Analysis of the effectiveness of website-based technological pedagogical content knowledge (TPACK) in physics learning: a meta-analysis

S. Laeli, H. Kuswanto, and P. Putra Wiratama

Magister of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Jl. Colombo Yogyakarta No.1, Karang Malang, Daerah Istimewa Yogyakarta, Indonesia.
e-mail: silvialaeli.2023@student.uny.ac.id

Received 28 May 2024; accepted 24 February 2025

The use of website technology-based learning in physics learning has become an alternative method of choice to support 21st-century education. However, there is still no data study on this topic. The meta-analysis in this research examines the effectiveness of website technology-based learning on students' physics learning achievement. In this study, 15 primary studies from Scopus, ERIC, and Google Scholar were collected that met the inclusion and exclusion criteria. The research results show that the use of website technology-based learning has a significant influence on students' physics learning achievement. No publication bias was found in this study. So it can be concluded that website technology-based learning has a good impact on students' physics learning achievement.

Keywords: Meta-analysis; website; TPACK; physics learning; learning achievement.

DOI: https://doi.org/10.31349/RevMexFisE.23.010207

1. Introduction

Technology is becoming an important tool in 21st-century education [1]. The use of technology as a learning medium has increased significantly [2,3]. Students are already familiar with the use of technology in the teaching and learning process [4]. The spread of a good internet network is one of the drivers of innovation in the development of learning technology [5]. There is great potential in implementing learning technology, namely that learning opportunities can be done anywhere [6,7]. This will support students' enthusiasm for learning because they can learn practically [8].

Website-based learning is a practical learning media innovation [9]. In the context of digital learning, students only require access to web-based platforms via the internet, which significantly reduces the need for internal storage space on their devices. This learning paradigm represents an innovative instructional technology alternative, facilitating efficient and effective accessibility to learning materials. Furthermore, this model enables the asynchronous and synchronous distribution and reception of information from remote locations, thereby eliminating reliance on geographical and temporal limitations in the educational process [10]. Therefore, educators with a focus on physics-related disciplines require the development and implementation of learning approach strategies that are comprehensively integrated with technology. This integration aims to enhance the effectiveness of material delivery, facilitate the understanding of abstract concepts, and foster active student engagement in the learning process [11,12]. In this context, technology not only serves as an auxiliary tool but also as an integral part of the curriculum that enables the exploration of physical phenomena through simulations, visualizations, and virtual experiments. This aligns with the demands of contemporary advancements that necessitate the mastery of technological skills as part of 21st-century competencies.

Technological Pedagogical Content Knowledge (TPACK) is a conceptual framework that integrates three main domains of knowledge-technology, pedagogy, and content-to design and implement effective learning [13,14]. TPACK emphasizes the importance of a deep understanding of how technology can be used synergistically with appropriate pedagogical strategies to deliver learning content meaningfully [15]. This approach aims to develop innovative, relevant learning content that meets the needs of learners in the digital age [16].

The TPACK (Technological Pedagogical Content Knowledge) framework is a theoretical construct that delineates the complex knowledge required by educators to effectively integrate technology into teaching practices. This framework transcends isolated understandings of content, pedagogy, and technology, and emphasizes the dynamic interactions among these three domains. Specifically, TPACK comprises seven interrelated knowledge components. First, Content Knowledge (CK) refers to an in-depth understanding of the subject being taught, including concepts, theories, facts, and disciplinary frameworks. Second, Pedagogical Knowledge (PK) encompasses an understanding of teaching processes and practices, including instructional strategies, classroom management, assessment, and an understanding of how students learn. Third, Technological Knowledge (TK) refers to an understanding of various digital technologies, including hardware, software, and applications, as well as the ability to use them effectively. Fourth, Pedagogical Content Knowledge (PCK) is an understanding of how subject content can be effectively taught to students, including an understanding of students' learning difficulties and strategies to address those difficulties. Fifth, Technological Content

Knowledge (TCK) involves an understanding of how technology can be used to represent and convey subject content, as well as an understanding of how technology can influence students' understanding of that content. Sixth, Technological Pedagogical Knowledge (TPK) focuses on an understanding of how technology can be used to support and enhance teaching practices, including an understanding of how technology can be used to facilitate student interaction and collaboration. Seventh, Technological Pedagogical Content Knowledge (TPACK) is the integration of all three knowledge domains (content, pedagogy, and technology), and includes an understanding of how these three domains interact and influence each other (Matthew J. Koehler 203). The TPACK framework provides a robust foundation for teachers' professional development and the design of effective technology-enhanced learning. By understanding and implementing this framework, educators can enhance the quality of instruction and prepare students for success in the digital age.

