Effectiveness of Robotic Technology in Vocational Education: A Meta-Analysis

Sukardi*, Herlin Setyawan, Risfendra, Usmeldi, and Doni Tri Putra Yanto

Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia
Email: sukardiunp@ft.unp.ac.id (S.); herlinsetyawan@student.unp.ac.id (H.S.); risfendra@ft.unp.ac.id (R.); usmeldi@yahoo.com (U.); donitriputra@ft.unp.ac.id (D.T.P.Y.)
*Corresponding author

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Abstract—**In the current era of technological development, robotic technology is widely used in educational institutions, especially in vocational high schools. Thus, the purpose of this meta-analysis is to experimentally test how effective robotic technology is when used in the overall learning process to improve the learning ability of vocational school students. The methodology of this study is a meta-analysis using a random effects hedging model with the number of studies used is 56 studies and taken from Google Scholar, ScienceDirect, and Proquest databases from 2014 to 2023. The effect size data analysis technique was used to find the impact on each study, and the JASP application was used to conduct meta-analyses on all studies. The study's conclusions showed that there was no publication bias and that, at a 95% confidence level, the average effect size of incorporating robotic technology into the learning process was 0.993 (high category). According to this study, introducing robotic technology into the classroom significantly affects students' learning outcomes. The findings indicate that the utilization of robotic technology in vocational schools can serve as an effective pedagogical instrument, fostering the development of computational thinking, creativity, innovation, communication, and teamwork skills among students. Proficiency in these skills is vital for students to acquire in light of the technological progressions in the 21st century.**

Keywords—**robotic technology, learning outcomes, vocational students, meta analysis, effectiveness**

I. Introduction

The advent of Industry 4.0 has profoundly transformed the learning process, exerting a substantial impact on the field of education. The integration of advanced technology such as robotics, augmented reality, and artificial intelligence enables the adoption of interactive and adaptable learning approaches. Educational resources can be accessed by teachers and students from many global locations, thereby enhancing virtual classrooms and facilitating more interactive learning experiences. Furthermore, education 4.0 also promotes the development of skills that are pertinent to the future demands of industries, such as programming, data analysis, and intricate problem-solving. In addition, these developments are also giving rise to a novel framework in relation to employment, necessitating workers to possess advanced digital proficiencies and flexibility.

A robotic control system is a control system that has been very much developed in the development of Industry 4.0, both in the mining, agriculture, military, food, surveillance, and education sectors [1]. Robotic control systems, or industrial robots, are used to improve process efficiency, increase accuracy, and reduce work risks for humans [2]. Industrial development 4.0 is characterized by the presence of production equipment capable of autonomous operation, real-time controlled systems that can link through the Internet of Things (IoT), and the utilization of artificial intelligence. Several types of technology that are quickly growing in the period of industrial development 4.0 include Artificial Intelligence (AI), robotics, Augmented Reality (AR), three-dimensional printing, IoT, big data analytics, and cloud computing. Researchers have prioritized the development of robotic technology due to its comprehensive integration of several emerging technologies, particularly AI. The integration of AI with robotic technology enables the development of autonomous robots capable of independent thinking and learning. This advancement impacts several aspects of life, including the educational learning process [3–6].

The delivery of education at vocational schools will undergo changes due to technological advancements in this domain. Within the realm of education, this alteration is commonly referred to as Digital Transformation (DT). The growth of DT in education is primarily composed of two components: the learning process and education administration. Training and development represent a necessary learning process that must be implemented in vocational schools for the advancement of DT. This educational program aims to offer students valuable insights and practical information pertaining to the essential skills and expertise required in the professional realm. The rapid advancement of technology in vocational schools is closely tied to the industry's utilization of technology in manufacturing processes [6–8]. Hence, this study will primarily focus on the efficacy of employing robotic technology in the educational process to foster digital transformation. In order for vocational school students to effectively prepare for entering the industry, it is crucial that they utilize educational technology that is in line with the ongoing digital transformation. This will ensure that their learning experience is both pertinent and beneficial.

In order to make education more focused on the industrial workplace, robotics-based learning should be implemented in vocational high schools. If vocational high school learning is closer to the work done by the industry, the graduates produced will be competent in that field [9]. Furthermore, integrating robotics into vocational high schools would enhance students' critical thinking, problem-solving abilities, and character. It will also foster greater creativity among the student body [10].

It is predicted that integrating robotics into the classroom will help students develop their communication, collaboration, critical thinking, and creative thinking skills—all of which are essential for entering the workforce in the

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21st century [11]. The application of robotic technology will also help students develop their computational thinking abilities, which are necessary for resolving challenging engineering problems [12]. In addition to the benefits to the cognitive and psychomotor parts of students, the use of robotic technology can also train the character and attitude of students at work [13]. Based on these opinions, it can be seen that using robotic technology in learning at vocational school, gives students the habit of doing what will be done in the industrial world. The intention is for them to be prepared to join the industrial world.

In vocational high schools, robotics technology is extensively employed in the teaching process, particularly in the field of industrial electronics engineering, which is based on an understanding of automation control systems and industrial robots [14]. Pellas and Tzafilkou further claimed that, in order to meet the demands of the technological advancements of the 21st century and the industrial revolution 4.0, robotics-based learning will drastically alter the curriculum at vocational high schools [15]. This is predicated on the requirement that vocational high schools keep up with the advancements in industry-useful technology. There has been a great deal of study done on the application of robotic technology in education, and the results could improve the quality of instruction in the vocational studies field. Technological developments in 21st century vocational high schools, especially in the industrial electronics department, should have a curriculum that is integrated with the robotic learning process [16].

Every curriculum policy set by the school is taken with full consideration of both the benefits and challenges that will be faced. Especially paying attention to the availability of teachers who have the ability in this field and the availability of facilities and infrastructure owned by the school [17]. So in this meta-analysis, researchers analysed two aspects of the use of robotic technology in learning. One initial step involves examining the effects of robotic technology in the context of vocational education. According to Chen and Chang [18], robotic learning applications can improve knowledge, motivation, interest, and a stronger career direction in linked subjects, as well as the capacity for logical problem solving. As science advances, students will encounter increasingly complicated challenges when utilizing traditional approaches. It will be difficult to solve these problems. Robotic technology in education is required to address these issues.

