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PAPER

Effectiveness of Distance Learning Computer Numerical Control Based on Virtual Laboratory Using a Metaverse Platform to Improve Students' Cognitive Ability and Practice Skills

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ABSTRACT

This study analyzes the effectiveness of virtual laboratory-based distance learning as a means of improving the learning outcomes of students' cognitive abilities and practical skills in the Computer Numerical Control course. This study utilized a pre-experimental design with a one-group pretest-posttest structure. The research subjects were 31 second-year vocational students from the Department of Mechanical Engineering at Universitas Negeri Padang who had recently participated in four distance learning sessions. The research instruments included a pre-test, a post-test, and a student perception survey to assess the effectiveness of virtual laboratory treatment. The findings of this study demonstrate that the presence of a virtual laboratory enhances learning outcomes in terms of cognitive abilities. The pre-test value for cognitive abilities was 52.04, which increased to 82.36 in the post-test. Similarly, the pre-test value for practical skills was 56.98, which improved to 83.44 in the post-test. These improvements significantly contribute to the enhancement of learning outcomes, as indicated by an average N-gain value of 0.642 in the medium/effective category. We conclude that the use of virtual laboratory media through the Metaverse platform is effective for distance learning. This method reduces the initial requirement of 24 hours of face-to-face learning to just five hours of more effective self-study.

KEYWORDS

virtual laboratory, distance learning, computer numerical control, cognitive ability, practice skills

1 INTRODUCTION

Technology and scientific advancements in the modern age 5.0 have created a system that enhances the quality of collaborative, creative, and innovative learning.

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This system has a profound impact on society as a whole and is closely related to the field of education [1] [2] [3] [4]. Education is the cornerstone of Indonesia's development, as it raises the standard and caliber of individuals who can contribute to the progress of a morally advanced nation [5] [6]. Moreover, the presence of rapidly advancing technology has brought about significant changes in several countries, including Indonesia, which has had a positive impact on students. The COVID-19 pandemic has highlighted the importance of developing online or remote learning systems that do not require face-to-face interaction [7] [8] [9]. This is an opportunity and a challenge for every university to adopt distance learning using digital technology-based learning media [10] [11] [12].

Distance learning is a form of education that allows lecturers and students to interact indirectly without being physically present in the same location [13] [14]. Implementing distance education with communication systems in higher education is relevant to 21st-century skills that focus on developing a highly intelligent society that encourages the use of the latest information technology [15] [16]. Technology's presence and growth offer opportunities to utilize digital learning media such as augmented reality (AR) [17], virtual reality (VR) [18], artificial intelligence, and Metaverse platforms. These technologies have emerged as significant trends since 2022 [19] [20] [21]. Therefore, the importance of education has a positive impact on improving the quality of life within the scientific community.

According to data from the Central Bureau of Statistics, the main factor contributing to the high unemployment rate in the education sector from 2020 to 2022 is the number of vocational education graduates in the highest unemployment category, which accounts for 6–8% [22]. Meanwhile, vocational education is considered competent in preparing highly skilled human resources to maximize Indonesia's demographic advantage and avoid the middle-class income trap [23] [24]. However, the impact of the post-COVID-19 era has affected the quality of vocational education graduates in the workplace. This is primarily due to the absence of practical activities that help develop specific skills or competencies during the pandemic.

Digital-based learning media have been widely developed, and one such medium is VR, which can visualize practical learning, equipment, machines, and virtual laboratory rooms [25] [26]. VR in the Department of Mechanical Engineering is a new educational trend that requires further study to determine its effectiveness in specific competencies. The use of VR, which provides an immersive simulation experience and a real-time 3D learning environment, has a positive impact on students who are learning computer numerical control (CNC) course [27], It is able to increase the effectiveness of learning materials and improve learning outcomes. Other than that, the advantages provided by Metaverse's VR technology are noteworthy. Metaverse is a new technology platform that allows users to enter the virtual world through a virtual laboratory. This not only saves budget by eliminating the need for a physical laboratory environment but also enhances learning by providing real-time interaction for both theoretical and practical aspects. This technological advancement has the potential to revolutionize the use of technology in universities [28] [29] [30]. Therefore, virtual laboratory facilities are a significant development program for universities to train mechanical engineering vocational students to improve cognitive and practical learning as an alternative means of distance education activities from 2020 to 2021 [31].

This research focuses on enhancing students' cognitive abilities and practical skills, as well as evaluating the efficacy of a remote virtual laboratory with 360° visual capabilities. The novelty of this research lies in the utilization of a virtual laboratory to study the CNC course. The aim is to measure students' cognitive and practical skills in a research publication, which has not been extensively explored before. This research contributes to the education sector, which has a significant impact on science and technology.

