusion criteria determined by PRISMA 2020, resulting in 13 studies that met the inclusion criteria. Furthermore, 13 research journals that have met the inclusion criteria calculated

the effect size value which can be seen in Table 2.

Table 2. Effect Size Value

Journal Code	Year	Source	Index	Effect Size	Criterion
J1	2021	Google Scholar	SINTA	0.71	Moderate
J2	2021	Mendeley	SINTA	0.66	Moderate
J3	2023	Mendeley	Scopus	2.18	High
J4	2021	ERIC	Scopus	1.92	High
J5	2023	ERIC	Scopus	1.15	High
J6	2023	Google Scholar	SINTA	0.43	Moderate
J7	2023	Google Scholar	SINTA	0.92	High
J8	2024	Google Scholar	SINTA	0.44	Moderate
J9	2021	ERIC	Scopus	0.81	High
J10	2022	ERIC	Scopus	0.75	Moderate
J11	2022	ERIC	SINTA	1.08	High
J12	2021	Taylor of Francis	Scopus	2.04	Moderate
J13	2024	Google Scholar	SINTA	1.13	Moderate
Average Effect Size Value				**1.09**	**High**

Table 2, the results of effect size analysis from 13 journals obtained 8 studies have effect size values ranging from 0.43 to 0.75 with medium effect size criteria and 5 studies that have effect size values ranging from 0.92 to 2.18 with high effect size criteria. Furthermore, the average value of effect size is 1.09 with high effect size criteria. The results of the study concluded that STEM-based TPACK learning has a positive influence on the thinking skills of 21st century students in Indonesia. This research is in line with (Rahayu, 2017) The STEM-based TPACK learning model can develop students' 21st century thinking skills. This research is supported by Ayunda et al., (2022) the application of STEM-based TPACK models can improve students' higher-order thinking skills.

Furthermore, the TPACK (Technological Pedagogical Content Knowledge) learning model based on STEM (Science, Technology, Engineering, Mathematics) offers an integrative approach in education to develop students' 21st century skills in Indonesia (Sukmanasa, 2022). This approach combines technological knowledge, pedagogy, and content (TPACK) with STEM elements to create a dynamic, interactive, and well-rounded learning environment. In the Indonesian context, the application of this model is very relevant considering the urgent need to produce graduates who are not only competent in the academic field but also able to adapt and innovate in facing global challenges (Valtonen et al., 2017; Supriyadi et al., 2023).

Integrating TPACK in a STEM-based learning approach can enrich students' learning experience by utilizing the latest technology (Zulkifli et al., 2022). In this context, technology is not only used as a teaching aid, but also as an integral part of the learning process that allows students to explore and experiment in greater depth. This is in line with the needs of 21st century skills that demand the ability to think critically, collaborate, and solve problems creatively. The STEM-based TPACK model supports the development of pedagogy that is responsive and adaptive to students' learning needs (Chaipidech et al., 2021). This approach allows teachers to design learning activities that not only emphasize mastering academic content but also develop students' ability to apply that knowledge in real contexts (Ilmi et al., 2020). Thus, learning becomes more relevant and meaningful, which in turn can increase student motivation and involvement in the learning process.

STEM within the TPACK framework broadens students' horizons towards the application of science and technology in everyday life (Moreno et al., 2019)i. Through integrated learning, students are invited to understand the relationship between disciplines and apply this knowledge in solving actual problems. It not only helps students develop systematic and analytical thinking but also prepares them

to contribute in areas that require interdisciplinary understanding. In addition, the STEM-based TPACK model has great potential in developing the 21st century skills of Indonesian students (Yupani &; Widana, 2023). Through the integration of technological knowledge, pedagogy, and content in STEM contexts, students can experience holistic and applicable learning. It will equip them with the skills needed to innovate, adapt and contribute effectively in an ever-evolving and increasingly interconnected society (Sari et al., 2021).