The learning approach used by teaching staff can influence the effectiveness of physics learning [18]. In this context, learning effectiveness is not solely measured by students' ability to memorize formulas or solve problems, but also by their conceptual understanding, critical thinking skills, and the problem-solving skills they have developed. This research analyzes further the effectiveness of implementing TPACK in physics learning.

Research problem

The implementation of website-based learning, while promising high flexibility and accessibility, is not without its complex challenges. The primary advantage of this platform lies in its ability to facilitate real-time interaction and significant mobility, allowing learners to access learning materials anytime and anywhere. However, the pedagogical effectiveness of website-based learning is highly dependent on the ability to identify and mitigate factors that could potentially hinder the achievement of optimal learning outcomes [19].

One crucial challenge is the variability in technology accessibility and digital infrastructure. The digital divide, which encompasses disparities in hardware ownership, internet connectivity, and digital literacy, can create significant barriers for students from socio-economically disadvantaged backgrounds. Furthermore, the interface design and user experience (UX) of learning websites must be optimized to ensure intuitive navigation and inclusive accessibility for students with diverse learning needs.

Furthermore, the pedagogical aspects of website-based learning require special attention. The methods of material delivery, interaction strategies, and assessment techniques need to be carefully designed to maintain student engagement and motivation levels. The use of interactive multimedia, discussion forums, and adaptive feedback mechanisms can help create a more personalized and meaningful learning experience. However, it is important to remember that virtual interactions cannot fully replace face-to-face interactions, especially in terms of developing social and emotional skills.

In addition, the psychological and motivational factors of students also play an important role in the success of website-based learning. Students' levels of independence, self-regulation, and intrinsic motivation can vary significantly, which can affect their ability to effectively utilize online learning resources. Therefore, appropriate support and guidance strategies need to be implemented to help students develop independent learning skills and maintain their motivation throughout the learning process. Overall, the implementation of website-based learning requires a holistic and integrated approach, which considers the technological, pedagogical, and psychological aspects of students. By proactively identifying and addressing these challenges, educators and learning platform developers can maximize the potential of website-based learning to create effective, inclusive, and meaningful learning experiences for all students.

This aims to evaluate the learning process so that it can run optimally. Apart from that, other features on the device can be a distraction resulting in students being less focused on using website-based learning media so that students carry out multitasking activities. The next challenge is that students can carry out negative activities during learning such as cheating.

Research focus

In several previous studies, technology-assisted learning was proven to be able to improve student learning achievement [20] and significantly increase learning motivation [21]. With these potential opportunities, website-based learning can have a positive impact on students [22]. However, the conceptualization of website-based learning that can reach all locations with many users has yet to be implemented. There are empirical studies regarding theoretical assumptions that conflict with expected results, especially in physics subjects. Therefore, this research aims to conduct a literature study that is useful for analyzing the influence of website-based technology learning on learning achievement in physics learning. Apart from that, another aim is to describe the use of learning models and academic levels that make it possible to implement website-based learning media.

Research aim and research questions

This research aims to measure and analyze in a systematic way the effectiveness of using website-based technology learning on students' physics learning achievement. The research question that includes this is how does website-based technology learning influence students' physics learning achievement?

2. Research methodology

General background

The research method employed in this study is meta-analysis, a systematic quantitative approach that integrates and synthesizes findings from various empirical studies relevant to the research topic. This involves a series of rigorous stages, including the formulation of research questions, comprehensive literature searches, meticulous data extraction, and statistical analyses such as the calculation of pooled effect sizes, heterogeneity analysis, and sensitivity analysis. Consequently, it yields more precise, stable, and generalizable effect estimates, facilitates the identification of patterns and relationships that might be obscured in individual studies, and provides a robust foundation for drawing valid and reliable conclusions about the phenomenon under investigation [23]. Meta-analysis is a method that is explicit, systematic and reproducible [24]. This technique can explore potential variables that are useful for identifying factors that contribute to differences in effect size between studies on this research topic from 2017 to 2023.