In the second, the effectiveness of robotic technology utilization by teachers in the classroom and the availability of robotic technology at the school will be examined. Teachers in vocational high schools need to be proficient in integrating robotic technology into their lessons [18]. It is difficult to realize this since educators must always learn new things stay current with the robotic technology that is utilized in the classroom. Because robotic technology is developing so quickly these days, educators must be prepared to adjust to these circumstances [19]. In addition, schools must also provide media or robotic technology used for the learning process. It is well recognized that not every school has the same financial resources to supply instructional technology [20], especially robotic technology, which is relatively expensive [14].

Vocational schools must indeed overcome this obstacle in order to integrate robotic technology into the curriculum and enhance student learning outcomes to meet industry demands [21]. It must be recognized that the application of robotic technology to learning is very difficult. Therefore, there must be a calculation of the benefits of implementing robotic technology in learning in vocational schools. Additionally, for robotic technology to be successfully used in education, teacher collaboration is crucial. It is necessary to review how robotic technology is used in the educational process. This meta-analysis study is also based on the research of Kaloti-Hallak and Armoni *et al.*, which demonstrated that robotic technology had no discernible effect on student motivation and learning outcomes [13]. Thus, the effectiveness of the application of robotic technology really needs to be reviewed to see the urgency of implementing robotic technology. By comparing the outcomes of the deployment of robotic technology in various places, both at the national and international levels (between countries), it is possible to determine the necessity of doing so. The conclusions from the various research results conducted will be used as a reference for making policy decisions.

In order to solve these issues, a thorough comprehension of how robotic technology affects learning is required in order for it to produce knowledge that is helpful for legislation. With this meta-analysis aiming to examine this issue, a thorough understanding of how robotic technology affects learning is needed in order to generate knowledge that is beneficial to policymakers. Thus, this meta-analysis study aims to determine whether using robotic technology which is used both domestically and internationally can improve student learning outcomes. The results of this meta-analysis study should help shape recommendations for incorporating robotics into the classroom, which will help students pursuing vocational education do better academically. Additionally, it is anticipated that this research will serve as a foundation for developing policies on the use of robotic technology as an instructional aid in vocational schools. Thus, the aim of this meta-analysis study is to assess the application of robotic technology in vocational education, namely as follows:

1) How much of an overall influence does robotics technology have in the classroom on enhancing the learning outcomes of students at vocational schools?
2) What distinguishes the learning objectives of students in vocational schools using robotic technology (in the experimental class) from those of students not using robotic technology (in the control class)?

Based on the research objectives stated above, it is expected that this study will illustrate the effectiveness of using robotic technology to improve student learning outcomes and develop 21st century competencies that students should possess. Moreover, this study will illustrate the effectiveness of utilizing robotic technology to augment student learning outcomes and cultivate the essential 21st century competencies students must acquire. This research integrates several findings that employ robotic technology extensively in vocational education to enhance the learning process. This research demonstrates the significance of incorporating robotic technology in vocational education to enhance the skills of current students.

II. Literature Review

One of the technologies that is advancing quickly in the Industrial Revolution era is robotics 4.0. Where the production process works in the industry, it can be done automatically by machines [11]. With the advancement of technology comes the need for students, particularly those enrolled in vocational schools, to acquire new knowledge and abilities [22]. This is based on the fact that vocational schools aim to produce a competent workforce in their respective fields. Currently, the skills that must be mastered by students are problem-solving and critical thinking. Both of these skills can be trained by using robotic technology in the learning process. Because the robotics-based projects that students work on have complex problems and complex abilities to solve them, using robotic technology in learning can also improve students' communication and collaboration skills [23]. This opinion is based on robotic project-based learning that requires discipline and good teamwork to solve the problem or project.

The application of robotic technology in learning can also improve students' Computational Thinking (CT) skills, which are needed today. This thinking ability must be mastered by vocational students at this time. Because this thinking will train students to solve problems systematically and objectively [24]. The five ideas of problem-solving thinking that are typically included in this type of thinking are decomposition, abstraction, pattern recognition, algorithm creation, evaluation, and evaluation.

Decomposition is the process of dividing the main problem into several smaller problems. The task of pattern recognition, which follows the acquisition of several subproblems, is to determine patterns and rules by recognizing the regularity and repetition of multiple subproblems. It will generate abstraction patterns from a subset of the subproblem patterns based on a set of consistent and recurring guidelines known as CT abstraction concepts. It only goes on to discuss algorithm design after that, which is creating steps to go through each created abstraction pattern and following a preset process to replace with solve objective. Following the creation of steps to address the issue at hand, the steps are evaluated to make sure each one can accurately complete every step and confirm the best course of action [25, 26].

III. Methods

A. Data Collection

This research is a meta-analysis that collects all articles on the same topic from various literature sources and summarizes the results of the literature using statistical formulas [27]. This study's primary focus is on how robotics technology may help vocational students learn more effectively. All of the publications that will be gathered address how robotics technology might be used to enhance the learning outcomes of vocational students. The source of article data is taken from Google Scholar, ScienceDirect, and Proquest. These three pages are article search engines that are connected to various article sources around the world. So that the coverage of the data obtained is broad and avoids articles with biased data. The articles to be screened in this meta-analysis are articles published from 2014 to 2023 with the keywords learning using robotic technology improves learning outcomes of vocational school students. The technique of searching for articles that match the topic under study uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) search method, which consists of four steps: identification, screening, eligibility, and inclusion. PRISMA method is an effective method used to conduct a meta-analysis of studies with systematic selection steps of the proposed articles [28].

B. Criteria for Inclusion and Exclusion

The journal search was narrowed down using inclusion and exclusion criteria, yielding identical findings. The quality of articles to be scrutinised is known as inclusion criteria, while the characteristics of articles to be excluded are known as exclusion criteria. Articles that do not fulfil the inclusion criteria for the article under study will be excluded [28]. The inclusion criteria for this meta-analysis are shown in Table 1. While the exclusion criteria are all articles whose criteria are the opposite of the inclusion criteria. Articles included in the exclusion criteria were not included in the reference materials in this article.