Conclusion

From this study, it can be concluded that the STEM-based TPACK learning model has a positive influence on the thinking skills of 21st century students in Indonesia with an average value of effect size (ES = 1.09) high effect size category and standard error of 0.41. These findings provide information for teachers implementing STEM-based TPACK learning effectively developing students' 21st century thinking skills. Students who engage in STEM-based TPACK learning show significant improvements in critical thinking, collaboration, creativity, and problem-solving skills. This signifies that this learning model successfully facilitates students to not only understand theoretical concepts but also apply them in real situations, which is the essence of 21st century skills.

Reference

Abda, M. I., Muliana, M., & Fonna, M. (2020). Implementation of Somatic, Auditory, Visual and Intellectual (SAVI) Approaches to Improve Student's Mathematics Communication Skills in SMK Negeri 1 Nisam. *International Journal for Educational and Vocational Studies*, *2*(6), 422–428. https://doi.org/10.29103/ijevs.v2i6.27 29

Abdul Razak, Lufri Lufri, & Irdawati Irdawati. (2022). The Influence of the Science Technology Engineering and Mathematics Approach with Mind Maps on the Higher Order Thinking Skills (HOTS) of Students in Biology Learning Class X SMA N 4 Kerinci. *International Journal of Education and Literature*, *1*(2), 77–82. https://doi.org/10.55606/ijel.v1i2.34

Affandy, H., Aminah, N. S., & Supriyanto, A. (2019). The correlation of character education with critical thinking skills as an important attribute to success in the 21st century. *Journal of Physics: Conference Series*, *1153*(1). https://doi.org/10.1088/1742-6596/1153/1/012132

Asamoah, M. K. (2019). TPACKEA Model for Teaching and Students' Learning. *Journal of Academic Ethics*, *17*(4), 401–421. https://doi.org/10.1007/s10805-019-09326-4

Asghar, A., & Prime, G. M. (2012). Supporting STEM Education in Secondary Science Contexts. *Interdisciplinary Journal of Problem-Based Learning Volume*, *6*(2), 1–42.

Ayunda, D., Kustiawan, A., & Erlin, E. (2022). Pengaruh Model Problem Based Learning Berbasis Tpack Terhadap Peningkatan Kemampuan Berpikir Tingkat Tinggi Siswa. *J-KIP (Jurnal Keguruan Dan Ilmu Pendidikan)*, *3*(3), 584. https://doi.org/10.25157/j-kip.v3i3.8628

Bahri, A., Jamaluddin, A. B., Muharni, A., Fikri, M. J. N., & Arifuddin, M. (2021). The Need of Science Learning to Empower High Order Thinking Skills in 21st Century. *Journal of Physics: Conference Series*, *1899*(1). https://doi.org/10.1088/1742-6596/1899/1/012144

Borenstein, M., & Hedges, L. V. (2009). *Introduction to Meta-Analysis*

Introduction.

Bwalya, A., Rutegwa, M., Tukahabwa, D., & Mapulanga, T. (2023). Enhancing Pre-Service Biology Teachers' Technological Pedagogical Content Knowledge Through a Tpack-Based Technology Integration Course. *Journal of Baltic Science Education*, *22*(6), 956–973. https://doi.org/10.33225/jbse/23.22.956

Çevik, M., & Bakioğlu, B. (2022). The Effect of STEM Education Integrated into Teaching-Learning Approaches (SEITLA) on Learning Outcomes: A Meta-Analysis Study. *International Journal of Progressive Education*, *18*(2), 119–135. https://doi.org/10.29329/ijpe.2022.431.8

Chaidam, O., & Poonputta, A. (2022). Learning Achievement Improvement of 1st Grade Students by Using Problem-Based Learning (PBL) on TPACK MODEL. *Journal of Education and Learning*, *11*(2), 43–48. https://doi.org/10.5539/jel.v11n2p43

Chaipidech, P., Kajonmanee, T., Chaipah, K., Panjaburee, P., & Srisawasdi, N. (2021). Implementation of an Andragogical Teacher Professional Development Training Program for Boosting TPACK in STEM Education. *Educational Technology & Society*, *24*(4), 220–239. https://www.jstor.org/stable/48629257

Cohen, L., Manion, L., Lecturer, P., Morrison, K., & Lecturer, S. (2007). *Research Methods in Education*. Routledge is an imprint of the Taylor & Francis Group, an informa business.