It focuses on the universal accessibility of virtual laboratories for computer numerical control lectures, which simulate real-time theory and practice. With the presence of virtual laboratories, higher education institutions can significantly reduce their budget for purchasing consumables and maintaining physical laboratories. This, in turn, enhances students' ability to learn independently, regardless of their location or time constraints. The time used for learning becomes more flexible. Therefore, this research presents an opportunity and is logical in assessing the use of virtual laboratories as instructional media. The research objectives that need to be addressed in this study are:

1. What is the impact of virtual laboratory media treatment using the Metaverse Platform on increasing the effectiveness of distance learning?
2. How effectively does the Virtual Laboratory media use the Metaverse Platform to improve students' cognitive abilities and practical skills?
3. How do students perceive the effectiveness of virtual laboratory in learning computer numerical control?

2 METHODOLOGY

2.1 Research roadmap

This research aims to develop a virtual laboratory on the Metaverse platform for distance learning. The validity and practicality of this laboratory have been tested in CNC courses. The research is based on the development of AR and VR from 2019 to 2022. The successful implementation and publication of this research have been documented in [32] [33] [34] [35]. This research is a continuation of a study conducted in 2023 that tested the effectiveness of CNC learning. The study utilized VR technology, specifically the Oculus Quest 2 device, to combine the real world and the virtual world through the Metaverse platform. This combination created a virtual space for users to interact through distance learning, guided by previous research [36]. The research roadmap (see Figure 1) is as follows:

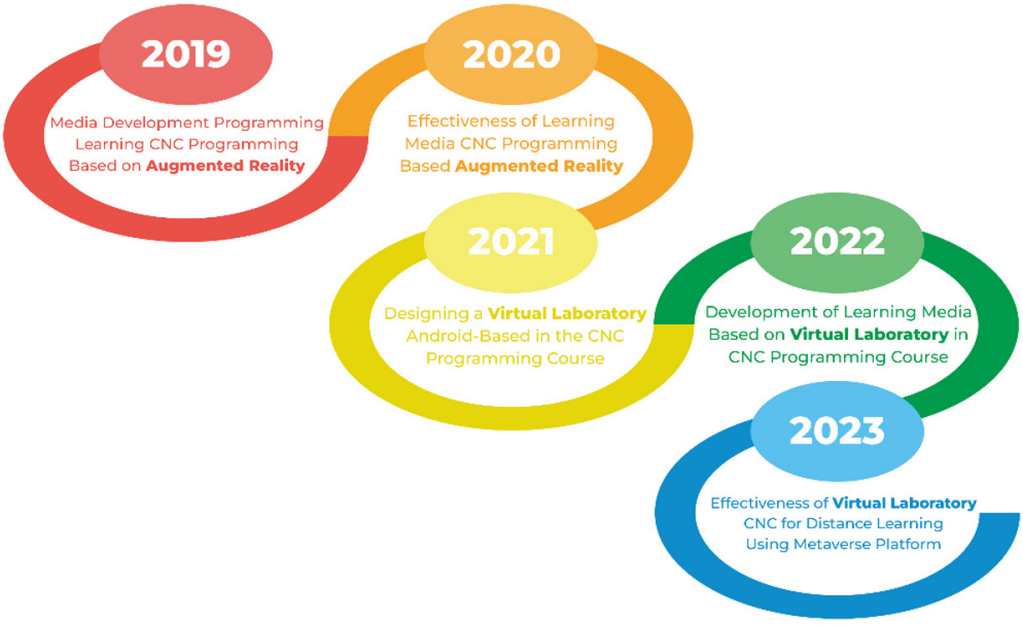

Fig. 1. Research roadmap

2.2 Subject and research procedure

This study utilized a pre-experimental design with a one-group pretest-posttest structure [37], [38]. Purposive sampling was conducted on 31 second-year students from the Department of Mechanical Engineering at Universitas Negeri Padang. The questionnaire was initially administered to an equal number of male and female students. However, after collecting the data, it was discovered that 25 male students (83.87%) and six female students (16.13%) belonged to a single group where the same lecturer provided the virtual laboratory learning treatment. One group received the same initial pre-test, treatment, and final post-test [39]. This study has limitations in the absence of a control group and the small number of participants, with experiments conducted only four times during each meeting. The flow of the research procedures is shown in Figure 2.

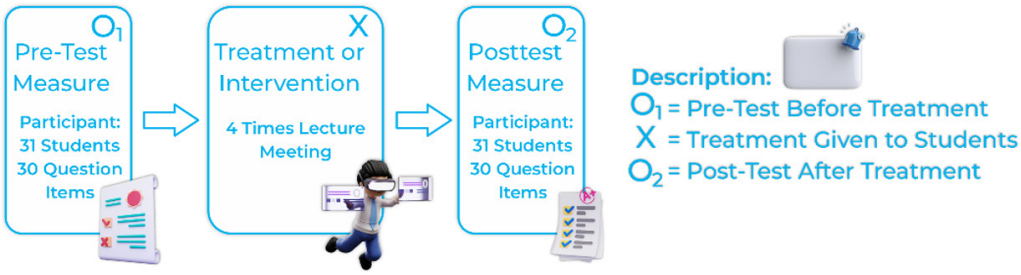

Fig. 2. Research procedure

This research builds upon previous studies on the design of virtual laboratory CNC learning media. In one year, the press has been designed, and it has successfully passed the test for validity and practicality in both categories. However, in the second year, the researcher intends to examine the effectiveness of this medium as a training model for CNC learning classes. There is also a fishbone diagram of the research that has been designed in Figure 3, as shown below.