Table 1. Article selection and inclusion criteria

Criteria	Inclusion
Field of science	All articles that discuss robotic learning to improve student learning outcomes
Year of journal publication	Articles published from 2014 to 2023
Type of article	Research published in accredited international/ national journals or proceedings
Research design	Research that uses a control group and an experimental group
Research instruments	Research that conducts pretests and posttests
Research data	Studies that provide information on the mean value (M), standard deviation (SD), and sample size (n)

C. Data Analysis Technique

The data analysis methodology in this study was the random effects hedge model meta-analysis method. In accordance with the requirements of this model, the data obtained must be heterogeneous. Data were collected and analyzed in the publications that were searched to ascertain the impact size value (d), Standard Error (SEg), Mean (M), Standard Deviation (SD), and number of samples (n) [29]. Articles selected for meta-analysis must fulfill the inclusion criteria, and the data taken is in accordance with the data set out in the study inclusion criteria. Eq. (1) can be used to find the effect size value of the article [30].

$$d = \frac{M_2 - M_1}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}}} \quad (1)$$

$$SE_g = \sqrt{J \times V_d} \quad (2)$$

$$J = 1 - \frac{3}{4(n_1+n_2-2)-1} \quad (3)$$

$$V_d = \frac{n_1+n_2}{n_1.n_2} + \frac{d^2}{2(n_1+n_2)} \quad (4)$$

The four equations used can be explained that d is the effect size generated, M_2 is the average score of the experimental class and M_1 is the average of the control class. n_1 is the number of control group samples and n_2 is the number of experimental group samples. S_1^2 is the variance of the control group and S_2^2 is the variance of the experimental group. SE_g is the standard error of the effect size and J is a correction factor used to reduce the bias caused by the effect size calculation results. The last variable V_d is the effect size variance value which can be calculated using Eq. (4).

After determining the effect size and standard error values, data analysis was carried out using the statistical analysis application JASP. This application is used to help conduct a meta-analysis of the articles obtained. The JASP application is used to look for the bias value of the papers examined and assist in analyzing the meta-analysis's heterogeneity value, effect size, and minimum/maximum effect size values. Thus, the conclusion of the meta-analysis was obtained. It should be emphasised that before using the JASP application, data analysis first uses Eqs. (1)–(4) above.

IV. Result and Discussion

A. Result

By using the search keywords that have been determined, the total number of articles obtained is 240 articles. These articles were obtained from search results in the Google Scholar, ScienceDirect, and Proquest databases. A total of 240 articles obtained must be eliminated as many as 12 articles. This is because the eliminated articles are the same as the articles searched using other search engine databases. So the same article must be eliminated. Thus the articles obtained were 228 articles. Articles that have gone through similarity selection are then analysed for the title and abstract of the article. After analysing the abstracts and titles of the articles obtained, many articles were eliminated at this stage because many articles did not match the purpose of this meta-analysis. In addition, the subtitles in the article were also analysed to see the number of classes used in the study and to see whether the form of the test was appropriate or not.

After going through this stage, 93 articles were declared to meet the initial requirements of this meta-analysis. However, the articles still went through a selection stage, namely the final selection, to see whether the presentation of the data required in each article was fulfilled or not. The final selection resulted in 51 publications being included in the meta-analysis. A total of 51 publications satisfied the study's data requirements, which included the mean (M), standard deviation (SD), and the number of participants (n) from the control and experimental classes. The selection of articles carried out is shown in Fig. 1 and the recapitulation of the articles obtained as shown in Table 2.

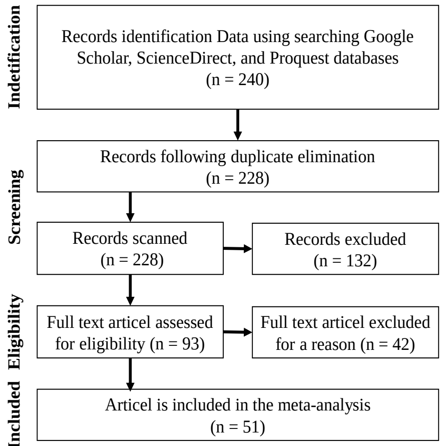

Fig. 1. Article selection using PRISMA method.

Table 2. Recapitulation of meta-analysis articles

No	Researcher Name	Year	Code	Citation	Research Title
1	Chin *et al.*	2014	[31]	163	Impact of using an educational robot-based learning system on students' motivation in elementary education
2	Kennedy *et al.*	2015	[32]	180	Comparing robot embodiments in a guided discovery learning interaction with children
3	Alemi *et al.*	2015	[33]	197	The impact of social robotics on l2 learners' anxiety and attitude in English vocabulary acquisitions
4	A. M. Ortiz	2015	[34]	69	Examining students' proportional reasoning strategy levels as evidence of the impact of an integrated LEGO robotics and mathematics learning experience
5	Alfieri *et al.*	2015	[35]	41	Case studies of a robot-based game to shape interests and hone proportional reasoning skills
6	Berland and Wilensky	2015	[36]	222	Comparing virtual and physical robotics environments for supporting complex systems and computational thinking
7	Juli àand Antol í	2016	[37]	70	Spatial ability learning through educational robotics
8	Leonard *et al.*	2016	[38]	275	Using robotics and game design to enhance children's self-efficacy, stem attitudes, and computational thinking skills
9	Korkmaz	2016	[39]	101	The effect of scratch and LEGO Mindstorms EV3-based programming activities on academic achievement, problem-solving skills and logical-mathematical thinking skills of students
10	Barker *et al.*	2017	[40]	550	Robotics as means to increase achievement scores in an informal learning environment
11	O. O. Ortiz *et al.*	2017	[41]	47	Innovative mobile robot method: improving the learning of programming languages in engineering degrees
12	Magen-Nagar and Cohen	2017	[42]	69	Learning strategies as a mediator for motivation and a sense of achievement among students who study in MOOCs
13	Witherspoon *et al.*	2017	[43]	123	Developing computational thinking through a virtual robotics programming curriculum
14	Merkouris *et al.*	2017	[44]	122	Teaching programming in secondary education through embodied computing platforms: robotics and wearables
15	Conti *et al.*	2017	[45]	179	Robots in education and care of children with developmental disabilities: a study on acceptance by experienced and future professionals
16	Park *et al.*	2017	[46]	139	Growing growth mindset with a social robot peer
17	Van Den Heuvel *et al.*	2017a	[47]	39	Robot ZORA in rehabilitation and special eucation for children with severe physical disabilities: A pilot study
18	Van Den Heuvel *et al.*	2017b	[48]	29	Can the IROMEC robot support play in children with severe physical disabilities? A pilot study

