INDONESIAN JOURNAL OF EDUCATIONAL RESEARCH AND REVIEW
Volume 7 Nomor 2 2024, pp 333-346
E-ISSN: 2621-8984; P-ISSN: 2621-4792
DOI: https://doi.org/10.23887/ijerr.v7i2.76166

Effectiveness of E-Learning-Based Learning in the Era of Digital Transformation: A Meta-Analysis

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Abstrak

Di tengah transformasi digital di abad ke-21, penggunaan teknologi digital, seperti e-learning, dalam proses pembelajaran telah menjadi hal yang mendesak untuk mengembangkan pengetahuan dan keterampilan siswa SMK. Namun, beberapa penelitian menunjukkan bahwa pembelajaran online tidak efektif dalam meningkatkan pengetahuan dan keterampilan siswa SMK. Pembelajaran daring tidak dapat meningkatkan keterampilan kejuruan siswa karena proses pembelajaran daring tidak dapat melakukan praktikum secara nyata. Oleh karena itu, penelitian ini bertujuan untuk menganalisis efektivitas pembelajaran daring dalam meningkatkan pengetahuan dan keterampilan siswa SMK. Metode penelitian yang digunakan adalah meta-analisis model efek acak dengan teknik analisis artikel Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA). Sebanyak 25 artikel dari database Scopus, Google Scholar, dan Wiley diperoleh dan dianalisis dalam penelitian ini. Artikel yang dianalisis bebas dari bias publikasi, yang ditunjukkan oleh hasil uji funnel plot, Egger's, dan Fail-safe N. Berdasarkan hasil meta-analisis, diketahui bahwa nilai effect size yang diperoleh sebesar 0,703 (kategori sedang). Dengan demikian, penerapan pembelajaran daring di SMK memberikan dampak yang sedang terhadap peningkatan pengetahuan dan keterampilan siswa SMK. Temuan penelitian ini menunjukkan bahwa penerapan pembelajaran daring di SMK dapat mendukung efektivitas pembelajaran di SMK dan mendorong siswa untuk mengembangkan pengetahuan dan keterampilan yang akan dikuasainya. Penelitian ini diharapkan dapat menjadi dasar bagi guru dan sekolah kejuruan untuk mengintegrasikan pembelajaran online ke dalam proses pembelajaran.

***Kata kunci**: Efektivitas, E-Learning, Transformasi Digital, Meta-Analisis, Abad 21*

Abstract

Amid digital transformation in the 21st century, the use of digital technology, such as e-learning, in the learning process has become urgent to develop vocational school students' knowledge and skills. However, some studies show that online learning is ineffective in improving vocational school students' knowledge and skills. Online learning cannot improve students' vocational skills because the online learning process cannot conduct actual practicum. Therefore, this study aims to analyze the effectiveness of online learning to improve vocational students' knowledge and skills. The research method used was random effect model meta-analysis with Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) article analysis technique. A total of 25 articles from the Scopus, Google Scholar, and Wiley databases were obtained and analyzed in this study. The articles analyzed were free from publication bias, as indicated by the funnel plot, Egger's, and Fail-safe N test results. Based on the meta-analysis results, it is known that the effect size value obtained is 0.703 (medium category). Thus, implementing online learning in vocational schools has a moderate impact on improving vocational students' knowledge and skills. The findings of this study indicate that the implementation of online learning in vocational schools can support the effectiveness of learning in vocational schools and encourage students to develop the knowledge and skills they will master. This research is expected to be the basis for teachers and vocational schools to integrate online learning into the learning process.

Keywords: Effectiveness, E-Learning, Digital Transformation, Meta-Analysis, 21st Century

History:
Received : March 05, 2024
Accepted : July 06, 2024
Published : July 25, 2024

Publisher: Undiksha Press

1. INTRODUCTION

Vocational education is one of the educational paths students take to enhance their abilities and knowledge to compete in the workforce. Technological developments in 21st-century vocational education are experiencing rapid growth, accompanied by rapid changes

needed by the world of work and technological advances in the industrial world (Mukul & Büyüközkan, 2023; Quy et al., 2023). The learning process in the 21st-century technological development is now integrated with various technologies supporting the learning process. The learning process and education management comprise the two primary components of DT development in education. Training and development are two of the learning processes that must be applied in vocational schools to develop DT (Cattaneo et al., 2022; Wang et al., 2023). Through this study, students will gain experience and knowledge about the abilities and know-how required in the workforce. Through the development of DT today, learning has become more flexible, can be done anywhere, and can equip students with lifelong learning, which is very important for students to master today (Almaazmi et al., 2021; Ananda & Mukhadis, 2016).