Elfira, I., & Santosa, T. A. (2023). Literature Study : Utilization of the PjBL Model in Science Education to Improve Creativity and Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 133–143. https://doi.org/10.29303/jppipa.v9i1.2555

Elly Sukmanasa, L. N. (2022). Teacher Professional Development As an Effort To Improve Tpack Skills in 21St Century Learning. *Jurnal Pendidikan Dan Pengajaran Guru Sekolah Dasar (JPPGuseda)*, *5*(3), 97–100. https://doi.org/10.55215/jppguseda.v5i3.6509

English, L. D. (2016). STEM education K-12 : perspectives on integration. *International Journal of STEM Education*, 1–8. https://doi.org/10.1186/s40594-016-0036-1

Fazilla, S., & Bukit, N. (2024). Enhancing Prospective Teachers ' Professional Competence : A Project-based Learning Approach with the Technological Pedagogical Content Knowledge (Tpack) Model. *Kurdish Studies*, *12*(1), 1934–1945.

Fazilla, S., Bukit, N., & Sriadhi, S. (2023). Professional Competence of Prospective Elementary School Teachers in Designing Lesson Plans Integrating Project-Based Learning Models and TPACK. *Mimbar Sekolah Dasar*, *10*(1), 226–239. https://doi.org/10.53400/mimbar-sd.v10i1.54875

Higgins, S. (2014). *Critical thinking for 21 st -century education : A cyber-tooth curriculum ? 4*.

Ilmi, A. M., Sukarmin, S., & Sunarno, W. (2020). Development of TPACK based-physics learning media using macro VBA to enhance critical thinking skills. *Journal of Physics: Conference Series*, *1521*(2). https://doi.org/10.1088/1742-6596/1521/2/022052

Irmita, L., & Atun, S. (2018). The influence of

Technological Pedagogical and Content Knowledge (TPACK) approach on science literacy and social skills. *Journal of Turkish Science Education*, *15*(3), 27–40. https://doi.org/10.12973/tused.10235a

Judijanto, L., Maulinda, R., Pamulang, U., Abda, M. I., Yogyakarta, U. N., Makassar, U. N., & Sarkawi, S. (2023). *EXAMINING MULTIMODAL LEARNING AND PROJECT-BASED PEDAGOGIES : IMPACT ON ACADEMIC ATTAINMENT AND 21ST CENTURY*. *1*(2), 67–79.

Kennedy, T. J. (2014). Engaging Students In STEM Education. *Science Education International*, *25*(3), 246–258.

KULOĞLU, A., & KARABEKMEZ, V. (2022). The Relationship Between 21st-century Teacher Skills and Critical Thinking Skills of Classroom Teacher. *International Journal of Psychology and Educational Studies*, *9*(1), 91–101. https://doi.org/10.52380/ijpes.2022.9.1.551

Miterianifa, M., Ashadi, A., Saputro, S., & Suciati, S. (2021). *Higher Order Thinking Skills in the 21st Century: Critical Thinking*. https://doi.org/10.4108/eai.30-11-2020.2303766

Morales, D. A., Aguilera, D., Javier, F., & Palacios, P. (2019). What are we talking about when we talk about STEM education ? A review of literature What are we talking about when we talk about STEM education ? A review of literature. *Science Education*, *103*(4). https://doi.org/10.1002/sce.21522

Moreno, J. R., Montoro, M. A., & Colón, A. M. O. (2019). Changes in teacher training within the TPACK model framework: A systematic review. *Sustainability (Switzerland)*, *11*(7). https://doi.org/10.3390/su11071870

Nurdiana, R., Nur Effendi, M., Puspita Ningsih Fakultas Kesehatan Universitas Jenderal Achmad Yani Yogyakarta, K., & Ichsan Abda, M. (2023). Collaborative Partnerships for Digital Education To Improve Students' Learning Achievement At the Institute of Islamic Religion of Sultan Muhammad Syafiuddin Sambas, Indonesia. *International Journal of Teaching and Learning (INJOTEL)*, *1*(1), 1–15.