19	Y. Chen and Chang	2018	[49]	56	The impact of an integrated robotics STEM course with a sailboat topic on high school students' perceptions of integrative STEM, interest, and career orientation
20	Barak and Assal	2018	[50]	184	Robotics and STEM learning: students' achievements in assignments according to the P3 Task Taxonomy—practice, problem solving, and projects
21	Ramachandran *et al.*	2018	[51]	68	Thinking aloud with a tutoring robot to enhance learning
22	P.N. Chou	2018	[52]	64	Skill development and knowledge acquisition cultivated by maker education: evidence from arduino-based educational robotics
23	Taylor and Baek	2018	[53]	47	Grouping matters in computational robotic activities
24	Leyzberg *et al.*	2018	[54]	50	The effect of personalization in longer-term robot tutoring
25	Chiazzese *et al.*	2018	[55]	22	Exploring the effect of a robotics laboratory on computational thinking skills in primary school children using the Bebras tasks
26	Isabelle *et al.*	2019	[12]	18	Analyzing the effect of computational thinking on mathematics through educational robotics
27	Chiazzese *et al.*	2019	[56]	69	Educational robotics in primary school: measuring the development of computational thinking skills with the bebras tasks
28	Ching *et al.*	2019	[16]	91	Elementary school student development of stem attitudes and perceived learning in a stem integrated robotics curriculum
29	Manuel *et al.*	2019	[57]	116	The effect of programming on primary school students' mathematical and scientific understanding: educational use of mBot
30	Michaelis and Mutlu	2019	[58]	49	Supporting interest in science learning with a social robot
31	Nam *et al.*	2019	[59]	47	Connecting plans to action: the effects of a card-coded robotics curriculum and activities on korean kindergartners
32	H. Chen *et al.*	2020	[60]	97	A chatbot for learning chinese: learning achievement and technology acceptance
33	Hakim *et al.*	2020	[61]	7	Interactive robot as classroom learning host to enhance audience participation in digital learning theater
34	de Haas *et al.*	2020	[62]	23	The effects of feedback on children's engagement and learning outcomes in robot assisted second language learning
35	Kert *et al.*	2020	[63]	37	The effect of robotics on six graders' academic achievement, computational thinking skills and conceptual knowledge levels
36	Arshad *et al.*	2020	[64]	32	Robots as assistive technology tools to enhance cognitive abilities and foster valuable learning experiences among young children with autism spectrum disorder
37	Munoz *et al.*	2020	[65]	28	Developing an interactive environment through the teaching of mathematics with small robots
38	Turan and Aydogdu	2020	[66]	51	Effect of coding and robotic education on pre-school children's skills of scientific process
39	Konijn and Hoorn	2020	[67]	59	Robot tutor and pupils' educational ability: teaching the times tables
40	Çınar and Tüzün	2021	[68]	8	Comparison of object-oriented and robot programming activities: the effects of programming modality on student achievement, abstraction, problem solving, and motivation
41	Roll and Ifenthaler	2021	[69]	22	Learning factories 4.0 in technical vocational schools: can they foster competence development?
42	Yilmaz Ince and Koc	2021	[70]	30	The consequences of robotics programming education on computational thinking skills: an intervention of the young engineer's workshop (YEW)
43	Fegely *et al.*	2021	[21]	3	The effects of robotics professional development on scaience and mathematics teaching performance and student achievement in underserved middle schools
44	Sisman *et al.*	2021	[71]	63	The effects of robotics training on children's spatial ability and attitude toward STEM
45	Fanchamps *et al.*	2021	[72]	52	The influence of SRA programming on algorithmic thinking and self-efficacy using LEGO robotics in two types of instruction
46	Zhong and Xia	2022	[10]	2	Effects of new coopetition designs on learning performance in robotics education
47	Yang *et al.*	2022	[73]	35	Robot programming versus block play in early childhood education: effects on computational thinking, sequencing ability, and self-regulation
48	Veber *et al.*	2022	[74]	6	Implementation of the modern immersive learning model CPLM
49	Pellas and Tzafilkou	2023	[15]	1	The influence of absorption and need for cognition on students' learning outcomes in educational robot-supported projects
50	Veber *et al.*	2023	[75]	0	Assessment of supporting visual learning technologies in the immersive VET cyber physical learning model
51	Ajlouni	2023	[76]	0	The Impact of instruction-based LEGO WeDo 2.0 robotic and hypermedia on students' intrinsic motivation to learn science

Of the 51 articles obtained, 56 studies were meta-analysis. There were five articles that produced two research results on the impact of using robotic learning. Chen and Chang [49] revealed that robotic learning can improve students' programming and electronics learning. Isabelle *et al.* [12] claimed that robotic learning can enhance students' learning outcomes in mathematics and computational thinking. Korkmaz [39] revealed that robotic learning can improve students' problem-solving ability and academic achievement. Magen-Nagar and Cohen [13] also stated that robotic learning can improve students' academic achievement and learning motivation. Robotic learning, according to Won *et al.*, can help students become more adept at problem-solving and thinking sequencing [59]. Overall, the articles obtained contain student learning outcomes from the application of robotic learning, whether they contain cognitive, psychomotor, or affective learning outcomes. The studies that were considered in this analysis had sample sizes, mean values, standard deviations, and experimental and control group research designs. So the effect size and standard error values needed for the meta-analysis data are produced using this data. Table 3 displays the effect size and standard error data for each study that was used.