The use of digital technology in the classroom to improve student learning, streamline the process, and equip students to meet the expectations of a competency- and knowledge-based society is known as "digital transformation" in education. Utilizing the digitalization of education will make learning more innovative to accelerate the achievement of equal, personalized, and lifelong education (Cattaneo et al., 2022; Wang et al., 2023). Nowadays, lifelong learning is one of the learning concepts that must be provided to students. Digital transformation is not only a shift from conventional learning to the use of technology but also a significant approach in terms of managing learning, learning efficiency, human resources, and designing learning processes that support the use of technology in the learning process (Almaazmi et al., 2021; Mukul & Büyüközkan, 2023).

The use of digital technology in the education process is often called e-learning. E-learning-based learning uses digital technology in its implementation process to deliver learning materials, communicate with both students and educators, and provide accessibility to various learning resources (Bossman & Agyei, 2022; Prashanth Kumar et al., 2024). Through e-learning, the learning process can be done virtually or online, not only through the face-to-face process. E-learning-based learning will provide greater flexibility and accessibility to the learning process. However, schools need to consider the digital access gap of learners and maintain students' social interaction in the online learning process (Fahmi et al., 2019; Ullah et al., 2023).

Based on the benefits and gaps in the online learning process, many researchers have examined the effectiveness of online learning in the learning process at Vocational Schools, whether using virtual laboratories, zoom platforms, and Google Meet combined with various supporting applications in the learning process. Using a virtual laboratory, students can simulate modeling that will be practiced in real life. The use of virtual laboratory technology in the learning process of vocational education can improve skills, creativity, and communication and train students' problem-solving abilities, which are needed today (Nurhasanah et al., 2023; Seifan et al., 2020; Yanto et al., 2022). *Virtual laboratory* is a valuable educational technology that provides greater accessibility, flexibility, and innovation in understanding scientific concepts and developing practical skills that vocational school students need. Virtual reality technology can create a natural work environment through digital simulation. Previous studies have revealed that virtual reality technology is very effective in improving the skills and knowledge of vocational school students (Fokides & Antonopoulos, 2024; Ifanov et al., 2023).

In addition, online learning significantly impacts learning in vocational schools. Utilizing interactive multimedia learning media and simulation applications that help projects in the learning process will make students more confident and can increase students' knowledge and skills. This benefit can be obtained because online learning will make students learn more independently (Burns et al., 2021; Wannapiroon et al., 2023). Previous research also utilized the Edmodo online discussion forum, which revealed that learning

could improve reading comprehension skills and learning outcomes for vocational school students. Implementing online-based learning will provide flexible access to the learning process for students (Eslami & Bahrami, 2022; Wajong et al., 2020). However, implementing the online learning process also experiences many controls, both limited internet access and limited technology owned by students in the learning process.

The success of technology-based learning is also supported by the readiness of educational technology owned by schools, teachers, and students. So, the technology gap experienced by schools, teachers, and students must be considered when implementing learning technology at school. If the technology gap occurs in the learning process, digital technology-based learning will not run effectively (Ifanov et al., 2023; Labata-Lezaun et al., 2023). Previous research supports this claim by demonstrating that e-learning does not affect the learning process or enhance student learning results. E-learning is ineffective because not every student has equal access to digital technologies (Baharudin et al., 2022; Hakim et al., 2023). A study of the efficacy of e-learning applications in vocational school learning processes is warranted in light of the research findings. The need for e-learning to be applied urgently can then be determined. The conclusions drawn from various research findings will reinforce the utilization of e-learning in vocational schools, serving as a reference point.

Learners' knowledge and abilities and address this issue, a detailed understanding of how e-learning influences learning is required. So, meta-analysis methods were applied in this study. This research is unusual since it looks at e-learning's effectiveness overall, considering a more comprehensive range of conditions and additional study data. This meta-analysis can ensure the validity and accuracy of quantitative data on the effectiveness of e-learning use in the learning process. Thus, this meta-analysis study aims to analyze whether e-learning technologies, both domestically and internationally, can enhance student learning results. The novelty of this study enhances the academic performance of students pursuing vocational education by incorporating e-learning technologies into the process. This research will also form the foundation for policies about using e-learning technologies in teaching and learning.