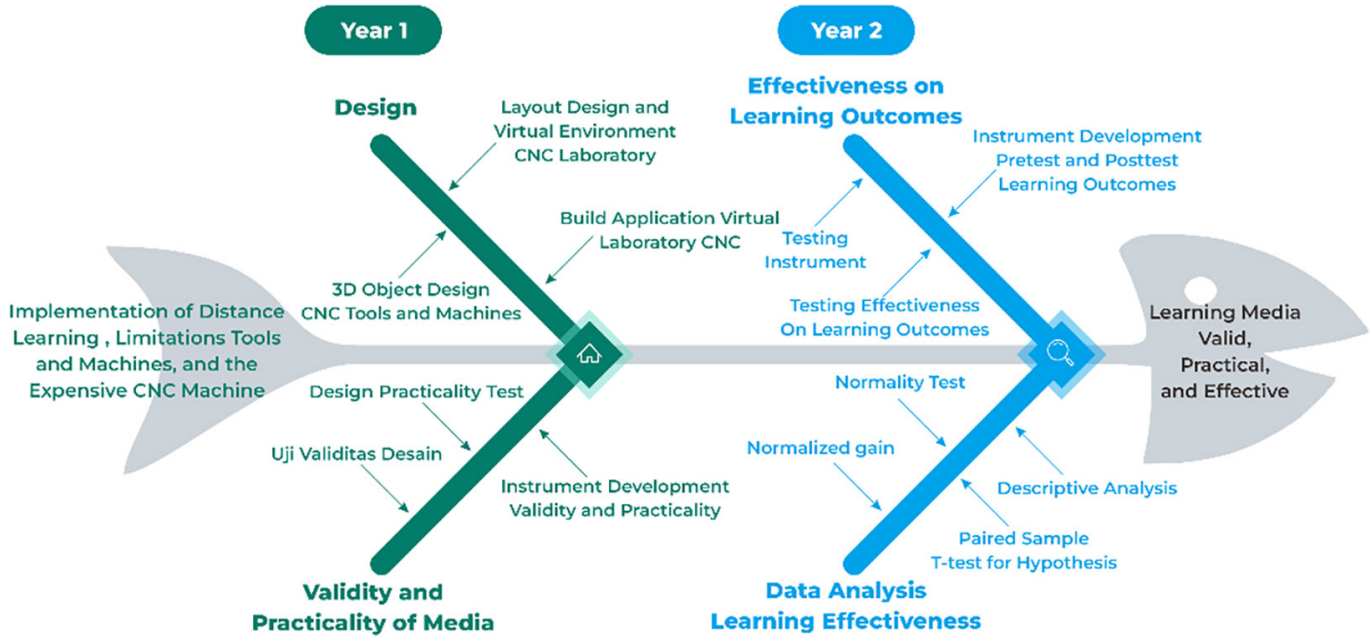

Fig. 3. Fishbone diagram of the research

2.3 Data collection

Questionnaires were distributed to students who attended classes both before and after the lecture in order to assess the utilization of virtual laboratory devices integrated with the Metaverse Platform and the efficacy of distance learning. The instrument used was based on the aspects of cognitive ability and practice skills developed by D. Nathanael [39]. Indicators assessed from research instruments on pre-test, post-test, and student perception surveys have undergone a trial stage and have been evaluated by three experts in media and learning materials for virtual laboratory CNC. These experts, who have 30–40 years of pedagogical and research experience, hold the titles of doctor and professor. The indicators assess cognitive ability and practice skills [40]. The Aiken V coefficient was used to examine the information gathered from the experts [41], with an interpretation of greater than 0.05, which is known to be the r-table value of 0.3550 [42]. As indicated in Table 1, each question item was assessed using a 5-point Likert scale that ranged from "strongly agree" to "strongly disagree."

Table 1. Statistical validity and reliability of the instruments

Aspects	Indicators	Validity	Reliability
Cognitive ability	Knowledge of laboratory work safety	0.73	0.81
	Introduction to CNC laboratory tools and machines	0.67	
	Working principle of the CNC lathe machine	0.65	
	CNC lathe machine setup	0.63	
	Visual display of the CNC machine	0.72	
Practice skills	Using safety devices	0.71	0.89
	Basic CNC programming	0.66	
	Operation of the lathe and CNC milling machine according to the procedure	0.53	
	Programming flat and multilevel CNC machine commands	0.56	
	Practice using CNC lathes and milling machines in a virtual	0.68	

Cognitive ability and practical skills were assessed using thirty objective and essay questions specifically designed for the learning material. These questions were validated by three lecturers who had pedagogical experience in CNC courses. The reliability test was assessed based on the knowledge of CNC among 31 students who had completed the course in the previous semester. Based on Cronbach's alpha analysis, a cognitive ability of 0.81 meets the criteria of > 0.70, indicating strong reliability [43]. The assessment instrument was administered using a Likert scale with the Aiken V coefficient formulation [41]. It evaluated student practical skills with a reliability coefficient of 0.89 in the relevant category. The paired sample t-test compares the means of one group while analyzing the evaluation results of students' cognitive and practical skills.