All study that is published in conferences or journals uses two classes: the experimental group and the control group, each with a sample size (n), Mean value (M), and Standard Deviation (SD), as Table 3 shows. After obtaining these values, the Standard Error (SEg) and effect size (d) can be determined. With the effect size value in each of the collected studies, it can be seen how much the average impact of learning using robotic learning (experimental group) and not using robotic technology (control group). After obtaining the data as shown in Table 3, the data analysis is continued by using the JASP application to determine whether the research conducted will produce good or bad results.

Table 3. Recapitulation of meta-analysis article data

Researcher Name	Year	Control Group			Experiment Group			d	SE_g
		n	M	SD	n	M	SD		
Chin *et al.*	2014	27	79.78	17.66	25	90.84	10.61	0.752	0.29
Kennedy *et al.*	2015	12	4.13	1.12	14	5.19	1.29	0.872	0.41
Alemi *et al.*	2015	16	3.00	0.77	30	3.48	0.52	0.78	0.32
A. M. Ortiz	2015	15	1.00	0.66	15	2.47	0.52	2.49	0.48
Alfieri *et al.*	2015	22	2.49	0.65	22	2.95	0.72	0.67	0.31
Berland and Wilensky	2015	34	2.24	1.23	44	2.42	0.96	0.17	0.23
Julià and Antolí	2016	12	57.3	10.20	9	58.40	8.80	0.11	0.43
Leonard *et al.*	2016	29	3.43	0.88	20	4.02	0.73	0.72	0.29
Korkmaz (A)	2016	24	20.00	11.07	24	44.33	15.73	1.79	0.34
Korkmaz (B)	2016	24	3.75	8.87	24	5.38	17.27	0.12	0.29
Barker *et al.*	2017	18	7.44	2.98	14	17.00	0.90	4.13	0.62
O. O. Ortiz *et al.*	2017	27	58.93	4.14	33	59.67	5.11	0.16	0.26
Magen-Nagar and Cohen (A)	2017	70	2.63	1.00	93	3.20	0.98	0.58	0.16
Magen-Nagar and Cohen (B)	2017	70	3.24	0.87	93	3.91	0.85	0.78	0.16
Witherspoon *et al.*	2017	364	7.20	3.10	364	7.80	3.40	0.18	0.07
Merkouris *et al.*	2017	36	4.31	0.67	36	4.61	0.645	0.46	0.24
Conti *et al.*	2017	25	2.75	0.83	55	3.18	0.82	0.52	0.24
Park *et al.*	2017	16	6.69	1.14	36	6.75	1.07	0.06	0.29
Van Den Heuvel *et al.* a	2017	7	6.90	1.46	8	7.40	0.92	0.42	0.51
Van Den Heuvel *et al.* b	2017	16	7.00	1.50	15	7.60	0.61	0.52	0.36
Y. Chen and Chang (A)	2018	40	3.11	0.31	42	3.45	0.51	0.80	0.23
Y. Chen and Chang (B)	2018	40	2.88	0.54	42	3.63	0.34	1.67	0.26
Barak and Assal	2018	32	3.61	0.08	32	3.64	0.08	0.39	0.25
Ramachandran *et al.*	2018	52	6.08	4.70	52	22.23	17.84	1.24	0.21
P.-N. Chou	2018	15	59.00	2.34	15	70.00	2.34	4.70	0.69
Taylor and Baek	2018	57	2.58	0.498	40	2.68	0.474	0.21	0.21
Leyzberg *et al.*	2018	9	0.63	0.09	10	0.84	0.08	2.48	0.59
Chiazzese *et al.*	2018	8	3.31	0.70	14	4.49	0.60	1.85	0.51
Isabelle *et al.* (A)	2019	15	4.92	1.60	17	7.14	2.07	1.19	0.38
Isabelle *et al.* (A)	2019	15	7.63	0.80	17	8.90	0.80	1.59	0.40
Chiazzese *et al.*	2019	16	15.5	5.79	21	19.76	7.24	0.64	0.34
Ching *et al.*	2019	14	3.82	0.68	14	4.18	0.72	0.51	0.38
Manuel *et al.*	2019	36	6.39	1.23	93	7.45	1.26	0.85	0.20
Michaelis and Mutlu	2019	29	5.29	2.16	29	5.40	2.32	2.12	0.33
Nam *et al.* (A)	2019	28	24.18	3.50	25	26.64	1.96	0.85	0.29
Nam *et al.* (B)	2019	28	29.75	6.33	25	37.16	3.88	1.39	0.30
H. Chen *et al.*	2020	39	80.95	15.76	19	93.21	8.28	0.89	0.29
Hakim *et al.*	2020	26	3.53	4.28	24	5.17	4.94	0.36	0.28
de Haas *et al.*	2020	27	4.74	1.58	27	5.31	1.95	0.32	0.27
Kert *et al.*	2020	33	5.55	2.32	23	7.70	2.18	0.95	0.28
Arshad *et al.*	2020	88	61.25	11.88	88	91.25	9.91	2.74	0.21
Munoz *et al.*	2020	96	3.18	1.87	96	4.17	2.42	0.46	0.15
Turan and Aydogdu	2020	15	12.00	2.10	15	14.33	2.16	1.09	0.39
Konijn and Hoorn	2020	45	5.38	20.72	41	7.51	22.41	0.09	0.22
Çınar and Tüzün	2021	21	9.90	4.38	20	10.25	3.39	2.27	0.39
Roll and Ifenthaler	2021	71	2.14	1.07	71	2.94	1.24	0.69	0.17
Yilmaz Ince and Koc	2021	32	82.33	9.69	32	87.33	11.47	0.47	0.25
Fegely *et al.*	2021	291	217.00	5.57	291	222.97	2.11	1.42	0.09
Sisman *et al.*	2021	39	4.25	0.81	39	4.57	0.50	0.48	0.23
Fanchamps *et al.*	2021	29	0.59	0.45	33	0.73	0.49	0.29	0.25
Zhong and Xia	2022	40	119.50	59.47	42	147.33	40.82	0.55	0.22
Yang *et al.*	2022	47	8.94	2.86	54	9.24	2.91	0.10	0.19
Veber *et al.*	2022	15	3.73	1.16	15	4.00	0.85	3.63	0.59
Pellas and Tzafilkou	2023	20	55.30	1.20	37	87.5	24.3	1.46	0.31
Veber *et al.*	2023	15	57.88	11.63	15	63.17	12.03	0.45	0.37
Ajlouni	2023	25	2.86	0.25	25	3.20	0.24	1.39	0.31

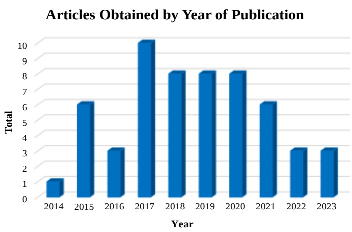

Fig. 2. Articles obtained by year of publication.