Procedures

The purpose of using meta-analysis is to identify, evaluate, and synthesize research results and previous researchers' thoughts with certain hypotheses [24]. The coding sheet used in meta-analysis has a role in assisting the researcher's process in collecting and analyzing data. The variables used in the coding sheet provide information to calculate the effect of website-based technology learning on students' physics learning achievement. The steps for meta-analysis are: (1) identifying and reviewing the research topic to be studied; (2) searching for and collecting relevant studies from trusted sources; (3) using the meta-analysis method to calculate the magnitude of the effect; (4) determining whether the effect size is heterogeneous and how it relates to the research topic; and (5) drawing conclusions and interpreting the results of meta-analysis research [24]. Writing the results of the review in this research consists of four stages, the following stages of writing the results of the review can be seen in Fig. 1.

Literature sources were taken from various national and international journal sources using ERIC, Scopus, and Google Scholar. The literature sources used are articles published in the last 6 years. To be able to focus on literature studies, the keywords used are website-based physics learning media.

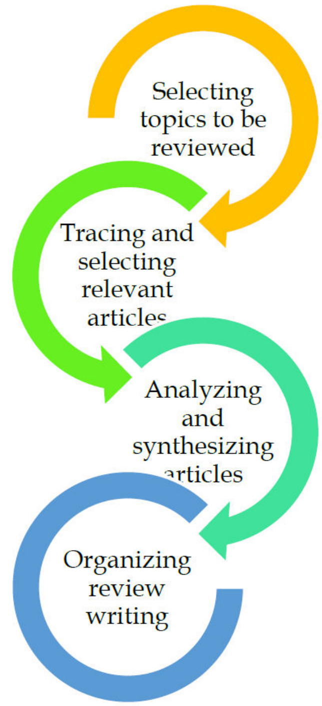

FIGURE 1. Stages of writing review results.

Inclusion and exclusion criteria

Studies related to the meta-analysis were selected based on specific inclusion criteria. First, the time span covers 2017 to 2023. Second, the research source is an academic journal. Third, the research method uses experiments with experimental and control groups. With a focus on the dependent variable, namely physics learning achievement and the independent variable website-based technology learning. Fourth, the article must contain complete numerical data including sample size (N), mean (M), and standard deviation (SD) in the experimental and control groups. Studies that do not meet these criteria will not be analyzed in this study.

Specifically, the exclusion criteria are open access scientific articles. The next process is identification based on the inclusion and exclusion criteria in the title, abstract and content. From the results of the review, 15 articles were found that met the meta-analysis inclusion and exclusion criteria. Articles were selected based on relevance, synthesized for review, and coding carried out.

Data analysis

So that the research objectives can be achieved, the limitations of the research scope are determined through coding. An overview of coding aspects in meta-analysis of this research includes (1) Research identity: first author, year of publication, research title, (2) Research characteristics: research methods, academic level, type of learning model, physics material, sample size and, type of achievement, (3) Quantitative research data: mean (M), sample size (N), standard deviation (SD).

Next, the code was collected and coded using Microsoft Excel. In this research, R-Studio was used to analyze metadata including effect size, heterogeneity testing, and publication bias. To be able to measure metadata, this research uses the 'meta' and 'metafor' packages. The following is Thalheimer and Cook's classification of effect sizes [25] which can be seen in Table I.

TABLE I. Thalheimer and Cook's classification of effect sizes.

Thalheimer dan Cook (2022)
$-0,15 < d < 0,15$, negligible
$0,15 < d < 0,40$, Senior High Schoolll
$0,40 < d < 0,75$, medium
$0,75 < d < 1,10$, large
$1,10 < d < 1,45$, very large
$1,45 < d$, excellent

TABLE II. Descriptive statistics of included studies.