2.4 Data analysis technique

The effectiveness of the virtual laboratory using the Metaverse platform on students' cognitive abilities and practical skills was measured by obtaining scores from an initial test before learning and the final test given after an entire series of learning. The validity of the Pearson correlation coefficient test,the reliability of the Cronbach's alpha test, and the normality of the Shapiro-Wilk test were used to analyze the data.

The data acquisition results were analyzed using SPSS with a paired sample t-test. The understanding results were obtained by assigning scores to the misconception diagnostic test using the Rights Only method [42]. In this method, a correct response is given a value of 1. In contrast, the value of the incorrect response is 0. Each student's score was based on the number of correct answers. Table 2 provides a comprehensive summary of the data analysis.

Table 2. Data analysis technique

Analyses Used	Test Type	Purpose of the Analysis
Descriptive analysis	Descriptive statistics	Analyzing the mean, standard deviation, and significance level of the data.
Normality test Shapiro–Wilk	Descriptive statistics (explore method)	We are determining whether data acquisition is normally distributed with a sample of 31 students.
Paired sample t-test	Parametric	We examined the mean difference between the pre-test and post-test in paired samples.
Normalized gain	Pre-test and Post-test	We are measuring the improvement of student learning outcomes with the treatment of virtual laboratory effectiveness by calculating the difference in pre-test and post-test values.
Student perception analysis	Survey	Survey of students' perceptions of the effectiveness of the Virtual Laboratory as a learning medium containing ten closed questions.

The effectiveness of learning is superior when using the virtual laboratory device approach with the Metaverse platform. The comparison of N-gain values demonstrates that this approach significantly impacts distance learning activities and understanding of basic CNC concepts. According to Meltzer [44], N-gain is the average of the treatment given to the learning that measures the effectiveness of the provided learning media. The benefit of N-gain is that it can distinguish the impact of the treatment and is not limited to the population of the pre-test and post-test. Finally, a survey was conducted to determine students' perceptions of the effectiveness of the virtual laboratory using a Likert scale.

Table 3 provides an interpretation of the N-gain value by D. E. Meltzer [44], which measures the improvement of learning outcomes and the effectiveness of the virtual laboratory used by students.

Table 3. N-gain classification and effectiveness interpretation category

Percentage (%)	N-Gain	Category
70–100	$(g) \geq 0.70$	High/Very Effective
0.31–0.75	$0.31 \leq (g) \leq 0.70$	Medium/Effective
0–0.30	$(g) < 0.30$	Low/Less Effective

3 RESULTS

3.1 Virtual laboratory CNC using the metaverse platform

This study aims to enhance students' cognitive abilities and practical skills in computer numerical control distance learning. It also seeks to evaluate the effectiveness of using 3D VR media in a real-time virtual laboratory environment as a treatment method.