Information acquired, as displayed in Table 3, can be categorized according to the year that the journal article was published. So that we can know the development of robotic technology research carried out every year. So that the data that has been classified based on the year of publication is obtained as shown in Fig. 2, this data indicates that vocational schools have been conducting more and more robotics research each year. Many studies discuss the impact of using robotic technology from 2017 to 2020.

1) Heterogeneity results

Heterogeneity testing aims to determine whether the meta-analysis model used can be used properly or not. The meta-analysis model used is the random effect hedge model. Random effect model meta-analysis testing must also meet the heterogeneity requirements [21]. With a value of Q = 467.462; $p < 0.001$, the data analysis results shown in Table 4 indicate that the impact size value of the studies conducted is heterogen. Therefore, the estimated mean effect size of the 56 studies that were used as material for the meta-analysis may be analysed using the random effect hedges analysis model.

Table 4. Testing for heterogeneity

	Q	df	*p*
Test of Residual Heterogeneity	467.462	55	0< 0.001

[1]*p*-values are approximate.
[2]The model was estimated using Hedges method.

2) Results summary effect/mean effect size

Statistical analysis was conducted to ascertain the level of significance related to the impact of robotics-based learning on student learning outcomes, using mean effect size or summary effect. The test was conducted using the Wald test statistical data analysis technique. One statistical test technique used to assess if a therapy applied to the study object has a substantial influence is the Wald test, also called the Wald chi-square test [77]. According to Table 5 data analysis, which is based on the results of a meta-analysis using random effects, robotic learning considerably enhances student learning outcomes. Wald test for hedge models (z = 7.421; $p < 0.001$; 95% CI) with upper and lower bounds [0.730, 1.255]. Robotic learning technology clearly has a good, high impact on student learning outcomes, as evidenced by the random effect value's average effect size of $r_{RE} = 0.993$. The interpretation of this category is based on Cohen's d (1988), which states that ($r = 0.1$) is the low category, ($r = 0.5$) is the medium category, and ($r = 0.8$) is the high category [78, 79].

Table 5. Summary effect test

	Estimate	Standard Error	z	*p*	95% Confidence Interval	
					Lower	Upper
Intercept	0.993	0.134	7.421	< 0.001	0.730	1.255

[1]Wald test.

In more detail, the forest plot image Fig. 3 displays the meta-analysis of all conducted investigations. The name of the researcher, the effect size, the effect size's lower and upper bounds, and the average effect size achieved are all displayed in a forest plot. The data presented in the forest plot illustration indicates that the impact size resulting from the examined studies fluctuates. The observed values range from the lowest of 0.06 to the highest of 4.70, with an overall average effect size of 0.99. The range that the final effect size value truly falls within, with a 95% confidence level, is indicated by the 95% Confidence Level (CI) for a parameter. The 95% CI for the computed data falls between 0.730 and 1.255. This indicates that the true value of the effect size parameter lies between 0.730 and 1.255 at a 95% confidence level. We can draw the more secure conclusion that there is a good chance the true value of the parameter falls inside the computed interval when the 95% CI is used.

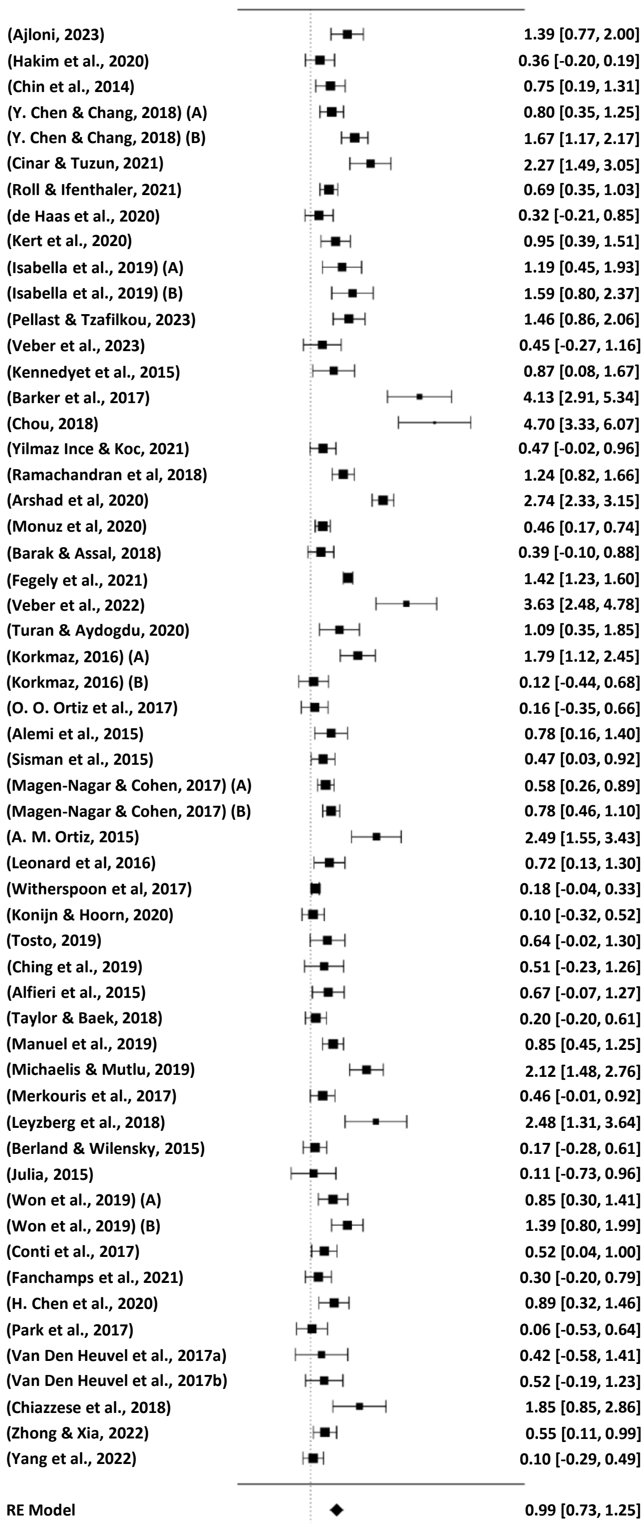

Fig. 3. Forest plot.