2. METHODS

This study employed a meta-analysis methodology to investigate the overall efficacy of e-learning in vocational schools. This meta-analysis method reviews synthesizes and quantitatively estimates (meta-analysis) the results of previous research on the same research problem (Agussuryani et al., 2022; Lo & Hew, 2019). This study's primary goal is to determine how e-learning might enhance students' vocational school students' learning results. Therefore, the articles searched in this meta-analysis are articles related to this. The article search strategy employs the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) article selection method based on the study topic. The PRISMA method is used to systematically compile and select articles relevant to research. So that the PRISMA method can be effectively used to find articles as primary data for meta-analysis. The four methodical steps of the PRISMA approach are identification, screening, eligibility, and inclusion (Arlinwibowo et al., 2022; Syafii et al., 2022; Wahono et al., 2020).

The inclusion and exclusion criteria were set as a guide for searching articles as primary data for meta-analysis. So, with these criteria, the searched articles will get articles with the same data according to the specified criteria. Inclusion criteria are criteria for articles that will be used as primary data for this meta-analysis, while exclusion criteria are criteria used to exclude articles from the primary data of this meta-analysis; in other words, the article is not used. The inclusion criteria contain five criteria: field of science, year of journal

publication, article type, research design, and research data (Agussuryani et al., 2022; Syafii et al., 2022). Table 1 shows the inclusion criteria for article selection in more detail.

Table 1. Inclusion Criteria for Meta-Analysis Articles

No	Criteria	Inclusion
1	Field of science	Articles that discuss the impact of e-learning implementation in the learning process in vocational schools.
2	Year of journal publication	Articles released between 2018 and 2023.
3	Article Type	Articles published in international journals or proceedings.
4	Research design	An article that uses experimental research methods by using a control class and an experimental class to implement e-learning in the learning process.
5	Research data	Articles containing control class and experimental class posttest data must have an average value (M), number of samples (N), and standard deviation (SD).

This meta-analysis applied the random effect model-restricted machine learning method as the data analysis strategy. To employ the analytic technique, the collected data must fulfill the heterogeneity test conditions. The data tested is the effect size (d) and standard error (SEg) data obtained from the primary data of the meta-analysis article used. In order to get the value of d and SEg, the meta-analysis article must contain data on the number of samples (N), the average value (M), and the standard deviation (SD) consisting of the post-test scores of students (Lo & Hew, 2019; Wahono et al., 2020). The inclusion criteria set this data, so the articles used in this meta-analysis must meet the criteria for article selection. Equation 1 was used to obtain the effect size value in an article, and Equation 2 was used to obtain the standard error value (Goulet-Pelletier & Cousineau, 2020).

Equation 4 can be used to calculate the impact size variance value, or V_d, which is the final variable (Arlinwibowo et al., 2022; Goulet-Pelletier & Cousineau, 2020). Using the statistical analysis program JASP, data analysis was performed after determining effect sizes and standard error values. The collected articles were subjected to a meta-analysis with the aid of this application. The heterogeneity value, effect size, minimum/maximum effect size value, and bias value of the publications under study were analyzed using the JASP tool.

3. RESULTS AND DISCUSSION

Results

Two hundred fourteen articles using the journal search strategy, which uses the PRISMA approach and predetermined inclusion and exclusion criteria. All of these articles have been grouped based on their titles to address the effects of using e-learning in the vocational education process. The data is based on the Google Scholar, Scopus, and Wiley databases. The first analysis is to analyze whether the articles have the same title despite being from different databases. The results of this analysis showed that six articles were declared the same or duplication of the same article from different databases, so 208 articles were further analyzed. This search eliminated one hundred twenty-six articles, and 82 met these criteria.

The last selection made in the selection of articles is by looking at the research data presented to determine whether it meets the inclusion criteria or not. Based on the results of the analysis that has been carried out, 25 articles are declared to meet the requirements of

data presentation inclusion. The 25 articles include all the information required for this meta-analysis, including the number of samples, mean scores, and standard deviations for the control and experimental groups. Figure 1 depicts the method used to select the articles for this meta-analysis, and Table 2 displays the distribution of the articles that were chosen.