Variabel	N	%
Publication Year		
2017	1	6,67
2022	7	46,67
2023	7	46,67
Sample Size		
Large ($n > 30$)	15	100
Small ($n \leq 30$)	0	0
Academic Level		
Bachelor	12	80,00
Senior High School	1	6,67
Junior High School	1	6,67
Elementary School	1	6,67
Learning Model Type		
PBL	2	13,33
PjBL	4	26,67
Discovery Learning	1	6,67
Others	8	53,33
Physics Content Type		
Panas, Suhu, dan Tekanan	1	6,67
Mechanics	8	53,33
Listrik dan Elektromagnetika	4	26,67
Berat dan Pengukuran	1	6,67
Hukum Newton	1	6,67
Achievement Type		
Cognitive	6	40,00
Affective	2	13,33
Psycomotor	7	46,67

3. Research results and discussion

Descriptive statistic of the included studies

In the context of meta-analysis, the process of identifying key characteristics of relevant studies is a crucial stage that determines the validity and reliability of the synthesis results. This stage begins with the formulation of strict and transparent inclusion and exclusion criteria, which serve as an objective guide in study selection. Research characteristics are explained in detail based on variables such as year of publication, sample size, academic level, research methods, learning model, physics material, and type of student achievement. Descriptive statistics of research that meets the meta-analysis requirements based on variables are shown in Table II.

The overall effect of using TPACK with a website on students learning achievement

The visual representation of the meta-analysis results for the 15 studies included in this research is displayed through a forest plot. This forest plot is a crucial tool in meta-analysis, as it allows researchers to comprehensively visualize the effect size of each individual study, as well as the estimated combined effect size of all studies. In the context of this research, the forest plot reveals a significant variability in effect sizes across the studies, which is reflected in the range of observed effect size values. This range spans from a negative value of -0.05 to a substantial positive value of 4.36. This wide variation indicates heterogeneity among the studies, which may be attributed to differences in research design, sample characteristics, or the interventions applied.

Within the forest plot, each individual study is represented by a gray square, the position of which reflects the estimated effect size of that study. The size of the square proportionally represents the study's weight in the meta-analysis, where studies with larger sample sizes or smaller variances will have larger squares, indicating a greater contribution to the estimated combined effect size. Additionally, the horizontal line connected to each square represents the 95% confidence interval for the study's effect size. This confidence interval provides an estimated range of values within which the true effect size of the study is likely to lie. The width of the confidence interval reflects the precision of the effect size estimate, where narrower intervals indicate more precise estimates. Collectively, this visualization allows researchers to evaluate not only the magnitude of the effect from each study but also the precision and consistency of findings across studies.

There is research that proves the effectiveness of using technology-based learning approaches with websites in physics learning, such as research conducted [26-31]. However, in research [32] studies 2 and 3 reported that the effect size was negative. This shows that technology-based learning with websites in physics learning does not consistently have higher effectiveness than other approaches. The magnitude of effectiveness and significance in statistics is represented in the following forest plot.

Overall effect

Data analysis was carried out thoroughly with the aim of determining the level of influence of using a website