3) Results of article bias testing

Articles used in this meta-analysis research should be free from research bias. To get quality research and there is no element of data manipulation in it. As stated by Kwon *et al.* [80], Given the large number of studies used in the meta-analysis, testing for bias in research attempts to uncover data misrepresentation in the studies used in the meta-analysis. The degree of bias in the study is discovered by employing statistical data analysis methods such as fail-safe N and funnel plot, which were created by Rosenthal. The research will be considered unbiased if the fail-safe N value exceeds (5K+10) [81]. K represents the total number of research that are part of the meta-analysis. To ascertain the degree of bias in the articles' publication, a total of 56 papers that were incorporated into the meta-analysis were assessed. The presence of bias can be determined by examining the symmetry, or lack thereof, of the funnel plot. If an article is symmetrical, it is devoid of prejudice. If the article utilized in the meta-analysis is asymmetrical, it might be inferred that there is bias present [82, 83].

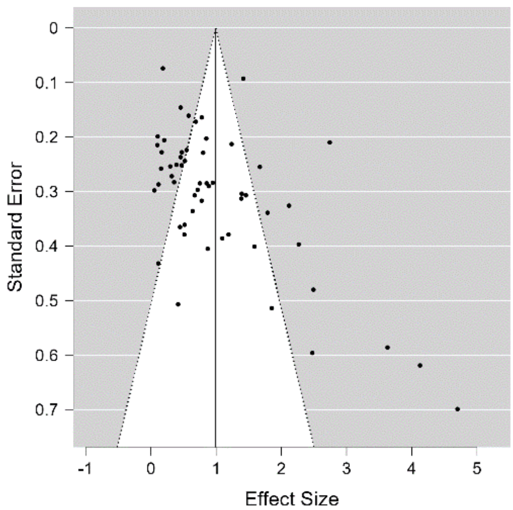

Fig. 4. Funnel plot.

The symmetrical nature of the final funnel plot is apparent from the results depicted in Fig. 4. The research data distribution is clearly illustrated in the funnel plot, where dot symbols are evenly dispersed and balanced between the left and right distributions, thereby demonstrating this finding. Furthermore, the kandell's τ test results provide additional evidence with a correlation coefficient of 0.336 and a *p*-value of 0.001, which is below the significance threshold of 0.05 ($p = 0.001 < 0.05$). These results demonstrate that the articles included in the study are unbiased, as indicated by the funnel plot test. To strengthen the argument of article bias, the N Rosenthal fail-safe test was conducted. The bias test findings are shown in Table 6, the results show that 12,986 is the fail-safe N number, with an observed significance of less than 0.001 and a significant target of 0.05. In the event when K = 56, the value of (5K + 10) will be 5 × 56 + 10 = 290. These findings indicate that N (12,986) > 5K + 10 (290) is the fail-safe value. This result further demonstrates the absence of publication bias in the publications that were used. That the 56 studies in the meta-analysis were free from publication bias can be supported by the results of the funnel plot analysis and Rosenthal's N fail-safe test.

Table 6. Bias measurement results of the fail-safe N rosenthal method

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	12,986.000	0.050	< 0.001

B. Discussion

Learning using robotic technology has been widely carried out by various educational institutions in various regions. Learning outcomes for students could be improved and learning effectiveness is predicted to increase with the development of robotic technology [16] Furthermore, robotics has been used in elementary school, junior high school, senior high school, vocational high school, college, and other educational levels [49, 59]. Students' motivation, interest, and learning results can all be improved by the employment of robotic technology in the classroom [49, 59]. Because robotic learning is so sophisticated, it may be applied to a wide range of Science, Technology, Engineering, and Mathematics (STEM) specialties. By applying robotic learning, it will also be able to effectively improve students' science, technology, engineering, and mathematics skills [49, 50]. Robotic technology is very suitable for use in vocational education because robotic technology can effectively improve students' problem-solving skills in the learning process [14]. So that with the design of the application of robotic technology that is good and in accordance with the learning context, it will produce good learning outcomes as well.

Additionally, education can help pupils develop the 21st century skills they'll need, like Computational Thinking (CT). Robotic learning and CT thinking are closely related to each other during the learning process. The application of robot-based learning can enhance students' capacity for CT thinking [43]. There are four CT thinking skills mastered by students, namely decomposition, pattern recognition, abstraction, and algorithms [84]. The same thing was also confirmed by Atmatzidou and Demetriadis [85], who stated that applying robotics-based learning can improve students' abstraction, generalization, algorithm, modularity, and decomposition abilities.

Computational thinking and 21st century thinking are intimately interconnected due to their alignment with the contemporary reliance on information technology and computing in various aspects of daily life, business, and education. In the 21st century, industrial technology is advancing alongside Industry 4.0, a paradigm that incorporates automation technologies such as robotics and digitalization systems across several sectors. Given these improvements, students today need a range of skills to be employable. First and foremost, the capacity to resolve intricate problems is facilitated by computational thinking, which offers a structured strategy to address the problem methodically. Furthermore, computational thinking fosters creativity and innovation by promoting abstract thinking, enabling individuals to approach problems from several angles and generate novel solutions [24–26, 86]. Implementing robotic technology in vocational school education will enable students to simulate real-world industry practices. Therefore, pupils must possess the necessary cognitive abilities to meet the requirements effectively.