Nurtamam, M. E., Santosa, T. A., Aprilisia, S., Rahman, A., & Suharyat, Y. (2023). Meta-analysis : The Effectiveness of Iot-Based Flipped Learning to Improve Students ' Problem Solving Abilities. *Edumaspul :Jurnal Pendidikan*, *7*(1), 1491–1501.

Oktarina, K., Santosa, T. A., Razak, A., & Ahda, Y. (2021). Meta-Analysis : The Effectiveness of Using Blended Learning on Multiple Intelligences and Student Character Education during the Covid-19 Period. *IJECA International Journal of Education & Curriculum Application*, *4*(3), 184–192.

Putra, M., Rahman, A., Suhayat, Y., Santosa, T. A., & Putra, R. (2023). The Effect of STEM-Based REACT Model on Students ' Critical Thinking Skills : A Meta-Analysis Study. *LITERACY : International Scientific Journals Of Social, Education and Humaniora*, *2*(1), 207–217.

Rahayu, S. (2017). Technological Pedagogical Content Knowledge (Tpack): Integrasi Ict Dalam Pembelajaran Ipa Abad 21. *Malang: Prosiding Seminar Nasional Pendidikan IPA IX Tahun 2017*, *February*, 1–12. https://www.researchgate.net/publication/331986261

Rahman, A. A., Santosa, T. A., Nurtamam, M. E., & Widoyo, H. (2023). Meta-Analysis : The Effect of Ethnoscience-Based Project Based Learning Model on Students ' Critical Thinking Skills.

Jurnal Penelitian Pendidikan IPA, *9*(9), 611–620. https://doi.org/10.29303/jppipa.v9i9.4871

Rahman, A., Santosa, T. A., Sofianora, A., Oktavianti, F., & Alawiyah, R. (2023). Systematic Literature Review : TPACK-Integrated Design Thinking in Education. *International Journal of Education and Literature (IJEL)*, *2*(1), 65–77.

Rahman, A., Santosa, T. A., & Suharyat, Y. (2023). *The Effect of Problem Based Learning-STEM on Students ' 21st Century Skills in Indonesia : A Meta-Analysis*. *2*(1).

Ramdani, D. (2016). The Effectiveness of Collaborative Learning on Critical Thinking, Creative Thinking, and Metacognitive Skill Ability: Meta-Analysis on Biological Learning. *European Journal of Educational Research Volume*, *11*(3), 1607–1628.

Rizqi, M. A., 1, P., Cahyono, E., & Aggraito, Y. U. (2019). Implementation of Problem Based Learning Model to Measure Communication Skills and Critical Thinking Skills of Junior High School Students. *Journal of Innovative Science Education*, *8*(3), 324–331. https://journal.unnes.ac.id/sju/index.php/jise/article/view/30788

Santosa, T. A., Razak, A., Arsih, F., & Sepriyani, E. M. (2021). Meta-Analysis : Science Learning Based on Local Wisdom Against Preserving School Environments During the Covid-19 Pandemic. *Journal of Biology Education*, *10*(2), 244–251.

Santosa, T. A., & Yulianti, S. (2022). Meta-analysis The Effect of the Technological Pedagogical Content Knowledge (TPACK) Model Through Online Learning on Biology Learning Outcomes , Learning Effectiveness , and 21 st Century Competencies of Post-Covid-19 Students and Teachers. *International Journal of Progressive Sciences and Technologies (IJPSAT)*, *34*(2), 285–294.

Saputri, A. C., Sajidan, Rinanto, Y., Afandi, & Prasetyanti, N. M. (2019). Improving students' critical thinking skills in cell-metabolism learning using Stimulating Higher Order Thinking Skills model. *International Journal of Instruction*, *12*(1), 327–342. https://doi.org/10.29333/iji.2019.12122a

Sari, I. M., Yusibani, E., Irwandi, I., Sofyan, H., & Suherman. (2021). Analysis TPACK framework in ISLE-based STEM approach model: Case study. *Journal of Physics: Conference Series*, *1882*(1). https://doi.org/10.1088/1742-6596/1882/1/012147

Solissa, E. M., Yustita, V., & Santosa, T. A. (2023). Effect Size Discovery Learning Model on Students Critical Thinking Skills. *Edumaspul - Jurnal Pendidikan*, *7*(2), 2083–2093.