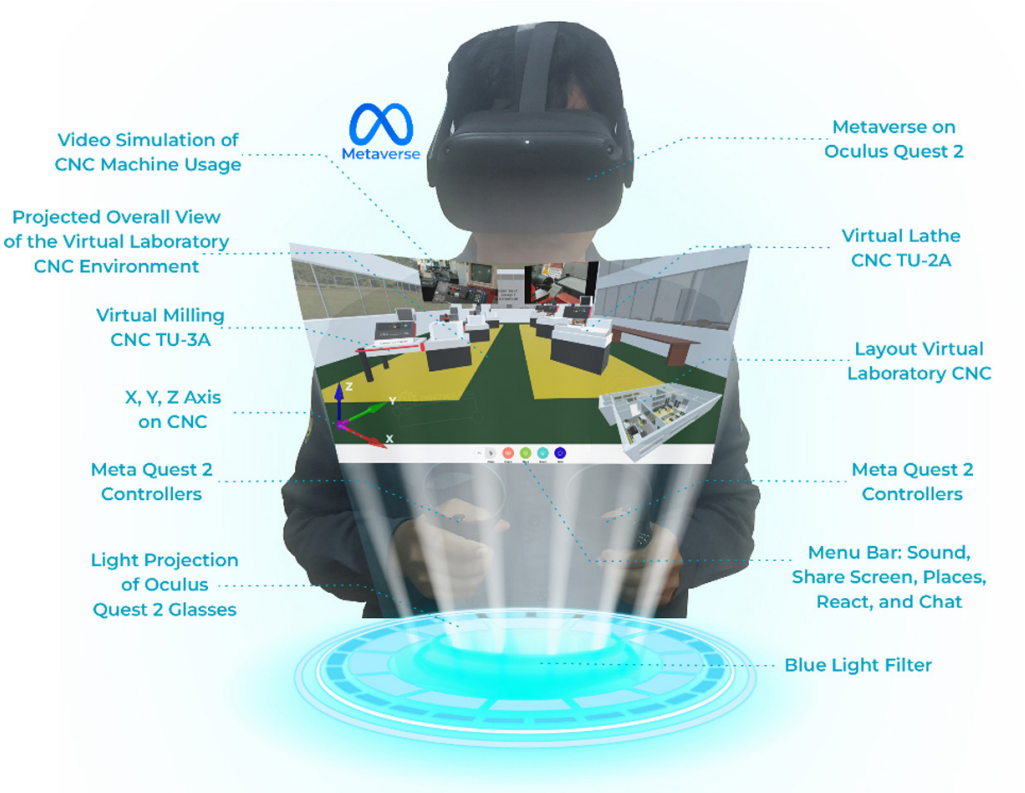

Fig. 4. Visualization of the usage of the virtual laboratory for CNC course

The display is provided using the Metaverse platform device, which is mounted on the user's head and provides a separate visual image for each eye. When the user enters the Metaverse world, they are greeted with the login menu to access the CNC virtual laboratory of the Department of Mechanical Engineering at Universitas Negeri Padang. The design of the virtual laboratory closely resembles the actual laboratory model, with a similarity level of over 90% [35] (see Figure 4).

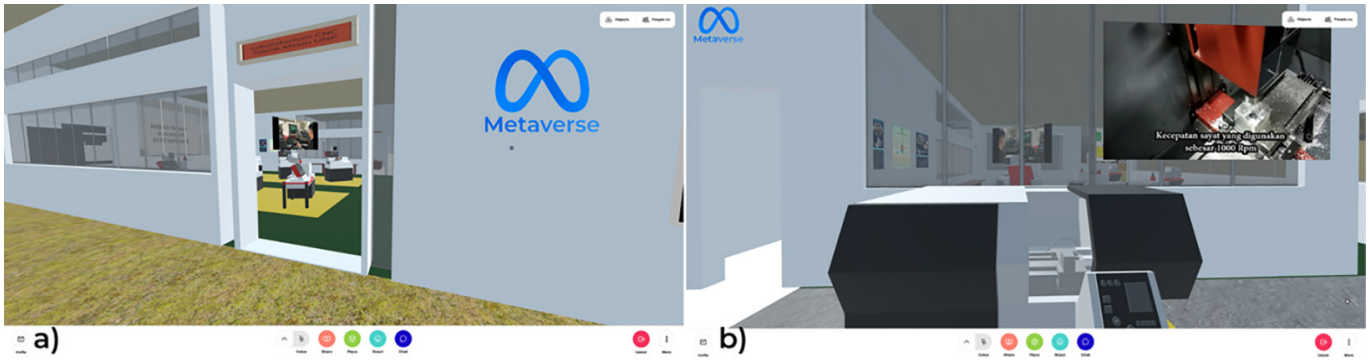

Fig. 5. a) Virtual laboratory login screen, b) Simulation of the use of TU 3A CNC machine

The experience received by students is more realistic, especially when objects displayed have images, sound, text, animation, and interactive video about the use of the axis and milling machine. This helps students understand the effect of motion deviation on the XYZ axis. The features that support students in following the learning process in the virtual laboratory include a study room that introduces the basic theory and working principles of machines, along with G-code programming. The practice room operates

CNC machines in accordance with standard operating procedures and inputs basic CNC programming commands for both flat and multilevel manufacturing (see Figure 5).

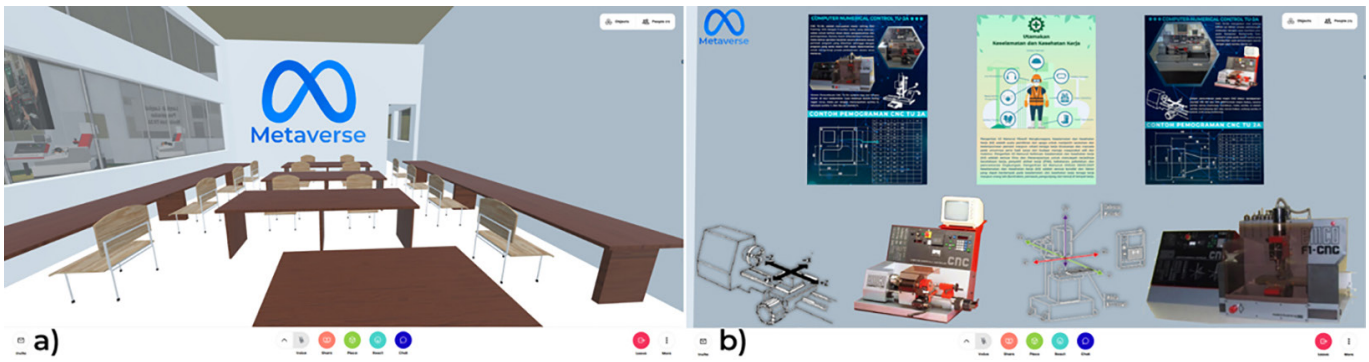

Fig. 6. a) Virtual laboratory theory study room, b) Safety health education and XYZ-axis system of CNC machine

In distance learning, students are not limited to focusing solely on the theory and practice of CNC machines. Safety and health education, however, is provided as a preventive measure in the event of accidents and occupational diseases during face-to-face learning. This helps enhance students' understanding of theory, practice, and safety in the laboratory, improving their cognitive abilities and fostering effectiveness, creativity, and collaboration (see Figure 6).