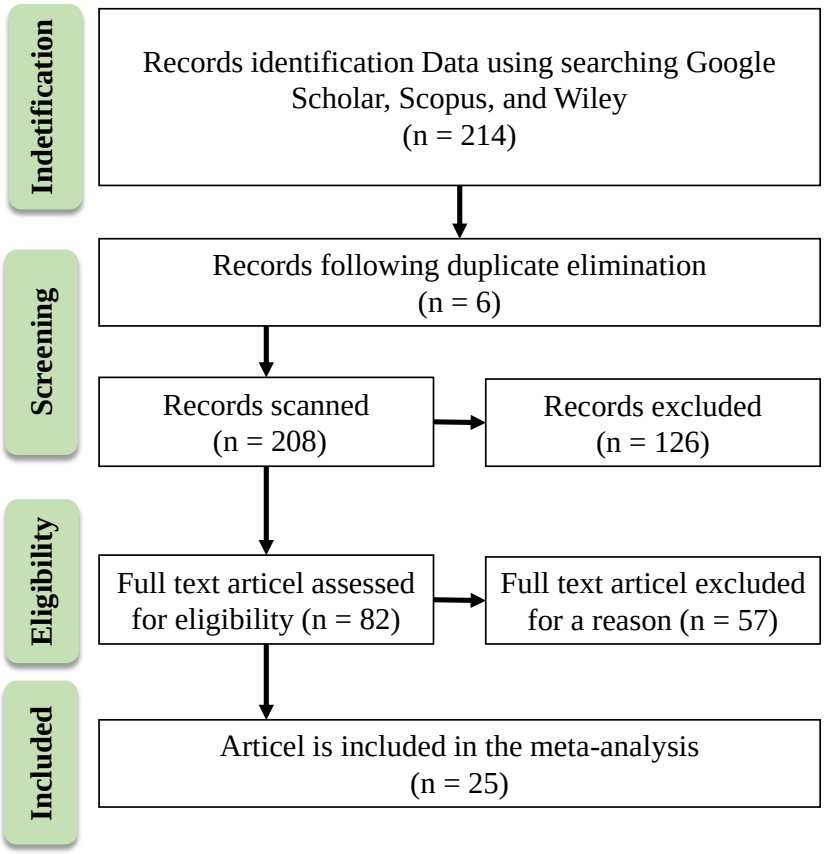

Figure 1. Selection of Articles Based on the PRISMA Method

Table 2. Frequency Distribution of Meta-Analysed Articles

Source Article	Group	Frequency	Percentage
Year of publication	2018	3	12 %
	2019	1	4 %
	2020	7	28 %
	2021	4	16 %
	2022	4	16 %
	2023	6	24 %
Article type	Journal articles	22	88 %
	Conference article	3	12 %
Database	Google Scholar	7	28 %
	Scopus	13	52 %
	Wiley	5	20 %

Based on Table 2, source of the database, the data obtained is more dominant in the Scopus database. Scopus index research on e-learning implementation in the vocational school learning process is a trending topic. Next, the 25 publications summarized all the information required for this meta-analysis, beginning with the number of samples, the mean, and the standard deviation of the control and experimental groups. After the data is obtained,

data analysis is conducted to find the effect size value and standard error value on the 25 articles used in this meta-analysis using equations 1 to 4 explained in the data analysis techniques above. In more detail, the research data obtained in this meta-analysis research sourced from 25 articles can be seen in Table 3.