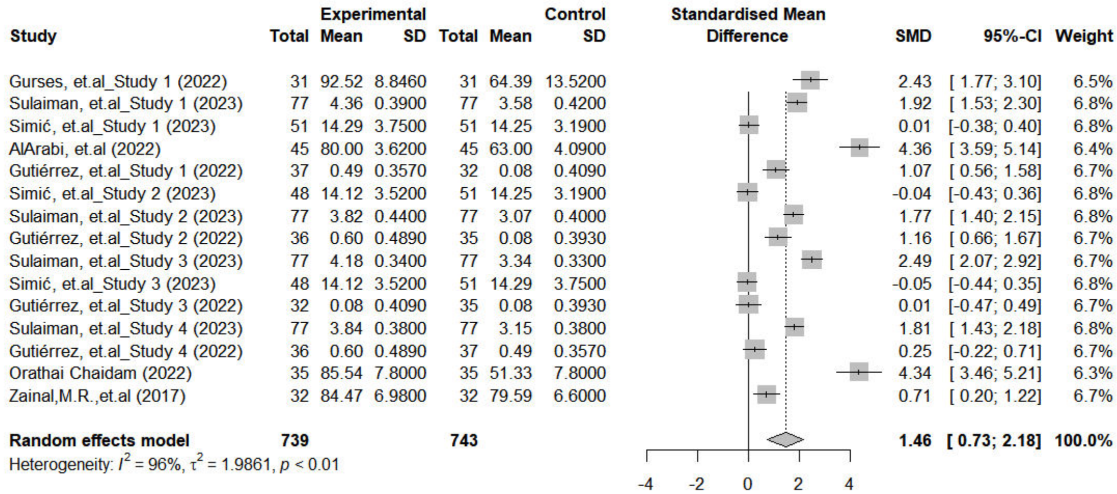

FIGURE 2. Forest plot.

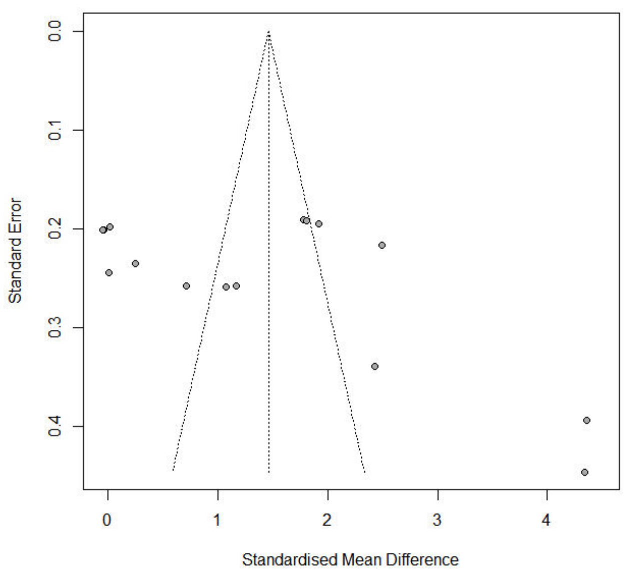

FIGURE 3. Publication bias.

technology-based learning approach on physics learning achievement. There were 15 studies (86.6%) with a positive effect size ranging from -0.05 to 4.36. The learning outcomes of the control group were lower than those of the experimental group. With a negative effect size percentage of 13.4%. The overall effect size is $d = 1.46$ or "excellent" which means that the random effect model shows that website-assisted learning has a significant influence on students' physics learning achievement. Additionally, publication bias can be interpreted in Fig. 3.

4. Conclusions

Based on the results of the meta-analysis conducted, it can be concluded that website technology-based learning has a significant positive impact on improving students' physics learning achievement. This finding is supported by the pooled effect size, which shows that students who participate in website technology-based learning demonstrate higher learning achievement compared to students who participate in conventional learning. The implication of this finding is that website technology-based learning can serve as an effective alternative to enhance students' learning outcomes in physics. However, it is important to note that the effectiveness of this learning approach also depends on factors such as instructional design, student characteristics, and the appropriate integration of technology within the learning process. Therefore, further research is needed to explore the factors that moderate the effectiveness of website technology-based learning and to develop optimal learning models.

Acknowledgments

The author would like to thank the supervisors who have contributed to the completion of this scientific article.

1. I. M. Gómez-Trigueros and C. Bustamante, New perspectives on teacher preparation in digital competencies, *Bordon. Rev. Pedagog.* **75** (2023) 11, `https://doi.org/10.13042/Bordon.2023.100532`.

2. Ö. Öztuzcu and Z. A. Mısırlı, Teachers' Self-Efficacy on the Use of Information Technologies in the Distance Education Process: A Scale Development Study, *Educ. Policy Anal. Strateg. Res.*, **18** (2023) 405, `https://doi.org/10.29329/epasr.2023.600.19`.

3. Y. Tao *et al.*, The impact of long-term online learning on social anxiety and problematic smartphone use symptoms among secondary school students with different levels of fear of missing out: Evidence from a symptom network and longitudinal panel network analysis, *J. Behav. Addict.* **13** (2024) 102, https://doi.org/10.1556/2006.2023.00081.