After the pre-test, the effectiveness test was conducted by administering the treatment using virtual laboratory media integrated with the Metaverse platform for four distance learning sessions.

3.2 Descriptive analysis of the normality test of the virtual laboratory CNC

The Shapiro-Wilk test allows us to analyze statistical data for normality testing, using SPSS software to calculate the values of the normal distribution. If the obtained data has a significance value (*p-value* > 5% or 0.05), then it can be categorized as normally distributed.

Table 4. Descriptive analysis of the normality test on students' cognitive ability

Measure	Mean	Std. Dev	N	Statistics (*S-W*)	*p*-Value	Note
Pre-Test	52.04	12.82	31	0.958	0.263	Normal
Post-Test	82.36	7.33	31	0.942	0.095	Normal

The analysis results are presented in Table 4, which includes the average value, standard deviation, the number of respondents (31 people), and the significance level of students' cognitive abilities. The average value obtained in the pre-test was 52.04, with a standard deviation of 12.82. In contrast, the average post-test score was 82.36, with a standard deviation of 7.33. Descriptive analysis indicates an enhancement in the average cognitive abilities of students, evident in the post-test scores having a smaller standard deviation compared to the pre-test scores. It is concluded that after using virtual laboratory media for the treatment, students' scores are closer to the average, while their cognitive abilities remain at a similar level.

Table 4 presents the results of the normality test. It indicates that the cognitive abilities of students in the pre-test are normally distributed [*S-W* = 0.958; *p-value* > 0.05 = 0.263], as well as in the post-test [*S-W* = 0.942; *p-value* > 0.05 = 0.095].

Based on the results of normality testing on students' cognitive abilities, it is appropriate to proceed with a paired sample t-test.

Table 5. Descriptive analysis of the normality test on practical skills

Measure	Mean	Std. Dev	N	Statistics (*S-W*)	*p*-Value	Note
Pre-Test	56.98	14.28	31	0.935	0.060	Normal
Post-Test	83.44	9.08	31	0.942	0.093	Normal

The results of the descriptive analysis of students' practical skills are presented in Table 5. The average pre-test score was 56.98, with a standard deviation of 14.28. In contrast, the average post-test score was 83.44, with a standard deviation of 9.08. Based on a descriptive analysis, there is an increase in the average value of practical skills. However, the standard deviation of the post-test is lower than that of the pre-test. This indicates that after using virtual laboratory media for instruction, the value of students' practical skills becomes diverse and significant compared to the average.

The results of the normality test on practical skills are shown in Table 5. The pre-test was also normally distributed [*S-W* = 0.935; *p-value* > 0.05 = 0.060], and the post-test was normally distributed [*S-W* = 0.942; *p-value* > 0.05 = 0.093]. Based on the results of normality testing on students' cognitive abilities, a paired sample t-test can be conducted.

3.3 Result of paired sample T-test virtual laboratory CNC

A paired sample t-test was conducted to determine the difference between the means of two paired samples. The samples in this study were from the same subject, but the treatment was administered at different times. The results of the paired sample t-test are presented in Table 6.

Table 6. Paired sample t-test results for cognitive ability and practical skills

Aspects	Descriptive Statistics				Paired T-Test		
	Pre-Test Mean	SD	Post-Test Mean	SD	*t*	df	Sig. (2-tailed)
Cognitive ability	52.04	12.81	82.36	7.99	–12.678	30	0.000
Practical skills	56.98	14.28	83.44	9.08	–14.786	30	0.000

The results of the paired sample t-test are presented in Table 6. There was a significant difference in the mean cognitive ability of [t = –12.678; df = 30; *p-value*. (2-tailed) < 0.05 = 0.000] and student practical skills of [t = –14.786; df = 30; *p-value*. (2-tailed) < 0.05 = 0.000]. These results indicate a significant effect on cognitive ability and practical skills. The treatment given after students use virtual laboratory-based media integrated with the Metaverse platform can improve their learning outcomes. This was followed by the N-gain test to determine the extent of the influence.

3.4 Analysis of N-gain values for improving learning outcomes using virtual laboratory effectiveness

Normalized gain aims to measure the magnitude of the increase in learning outcomes resulting from the effectiveness of the virtual laboratory using the Metaverse

platform. This is done by calculating the difference or comparison between pre-test and post-test scores, with a sample size of 31 students from the Department of Mechanical Engineering at Universitas Negeri Padang.