Table 3. Recapitulation of Article Data Used for Meta-Analysis

No	Researcher Name	Year	Control Class			Experiment Class		
			N	M	SD	N	M	SD
1	Cabi,	2018	31	3.29	1.11	28	3.50	1.00
2	Yustinaningrum,	2018	39	714.62	761.18	39	809.43	747.92
3	Ma'azi & Janfeshan,	2018	20	16.45	1.73	20	17.70	1.66
4	Mohammadi et al.,	2019	47	1.02	2.53	48	1.22	1.62
5	Wajong et al.,	2020	22	71.34	10.63	21	76.14	9.63
6	Setyawan et al.,	2020	32	62.50	1.63	32	67.08	7.12
7	Ritonga et al.,	2020	32	74.31	9.46	32	83.56	8.25
8	Wibowo & Astriawati,	2020	20	78.35	9.21	19	92.89	4.19
9	Sitinjak,	2020	20	71.65	7.00	20	76.92	5.00
10	Alwadei et al.,	2020	112	143.38	17.19	48	148.52	18.40
11	Bobrytska et al.,	2020	23	7.73	2.67	23	9.32	2.88
12	El Iq Bali et al.,	2021	21	126.72	12.00	21	135.15	14.00
13	Burns et al.,	2021	36	7.27	2.70	32	8.81	1.53
14	Karuović et al.,	2021	68	1.15	0.35	64	1.76	0.67
15	Liu & Xu,	2021	50	42.18	3.27	50	45.47	2.92
16	Baharudin et al.,	2022	40	2.02	6.68	40	1.55	6.62
17	Eslami & Bahrami,	2022	33	13.12	3.97	26	18.66	7.99
18	Safik & Aditya,	2022	27	48.78	15.96	27	54.19	15.95
19	Ferdian & Suyuthie,	2022	174	62.77	12.18	174	76.39	15.45
20	Mispandi et al.,	2023	32	76.13	7.07	32	82.03	5.24
21	Tran & Nguyen Thanh,	2023	153	5.31	1.63	152	7.73	1.59
22	Sofya et al.,	2023	31	43.40	8.70	31	41.30	10.00
23	Hakim et al.,	2023	16	76.25	7188.00	16	88.13	9.11
24	Diana et al.,	2023	32	56.17	9.19	32	77.03	11.25
25	Aldalalah et al.,	2023	15	8.13	3.41	17	9.52	2.69

Description: N (number of samples), M (mean), SD (standard deviation)

Heterogeneity Testing Results

Heterogeneity testing aims to know the effect method of the Restricted ML model, which can be used as a meta-analysis technique for this article. Using the random effect method in a meta-analysis must fulfill the heterogeneity test. Table 4 displays the outcomes of the heterogeneity testing conducted with the JASP application.

Table 4. Heterogeneity Test Results

	Q	df	p
Omnibus test of Model Coefficients	38.380	1	< 0.001
Test of Residual Heterogeneity	141.989	24	< 0.001

Note: *p* -values are approximate, the model was estimated using Restricted ML method

Base on Table 4, the residual heterogeneity test results obtained are (Q = 141.989), and the p-value obtained (p = < 0.001). These statistics show that the p-value's significance

value ($\alpha = 0.001 < 0.05$) is less than the conventional significance value of 0.05. Thus, it can be concluded that the 25 articles used in this meta-analysis are heterogeneous. This result shows that the random effect model-restricted ML method can be used to conduct a meta-analysis of this article. After the data passed this test, the second data test was carried out, testing the publication bias of the article.

Bias Testing Results

Bias testing is carried out by researchers presenting data in their articles to avoid publication errors. In order to generate high-quality research with accurate and trustworthy data, publication bias must not exist in the articles used in this study. Bias testing in research aims to identify data distortion in studies included in meta-analysis because of the vast number of studies utilized in this type of analysis. The three bias analysis methods used in this work are the funnel plot test, Egger's statistical test, and the fail-safe N statistical test. Bias testing also uses the help of the JASP application. However, the Fail-safe N test does vary in that it determines whether the item used is deemed unbiased and whether the number produced is more than the value determined by applying the formula (5K + 10). The variable K indicates the number of articles used in the meta-analysis. The results of bias testing through funnel plot interpretation are shown in Figure 2.

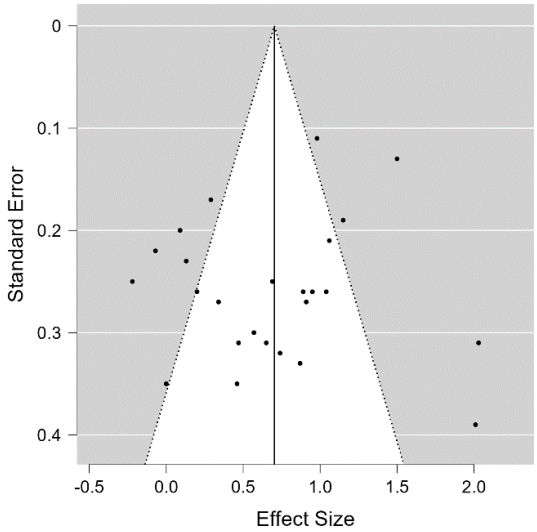

Figure 2. Funnel Plot

Base on Figure 2, the data distribution (points) depicted in the funnel plot clearly shows that the data is spread equally and symmetrically on the left and right sides of the funnel plot image. This chart demonstrates no article publication bias in the data used. The result of the funnel plot is only a graphical interpretation of the data and cannot be accounted for statistically. For this reason, the symmetrical funnel plot was tested using Egger's test to strengthen the funnel plot results. Egger's test shows that the resulting regression value is 0.171, and the p-value significance value obtained is 0.864. So, from these results, the significance alpha value obtained is greater than the significance standard of 0.05 (0.864 > 0.05). This finding suggests that the funnel flow generated by the data and the funnel plot produced by the data are symmetrical. It also demonstrates that there is no publication bias in the papers included in the meta-analysis.