4. A. P. Sarwendah, N. Azizah, and M. Mumpuniarti, The use of technology in hybrid learning for student with special needs, *J. Educ. Learn.*, **17** (2023) 317, https://doi.org/10.11591/edulearn.v17i2.20810.

5. I. Muhammad, H. K. Rusyid, S. Maharani, and L. M. Angraini, Computational Thinking Research in Mathematics Learning in the Last Decade: A Bibliometric Review, *Int. J. Educ. Math. Sci. Technol*., **12** (2023) 178, https://doi.org/10.46328/ijemst.3086.

6. D. Gnanasagaran, S. S. A. Rahim and D. Dewitt, Mobile Learning Readiness Among Malaysian Pre-University Students, *Malaysian Online J. Educ. Sci.*, **11** (2023) 13.

7. G. W. McDiarmid and Y. Zhao, Time to Rethink: Educating for a Technology-Transformed World, *ECNU Rev. Educ.*, **6** (2023) 189, https://doi.org/10.1177/20965311221076493.

8. J. Marquardson, Embracing Artificial Intelligence to Improve Self-Directed Learning: A Cybersecurity Classroom Study, *Inf. Syst. Educ. J.*, **22** (2024) 4, https://doi.org/10.62273/wzby3952.

9. B. E. Priando Purba, I. D. Riris, and Z. Muchtar, Development of Website-Based Learning Media Integrated Inquiri Learning Strategies in Learning Thermochemical Matter Chemistry, *Budapest Int. Res. Critics Linguist. Educ. J.*, **4** (2021) 454, https://doi.org/10.33258/birle.v4i1.1658.

10. S. Anshori, Pemanfaatan Teknologi Informasi Dan Komunikasi Sebagai Media Pembelajaran, *J. Ilmu Pendidik. PKn dan Sos. Budaya* **2** (2019) 88.

11. L. Bao and K. Koenig, Physics education research for 21st century learning, *Discip. Interdiscip. Sci. Educ. Res.*, **1** (2019) 2, https://doi.org/10.1186/s43031-019-0007-8.

12. Y. Ramma, A. Bholoa, M. Watts, and P. S. Nadal, Teaching and learning physics using technology: Making a case for the affective domain, *Educ. Inq.*, **9** (2018) 210, https://doi.org/10.1080/20004508.2017.1343606.

13. D. A. Schmidt, A. D. Thompson, M. J. Koehler, and T. S. Shin, 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 Information, Manufacturing and Service Systems' - Proceedings, CIE 2014 - 44th Int. Conf. Comput. Ind. Eng. IMSS 2014 - 9th Int. Symp. Intell. Manuf. Serv. Syst. Jt. Int. Symp. *The Soc. Impacts Dev. Information, Manuf. Serv. Syst. - Proc*., **42** (2014) 2531p.

14. M. J. Koehler *et al*., The Technological Pedagogical Content Knowledge Framework for Teachers and Teacher Educators, In ICT Integrated Teacher Education Models (2013) pp. 1-8.

15. Available: https://cemca.org.in/ckfinder/userfiles/files/ICTteachereducationModule1Final_May20.pdf.

16. J. R. Star, Revisiting the origin of, and reflections on the future of, pedagogical content knowledge, *Asian J. Math. Educ.*, **2** (2023) 147, https://doi.org/10.1177/27527263231175885.

17. I. S. G. Alhamid and B. Mohammad-Salehi, Examining EFL Teachers' Technological Pedagogical Content Knowledge (TPACK) and their Attitudes towards Online Teaching, *Learn J. Lang. Educ. Acquis. Res. Netw.*, **17** (2024) 715.

18. M. J. Koehler, P. Mishra and W. Cain, What Is Technological Pedagogical Content Knowledge (TPACK)?, *J. Educ.*, **193** (2013) 13, www.jstor.org/stable/24636917.

19. U. Saharsa, M. Qaddafi, and Baharuddin, Efektivitas Penerapan Model Pembelajaran Problem Based Learning Berbantuan Video Based Laboratory Terhadap Peningkatan Pemahaman Konsep Fisika, *J. Pendidik. Fis.*, **6** (2018) 57.