Sri Handayani1*, Muhammad Hussin2, H. N. (2023). Technological Pedagogical Content Knowledge (TPACK) Model in teaching: A Review and Bibliometric Analysis. *Pegem Journal of Education and Instruction*, *13*(3), 176–190. https://doi.org/10.47750/pegegog.13.03.19

Suharyat, Y., Santosa, T. A., & Satria, E. (2023). The Effectiveness of STEM-Based Learning in Teaching 21 st Century Skills in Generation Z Student in Science Learning : A. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 160–166. https://doi.org/10.29303/jppipa.v9i1.2517

Supriyadi, A., Suharyat, Y., Santosa, T. A., & Sofianora, A. (2023). The Effectiveness of STEM-Integrated Blended Learning on Indonesia Student Scientific

Literacy : A Meta-analysis. *International Journal of Education and Literature (IJEL)*, *2*(1), 41–48.

Suryono, W., Haryanto, B. B., Santosa, T. A., Suharyat, Y., & Sappaile, B. I. (2023). The Effect of The Blended Learning Model on Student Critical Thinking Skill : Meta-analysis. *Edumaspul - Jurnal Pendidikan*, *7*(1), 1386–1397.

Tajudin, N. M., Zamzamir, Z., & Othman, R. (2019). A thinking-based learning module for enhancing 21st century skills. *International Journal of Innovative Technology and Exploring Engineering*, *8*(6 Special Issue 4), 397–401. https://doi.org/10.35940/ijitee.F1080.0486S419

Tamur et al. (2020). The Effectiveness of the Application of Mathematical Software in. *International Journal of Instruction*, *13*(4), 867–884.

Teknowijoyo, F. (2024). *Exploring the Role of TPACK in Promoting Inquiry-based Learning in 21 ?? -century Science Learning*. *2024*, 1088–1100. https://doi.org/10.18502/kss.v9i2.14925

Utomo, W., Suryono, W., Santosa, T. A., & Agustina, I. (2023). The Effect of STEAM-Based Hybrid Based Learning Model on Students ' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 742–750. https://doi.org/10.29303/jppipa.v9i9.5147

Valtonen, T., Sointu, E., Kukkonen, J., Kontkanen, S., Lambert, M. C., & Mäkitalo-siegl, K. (2017). TPACK updated to measure pre-service teachers ' twenty-first century skills. *Australasian Journal of Educational Technology*, *33*(3), 15–31.

Widiawati, L., & Joyoatmojo, S. (2018). International Journal of Multicultural and Multireligious Understanding Higher Order Thinking Skills as Effect of Problem Based Learning in the 21st Century Learning. *International Journal of Multicultural and Multireligious Understanding (IJMMU)*, *5*(3), 96–105.

Yupani, E., & Widana, I. W. (2023). The Impacts of the Stem-Based Inquiry Learning Models on Critical Thinking and Concept Mastery. *IRJE |Indonesian Research Journal in Education| |Vol. 7| No. 1|June|Year 2023| Indonesian Research Journal in Education |IRJE|*, *7*(1), 171–184. https://doi.org/10.22437/irje

Zainil, M., Kenedi, A. K., Rahmatina, Indrawati, T., & Handrianto, C. (2023). The influence of a STEM-based digital classroom learning model and high-order thinking skills on the 21st-century skills of elementary school students in Indonesia. *Journal of Education and E-Learning Research*, *10*(1), 29–35. https://doi.org/10.20448/jeelr.v10i1.4336

Zhang, W., & Tang, J. (2021). Teachers' TPACK Development: A Review of Literature. *Open Journal of Social Sciences*, *09*(07), 367–380. https://doi.org/10.4236/jss.2021.97027

Zulkifli, Z., Satria, E., Supriyadi, A., & Santosa, T. A. (2022). Meta-analysis : The effectiveness of the integrated STEM technology pedagogical content knowledge learning model on the 21st century skills of high school students in the science department. *Psychology, Evaluation, and Technology in Educational Research*, *5*(1), 32–42.