To strengthen the argument's conclusion, further bias testing was carried out using the Fail-safe N test developed by Rosenthal. Table 5 presents the acquired results and indicates that the Fail-safe N value is 2098.

Table 5. Bias Testing Results with Fial-safe Technique N

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	2098.000	0.050	< 0.001

Base on Table 5, this outcome demonstrates that the value of Fail-safe N acquired is more significant than the value determined by applying the Fail-safe N formula (135). Subsequently, the outcomes derived from the Fail-safe N test demonstrate the absence of publication bias in the included publications. This finding adds to the evidence that the publications used did not exhibit publication bias. The results of the funnel plot analysis and the Rosenthal N fail-safe test support the idea that the 25 articles in the meta-analysis were free from publication bias.

Mean Effect Size Testing Results

The data obtained in this study are valid and free from article publication errors. This is shown in the results of heterogeneity testing and bias testing that has been done. The following meta-analysis analyzes the average effect size obtained from 25 articles used in this study. So, this test will describe the overall effect size of the application of e-learning in vocational education. This test was conducted using the Wald test data analysis method, commonly called the Wald chi-square test. The Wald test is one statistical test method used to determine whether the treatment given to the research object had a substantial impact. Table 6 displays the findings of the Wald test technique's average effect size testing.

Table 6. Effect Size Test Summary

	Estimate	Standard Error	z	p	95% Confidence Interval	
					Lower	Upper
intercept	0.703	0.113	6.195	< 0.001	0.481	0.926

Note: Wald test

Base on Table 6, the obtained p-value significance value is less than the usual significance value of 0.05 ($\alpha = 0.001 < 0.05$), as indicated by this result. Thus, e-learning dramatically enhances the learning results of vocational education students, according to Wald test data. The calculation of the effect size obtained also supports these results. The average effect size value obtained from the 25 articles used is 0.703, with a confidence interval value determined at 95%. The estimated upper value of the effect size obtained is 0.926, and the lower limit value is 0.481. These two findings support the notion that e-learning moderately affects students' learning objectives in vocational education. This category is determined based on the category of effect size values put forward by Cohen's d, where the value ($0.8 \leq d \leq 2.0$) is a large category, and the value ($0.5 \leq d < 0.8$) is a medium category. The value ($0.2 \leq d < 0.5$) is a small category.

The criteria for the impact of employing e-learning are also varied, as demonstrated which shows that the effect size value created differs. The lowest effect size value obtained is -0.22 with a confidence interval of 95%, so the estimated lower limit and upper limit of the effect size are -0.71 and 0.27, respectively. While the highest effect size value obtained is 2.03 with confidence intervals of 95%, the estimated lower and upper limits of the effect size are 1.42 and 2.64, respectively. These findings support the findings of two studies that find no influence on using e-learning in vocational education. Nonetheless, using e-learning in the classroom generally has a favorable effect on students' learning outcomes.

Discussion

ENumerous national and international vocational education institutions from different locations have implemented e-learning or digital technology-based learning. Some studies use virtual reality technology to implement e-learning-based learning in vocational schools, and some use simulation applications. Both technologies train students' skills by using simulations of what students will do in real life. Using technology based on simulation of work that students will do in the real world, the technology can significantly improve students' skills and knowledge (Fokides & Antonopoulos, 2024; Ifanov et al., 2023; Nurhasanah et al., 2023). In addition, e-learning-based learning is also applied using interactive multimedia technology. This technology allows learning to be presented creatively and innovatively to attract students' attention. Learning using interactive multimedia technology can contain videos, tutorials, text, and learning simulations to facilitate students' learning process (Aswardi et al., 2023; Yanto et al., 2023). Therefore, e-learning-based learning using interactive multimedia technology significantly impacts the learning process in vocational schools (Diana et al., 2023; Mispandi et al., 2023). A well-directed e-learning-based learning process can improve and enhance the learning process in vocational schools.