Table 7. Results of the analysis of the N-gain value on improving student learning outcomes with the effectiveness of the virtual laboratory treatment

Aspects	N	Pre-Test Mean	Post-Test Mean	N-Gain Score	SD	Category
Cognitive ability	31	52.04	82.36	0.623	0.205	Effective
Practical skills	31	56.98	83.44	0.625	0.169	Effective

The N-gain test results are shown in Table 7. The cognitive ability aspect of the pre-test was 52.04. After being treated, the post-test value increased to 82.36, with a standard deviation of 0.205. The N-gain score was 0.623, which falls into the medium/effective category. Simultaneously, the practical skills aspect had a pre-test value of 56.98. After treatment, it showed a post-test value of 83.44, with a standard deviation of 0.205. The N-gain score was 0.625, falling into the medium/effective category. Therefore, it can be concluded that there is an increase in cognitive and practical learning outcomes from pre-test to the post-test. This indicates that the virtual laboratory using the Metaverse platform is effective for distance learning.

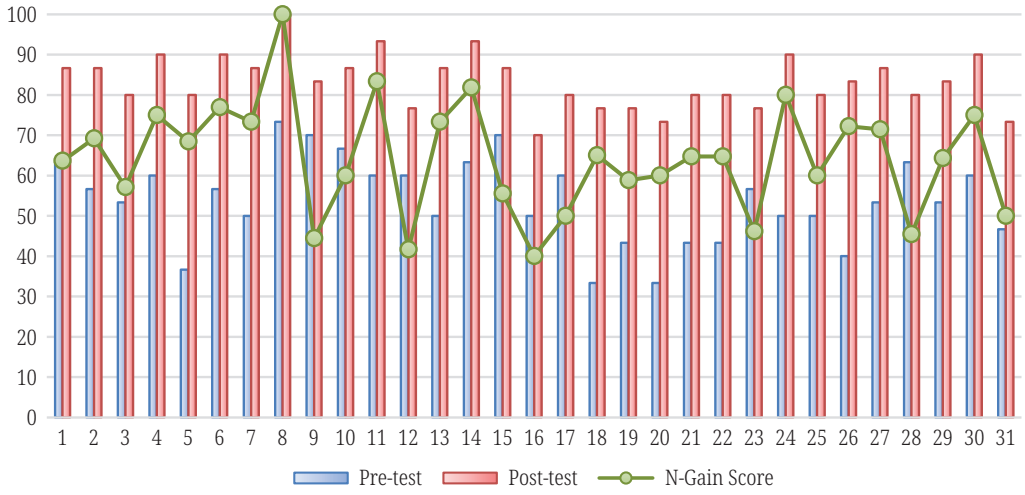

Fig. 7. Improving learning outcomes with the aid of virtual laboratory

Figure 7 visualizes the extent to which the improvement of learning outcomes influences the effectiveness of the virtual laboratory on students' cognitive ability and practical skills. The improved results yielded an overall average N-gain score of 0.642 in the medium/effective category.

3.5 Students' perception of virtual laboratory CNC in distance learning

The survey was conducted to determine the perceptions of students who have participated in the distance learning process in CNC and to assess the objectives and pedagogical impact on the effectiveness of virtual laboratory learning. It contains ten questions with Likert scale measurements ranging from "strongly disagree" to "strongly agree."

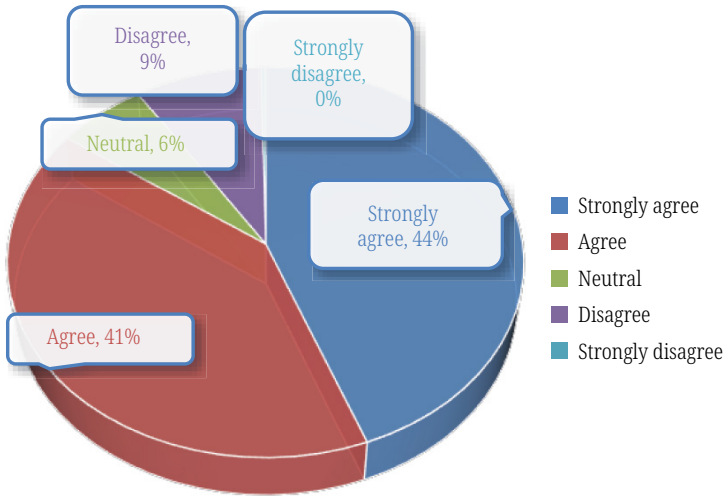

Fig. 8. Students' perceptions of virtual laboratory in CNC learning

Based on the results of the student perception survey (see Figure 8), the overall average value for each question item was as follows: 44% of students strongly agreed, 41% agreed, 6% were neutral, and 9% disagreed on the effectiveness of virtual laboratory CNC as a form of distance learning. The results of the discussion above show that 85% of students positively benefit from learning CNC materials, particularly in regards to the theory and practice of operating lathes, milling machines, G-code programming, and the application of work safety in face-to-face laboratories. The findings of this study are supported by research [45] [46] [47], which demonstrate that the use of VR media in CNC learning can enhance students' cognitive abilities and practical skills, leading to improved learning outcomes.