20. I. P. A. A. Payadnya, I. M. Wena, P. S. Noviantari, I. M. P. K. Palgunadi, and A. D. C. Pradnyanita, Development of RME Learning Media Based on Virtual Exhibition to Improve Students' High Order Thinking Skills (HOTS), *Math. Teaching-Research J.*, **15** (2023) 129.

21. H. Çavuş, and S. Deniz, The Effect of Technology Assisted Teaching on Success in Mathematics and Geometry: A Meta-Analysis Study, *Particip. Educ. Res.*, **9** (2022) 358, https://doi.org/10.17275/per.22.45.9.2.

22. Munawaroh, N. S. Setyani, L. Susilowati, and Rukminingsih, The Effect of E-Problem Based Learning on Students' Interest, Motivation and Achievement, *Int. J. Instr*., **15** (2022) 503, https://doi.org/10.29333/iji.2022.15328a.

23. T. H. Popp and H. Schuhbauer, Systematic Literature Review of the Effort of Gaming Elements on E-Learning Platforms, In 20th Int. Conf. Cogn. Explor. Learn. Digit. Age (CELDA) (2023) p. 305.

24. G. Savatsomboon, P. Yurayat, O. Chanprasitchai, W. Narkbunnum, J. K. Sharma, and S. Svetsomboon, A Proposed Categorization of Meta-Analysis, Their Respective Example Conceptual Frameworks, and Applicable R Packages for Education Research: *A Review, J. Pract. Stud. Educ*., **5** (2024) 1, https://doi.org/10.46809/jpse.v5i3.83.

25. T. D. Pigott and J. R. Polanin, Methodological Guidance Paper: High-Quality Meta-Analysis in a Systematic Review, *Rev. Educ. Res.*, **90** (2020) 24, https://doi.org/10.3102/0034654319877153.

26. W. Thalheimer and S. Cook, How to calculate effect sizes from published research: A simplified methodology. (Work-Learning Research, 2022).

27. K. Alarabi, H. Tairab, Y. Wardat, S. Belbase, and S. Alabidi, Enhancing the Learning of Newton'S Second Law of Motion Using Computer Simulations, *J. Balt. Sci. Educ*., **21** (2022) 946, https://doi.org/10.33225/jbse/22.21.946.

28. O. Chaidam and A. Poonputta, Learning Achievement Improvement of 1st Grade Students by Using Problem-Based Learning (PBL) on TPACK MODEL, *J. Educ. Learn.*, **11** (2022) 43, https://doi.org/10.5539/jel.v11n2p43.

29. A. G ürses, E. Şahin, and K. Güneş, Investigation of the Effectiveness of the Problem-Based Learning (PBL) Model in Teaching the Concepts of 'Heat, Temperature and Pressure' and the Effects of the Activities on the Development of Scientific Process Skills, *Educ. Q. Rev.* **5** (2022) 67, https://doi.org/10.31014/aior.1993.05.02.469.

30. O. A. Gutiérrez *et al.*, Assisted Discovery Based Learning of the Electric Force with Scaffolding for Novice Students, *Educ. Sci*. **12** (2022) 1, https://doi.org/10.3390/educsci12040269.

31. F. Sulaiman, J. J. Rosales, and L. J. Kyung, the Effectiveness of the Integrated Stem-Pbl Physics Module on Students' Interest, Sensemaking and Effort, *J. Balt. Sci. Educ.*, **22** (2023) 113, https://doi.org/10.33225/jbse/23.22.113.

32. M. R. Zainal, D. Djamas, and Y. Yohandri, Pengaruh Bahan Ajar Mobile Web dalam Pembelajaran Discovery terhadap Pencapaian Kompetensi Peserta Didik Kelas XI SMAN 4 Padang pada Materi Hukum Newton tentang Gravitasi, Usaha, dan Energi, *Pillar Phys. Educ.*, **9** (2017) 129.

33. B. Simić *et al*., Simulation-based and video-based approaches to diversifying physics homework, *J. Balt. Sci. Educ*. **22** (2023) 506, https://doi.org/10.33225/jbse/23.22.506.