Implementing e-learning can also improve the digital skills that students need in 21st-century technology development. These skills are literacy, problem-solving, teamwork, creativity, communication, and lifelong learning (Arlinwibowo et al., 2022; Lo & Hew, 2019). The results of previous studies show that learning using digital technology per the concept and learning objectives can improve students' digital literacy skills. The digital literacy skills in question are students adept at using and evaluating the technology used to support the work process carried out by students (Aldalalah et al., 2023; Ferdian & Suyuthie, 2022). In addition, one of the skills that students must have today is lifelong learning skills. This skill will equip students to be literate and learn independently to develop their skills. With these skills, students can adapt to the rapid changes and developments in technology in the 21st century (Almaazmi et al., 2021; Fokides & Antonopoulos, 2024).

This meta-analysis research has thoroughly investigated the impact of e-learning on learning in vocational education, yielding reliable and valid research findings. A total of 25 research results published in national or international journals and conferences were used in this meta-analysis (Labata-Lezaun et al., 2023; Wahono et al., 2020). Overall, the results of this study show that e-learning-based learning significantly impacts the learning process. This result is supported by the effect size analyzed thoroughly in all articles that get a value of 0.703 in the medium category, with a confidence interval value determined at 95%, the estimated upper value of the effect size obtained is 0.926, and the lower limit value is 0.481. These findings support that e-learning-based instruction can enhance students' critical thinking abilities and technical literacy in the twenty-first century (Labata-Lezaun et al., 2023; Tavares Oliveira et al., 2023). The findings of the statistical tests funnel plot, Egger's test, and Fail-safe N test indicate that the data utilized in this study are also devoid of bias. As a result, the data utilized in this study are reliable, and the research that served as the primary data source for this meta-analysis did not contain any misrepresented data.

The advantage of implementing e-learning-based learning is that learning is not only done face-to-face but can also be done online so that the learning process can be done anywhere and anytime without any time limit. To accommodate students with varying learning characteristics, e-learning can be combined with other advanced learning technologies, including virtual learning, simulation, video, image, text, and voice (Mahoney et al., 2023; Nyström & Ahn, 2024). By using e-learning-based learning, learning can be done by the learning character of students. Based on the research results that have thoroughly analyzed the impact of using e-learning technology in the learning process, vocational schools should implement an e-learning-based learning process and integrate it with other

supporting technologies. This is due to the demands of 21st-century technological developments, which require students to adapt to very rapid technological developments (Elas et al., 2019; Fatimah & Santiana, 2017). So, implementing a technology-based learning process will support students in mastering the digital skills needed to develop 21st-century technology.

The results of this study can help vocational schools build and implement online learning procedures that will improve students' knowledge and abilities. E-learning has significant implications for vocational education. It increases the accessibility of education, allows students to learn anywhere and anytime, and offers flexibility for students to carry out the learning process. The study's findings can help educators, curriculum designers, legislators, and other educational staff members by enabling the integration of e-learning-based learning into vocational school instruction. In order to create a compelling and dynamic learning environment to improve students' knowledge, practical skills, and digital literacy skills. In addition, using interactive tools such as videos, simulations, and discussion forums can enrich the learning experience and increase student engagement in the learning process. Using e-learning, teachers can develop innovative and adaptive learning methods tailored to students' learning needs.

4. CONCLUSION

The results of this meta-analysis show that e-learning-based learning significantly improves 21st-century knowledge and skills that students need. Based on the effect size results obtained, learning using technology is better than learning that does not use e-learning technology. This study used a total of 25 papers that were presented at conferences or published in national and international journals. Based on the overall meta-analysis results, the effect size obtained is 0.7023, with a confidence interval determined at 95%, the estimated upper value of the effect size obtained is 0.926, and the lower limit value is 0.481. The data used in this study are also free from bias, as stated from the results of statistical testing of funnel plot, Egger's test, and Fail-safe N test. Based on these findings, which are analyzed holistically, e-learning-based learning integrated with other advanced technologies can improve the knowledge and skills of vocational education students. This finding demonstrates how e-learning-based instruction can improve the efficacy of vocational education. This research is anticipated to serve as the foundation for teachers and vocational schools to use digital technology in the classroom to assist students in comprehending and mastering the knowledge and abilities of 21st-century digital technology.

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