4 DISCUSSION

Based on a review of previous research literature examining student acceptance of adopting learning environments with virtual laboratory technology, theoretical modeling supports both theoretical and practical learning with significant efficiency, cognitive, and practical benefits [48] [49]. Likewise, research results from K. A. A. Gamage [50] emphasize the need for universities worldwide to adapt to the impact of COVID-19 by implementing pedagogical measures such as virtual laboratories. These remote laboratories should focus on technology, engineering, and science and should also consider the potential for enhancing student learning experiences [51]. This study also aims to determine the effectiveness of a virtual laboratory for CNC by building upon the research conducted by W. M. Roth and M. K. McGinn [52]. This research focuses on cognitive and practical abilities that offer an alternative perspective for addressing the challenges learners face in problem-solving and assessing their learning difficulties. The findings of this study on the effectiveness of virtual laboratory learning in enhancing student learning outcomes in the cognitive abilities of computer numerical control courses [53]. This is because the development of VR technology trends provides opportunities for the use of virtual distance learning. It streamlines learning time and allows students to work independently. As a result, when students are given the task of operating CNC machines, they already have a solid foundation in theory and cognitive abilities. The findings of this study focus on improving learning outcomes in students' practical skills through the use of

virtual laboratories in CNC programming courses [54]. Utilizing this medium results in the development of vocational students who have a comprehensive understanding of the cognitive and practical aspects of operating CNC machines, thereby preparing them for entry into the industrial world.

The effectiveness of the virtual laboratory using the Metaverse platform as a treatment model has several advantages. It has been found to have a significant impact on the learning outcomes of CNC courses, particularly in the mastery of material related to the operation of lathe training unit 2A, milling machine training unit 3A, work safety in the laboratory, and G-code programming inputted on the computer. The research results above include the outcomes of the learning outcomes review and surveys, which were analyzed using descriptive analysis, normality tests, paired sample t-tests, and N-gain. The other advantages of the virtual laboratory are that it can save on budget by reducing the use of consumables in face-to-face laboratories. Additionally, it provides real-time interaction through voice features, screen sharing, and chat menus. This allows for both theoretical and practical learning to be conducted using Metaverse technology, which can be accessed anytime and anywhere by the user. This represents an advancement for universities as educational and pedagogical institutions to keep up with the technological trends in 2023 [55].

5 CONCLUSION

This research contributes to the education sector by significantly enhancing the universal accessibility of science and technology in virtual laboratories for distance learning. Using the Metaverse platform, virtual laboratory media effectively enhance students' learning outcomes and cognitive and practical abilities in CNC courses by providing an authentic, realistic, and real-time 3D learning environment. The technology presentation provided evidence that CNC teaching can be interesting, interactive, and collaborative. This approach creates a more varied learning experience and fosters a different atmosphere.

The findings of this study on the use of virtual laboratories for learning have been widely applied. However, measuring students' cognitive and practical abilities after using the virtual laboratory media on the Metaverse platform has shown an increase in learning outcomes and the effectiveness of distance learning. Initially, it required 24 hours of face-to-face learning, but now it only requires five hours of more effective self-study. This is one of the key findings of this research. The purpose of this research is to inspire teachers and learners to continuously develop and stay updated with technological advancements in order to enhance the quality of education in Indonesia.

6 LIMITATIONS AND FUTURE WORK

This study has provided valuable insights into the effectiveness of distance learning using virtual laboratories. However, it is important to acknowledge certain limitations. The research design employed a pre-experimental approach, utilizing a one-group pre-test-post-test structure without including a control group for comparison. This design limitation makes it challenging to establish a clear cause-and-effect relationship between virtual laboratory interventions and the observed improvements in learning outcomes. The sample size was relatively limited, comprising 31 second-year students from the Department of Mechanical Engineering at Universitas

Negeri Padang. Expanding the size and diversity of the sample would provide a more robust foundation for making generalizations and gaining a deeper understanding of the effects of virtual laboratories. Furthermore, the experiments in this study were conducted four times during meetings. This limited number of experiments may not have fully captured the entire range of potential results and may not have taken into account the long-term effects of the virtual laboratory intervention.

To address the recognized constraints and make further progress in virtual laboratory-based remote learning, additional measures are needed. Future research should incorporate a control group to enhance the rigor of evaluating the efficacy of virtual laboratories compared to traditional teaching techniques. This can improve the establishment of more explicit causal links and strengthen the validity of the findings. Subsequently, a more extensive and diverse sample of students from various departments and institutions will be included to improve the generalizability of the results. This will enhance our understanding of how virtual laboratories impact educational achievements in various settings. By incorporating different frequencies of experiments and adjusting the duration of virtual laboratory sessions, one can determine the most effective number and timing of sessions to optimize learning outcomes. This can provide valuable insight into the most efficient implementation options. By addressing these constraints and exploring opportunities for future research, we can enhance our understanding of the potential of virtual laboratory-based distance learning and improve its implementation in educational settings.

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