The average effect size of 0.993 indicates that the utilization of robotics in the educational setting has a substantial impact on students' learning goals. The data was acquired using the meta-analysis of the research data, as presented in Table 4. The fail-safe N test and the funnel plot results indicate that the findings of the meta-analysis are robust against publication bias. The meta-analysis aimed to analyze the quantitative results from several studies on the impact of employing robotic technology on student learning outcomes. Therefore, the findings of this study demonstrate a highly positive influence that can be achieved through the implementation of learning technology in vocational schools. Furthermore, this meta-analysis demonstrates that robotic technology can serve as an effective and precise learning tool for vocational schools. This may be demonstrated since the study has uncovered research findings from diverse phenomena previously conducted by other researchers, which have yielded favorable consequences for the academic performance of vocational school pupils. Despite variations among studies undertaken by researchers and the diverse range of phenomena observed, when analyzed collectively, the utilization of robotic technology is consistently deemed highly beneficial in the context of vocational school education.

This observation suggests that robotic learning can be effectively implemented to enhance and expedite the learning process. In more detail, the effect sizes obtained from the articles analysed can also be shown based on Cohen's grouping of effect sizes. The outcomes of the articles' clustering according to the significant effect size discovered are displayed in Fig. 5. Based on these statistics, the largest outcome among the 25 studies that were part of the meta-analysis is represented by the effect size in the large category. In the medium category, there are 12 study results, and in the small category, there are 18 study results. These findings also demonstrate how robotic technology is successfully incorporated into vocational schools' curricula.

Fig. 5 makes it clear that the experimental class, which uses robotic technology as an aid in the learning process, has distinct learning results from the control class. The experimental class learning outcomes are more valuable than the control group. So based on the results that have been discussed, it can be seen that the first research objective and the second research objective have been answered well. Robotic technology-based learning has a significant impact on student learning outcomes, and learning results in the experimental class score higher than those in the control class. The obtained results are classified as very valid and dependable due to the research being conducted not only on a single learning phenomenon, but also on multiple existing phenomena. Based on a comprehensive review of many phenomena, challenges, and research findings, it can be concluded that robotic technology has a significant influence on the learning process.

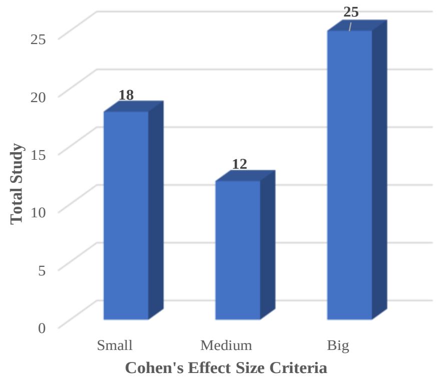

Fig. 5. Number of studies based on effect size criteria.

Overall, the results of the conducted meta-analysis showed that the use of robotic technology in vocational schools had a significant positive influence on the learning process. Consequently, utilizing robotic technology in vocational high schools to enhance instruction can lead to better learning results for students. When used to carry out the learning process, robotic technology can help pupils become more adept at solving problems. In addition, the application of robotic technology can foster critical thinking, motivation, teamwork, and computational thinking skills needed for technological advancement in the 21st century.

Technology is effectively utilized in the learning process. Utilizing robotic technology in vocational schools becomes highly efficacious in fostering proficiency in mechanical, electrical, Printed Circuit Board (PCB) circuitry, and programming skills [87, 89]. Robotic technology is widely utilized in the fields of electronic and electrical engineering with great efficiency. Through the utilization of robotic technology, students will receive instruction in electrical engineering, PCB circuitry, and programming skills in order to construct a comprehensive system [87, 90]. Furthermore, this technology will be efficiently utilized in the fields of mechanical engineering and mechatronics. Through the utilization of robotic technology, students will receive training in the creation of mechanical systems that can be controlled and function in accordance with specific instructions [3]. The implementation of robotic technology in vocational school education will involve the integration of a learning project for students. Students will be required to begin by designing the mechanics, electrical, and construction of robots, followed by programming, and concluding with the testing phase of the robot. In addition, students employ robotics as a method of competitiveness, engaging in a race against time to complete their ongoing robotic project. Completing multiple phases of workmanship, accomplished by students, enhances their experience and information acquisition throughout the learning process [22, 91, 92].

The future research direction can be determined by analyzing the outcomes of the 51 retrieved papers. To align vocational school education with industry demands, future research should focus on implementing robotic technology that can interface with either an AI or an artificial neural control system [93, 94]. This is based on the premise that in the 21st century, technology is being designed with the purpose of being self-governing and flexible. As advanced technology continues to progress in the industrial sector, it is imperative for students at vocational schools to possess problem-solving abilities. These skills encompass problem-solving, critical thinking, creativity, imagination, and computational thinking [95, 96]. In light of these improvements, vocational schools should ensure that they equip their students with competences that are in line with the skill development framework of the 21st century.

V. Conclusion

The findings of the meta-analysis demonstrated that robotic technology learning significantly improves student learning outcomes. It is known that the learning group that uses robotic technology (experiment) gets better learning outcomes than the group that does not use robotic technology (control). The effect size value found is an average of 0.993, with a 95% CI, the value of 0.730 as the lower limit and 1.255 as the upper limit of the effect size obtained. The effect sizes obtained were also heterogeneous, with a Q value of 467.462; $p < 0.001$. A total of 56 studies that were part of the meta-analysis did not show publication bias, this conclusion was based on the results of the fail-safe N test with a value of (12,986) > 5K + 10 (290) and funnel plot testing. These results have led to the understanding that the use of robotic technology can significantly affect the learning outcomes of students. Based on the findings obtained, the implication of robotic technology is that it can be used as a learning technology in vocational schools because applying this technology can improve students' computational thinking, creativity, innovation, communication, and collaboration well which is very necessary in the 21st century. Robotic technology and these skills are all competencies and technologies that must be mastered in facing industrial progress 4.0.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sukardi and Herlin Setyawan searched the literature and wrote the first draft of the article. Risfendra and Usmeldi analyzed the data using both formulas and the JASP application. All authors were involved in completing the final draft of the article.

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