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IMPROVING LEARNING MOTIVATION AND MATHEMATICAL PROBLEM-SOLVING ABILITIES VIA VERNIER CALIPER VIRTUAL LABS

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Abstract
The low learning motivation and mathematical problem-solving abilities of vocational high school students, regarding mechanical measuring instruments, such as vernier calipers, present a significant challenge in the learning process. An interactive simulation-based Virtual Lab is expected to be an innovative solution to address these issues. This study aims to examine the effect of using a Virtual Lab on students' learning motivation and mathematical problem-solving abilities. The method used was quantitative with a one-group pretest-posttest design involving 42 Mechanical Engineering vocational high school students. Data were collected through observation sheets, a learning motivation questionnaire, and a mathematical problem-solving test. The results showed that students' learning motivation was in the good category based on observation and questionnaire data, which had high validity and reliability (Cronbach's Alpha = 0.878). Furthermore, students' mathematical problem-solving abilities increased significantly, with the average score rising from 68.95 in the pretest to 79.74 in the posttest. The Wilcoxon Signed Ranks Test confirmed a significant improvement ($p < 0.001$). However, the results of this study did not show an effect of motivation on problem-solving ability, because it did not comply with the one-group pretest-posttest design. Thus, it can be concluded that the Virtual Lab is effective in improving learning motivation and mathematical problem-solving skills separately in vocational high school students.

Keywords: Calipers, interactive simulation, learning motivation, mathematical problem solving, virtual Lab

Introduction

Vocational High Schools (SMK), particularly in Mechanical Engineering, are required to equip students with contextual and applicable competencies, one of which is the mastery of mechanical measuring instruments. Vernier calipers, as a fundamental measuring tool, demand a concrete understanding of real numbers and high precision. However, in practice, students often encounter difficulties in reading the main and vernier scales, calculating tolerances, and analyzing measurement results. These challenges are not only due to the complexity of the material but are also exacerbated by low learning motivation and underdeveloped mathematical problem-solving abilities among students. Low motivation significantly impacts student engagement and learning outcomes. According to Sardiman (2019), learning motivation is a psychological condition that drives individuals to achieve learning goals, which is divided into intrinsic motivation (intrinsic

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Volume 12 | Number 2 | December 2025|

drive) and extrinsic motivation (external influence). In the context of learning about measuring instruments and real numbers, students require logical and analytical thinking skills to solve mathematical problems, such as interpreting scales and calculating measurements. A lack of engaging and interactive learning media often contributes to this low motivation and hampers the development of essential problem-solving skills. Consequently, innovative learning methods are needed to facilitate active, exploratory, and contextual learning experiences.

Mathematical problem-solving ability is a key competency for vocational students, especially in applying mathematical concepts to real-world technical situations. The process, as outlined by Polya (1945), involves understanding the problem, devising a plan, carrying out the plan, and looking back. These stages are highly relevant to using vernier calipers, where students must understand the measurement task, plan the steps, perform the measurement, and check for accuracy. However, empirical evidence indicates that students' problem-solving abilities in this technical context remain low, often due to theory-heavy instruction and a lack of contextual practice.

In response to these challenges, Virtual Labs emerge as a potential technological solution. A Virtual Lab is a digital environment that allows students to conduct experiments and simulations as if in a real laboratory, offering greater flexibility and safety. Previous studies (Jaya & Haryoko, 2010; Tyas Almira et al., 2023) have demonstrated the effectiveness of virtual labs in improving conceptual understanding and learning motivation. However, research focusing specifically on the implementation of an interactive Vernier Caliper Virtual Lab to enhance mathematical problem-solving abilities within a vocational education context remains limited. This creates a distinct research gap. While existing studies confirm the benefits of Virtual Labs for general motivation and science process skills, their targeted impact on the mathematical reasoning required for technical tasks like precision measurement is not yet well-established.

Therefore, this study aims to fill this gap by implementing an interactive Vernier Caliper Virtual Lab. The specific objectives of this research are: (1) to analyze students' learning motivation in learning mathematics on real number material using vernier calipers, (2) to measure the improvement in students' mathematical problem-solving abilities on the same material after the implementation of the Virtual Lab, and (3) to determine the effect of using the Virtual Lab in terms of learning motivation on mathematical problem-solving abilities. The findings of this study are expected to provide an innovative solution for addressing learning challenges in vocational mathematics education and offer practical insights for developing effective, technology-based learning media.

Literature Review

The literature review in this study explores the theoretical foundations and previous research relevant to the use of interactive simulation-based virtual labs in mathematics learning, particularly in the context of vocational education. This section discusses four key components: (1) the concept of interactive simulation virtual labs as innovative learning media, (2) theories of learning motivation, (3) mathematical problem-solving skills based on Polya's framework, and (4) the integration of these theories in the context of this research. Understanding these components is essential because they provide a conceptual basis for explaining how virtual labs can influence both students' learning motivation and their ability to solve mathematical problems. Moreover, reviewing these interrelated concepts helps identify the existing research gap that this study aims to address, namely, the limited empirical evidence on the effectiveness of virtual labs in enhancing

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

mathematical reasoning and technical problem-solving skills among vocational high school students.

Interactive simulation virtual lab

A Virtual Laboratory is defined as a simulated space in cyberspace that allows students and researchers to interact and conduct experiments digitally (Suryandi, 2023). In the context of learning, a Virtual Lab serves as a computerized representation of a physical laboratory, designed to simulate observation and experimentation that are often inaccessible or too risky in real-life situations. Its presence is a significant pedagogical innovation in the Society 5.0 era, demanding a learning process that is not limited to observation but also involves investigation and interpretation of findings.

As an interactive multimedia object, a Virtual Lab integrates various media formats such as text, audio, images, animation, and video to create an immersive learning experience. This media operates on digital devices such as PCs and smartphones, thus offering flexibility based on the principle of "anytime, anywhere, and by anyone" (Suryandari, 2023). This flexibility makes the Virtual Lab a strategic solution to overcome limited infrastructure, including in the context of Vocational High Schools (SMK), which require repetitive and intensive practice.

According to Suryandari (2023), the benefits of implementing a Virtual Lab in learning include:

- Cost Efficiency: Minimizing the budget for procurement, maintenance, and operation of conventional laboratory equipment.
- Increased Learning Motivation: Interactive and visual presentations can create a fun learning environment, thereby increasing student engagement and motivation.
- Developing Thinking Skills: Helping students hone their problem-solving and higher-order thinking skills, including literacy and numeracy.
- Accessibility and Security: Providing opportunities for students to experiment without the constraints of space and time, and in a safer environment.

Despite its many advantages, Suryandari (2023) also cautioned against the challenges of implementing virtual labs, such as reduced hands-on experience and the potential for misconceptions if there is no clear correlation between concepts in the virtual lab and those in the real laboratory. Therefore, the teacher's role as a facilitator, guiding students to reflect on simulation results into correct scientific concepts, is crucial. Based on this theoretical framework, this study implemented a Vernier Caliper Virtual Lab that not only leverages the advantages of interactivity and visualization but is also designed to specifically target increasing learning motivation and mathematical problem-solving skills in vocational high school students in the topic of real numbers and mechanical measuring instruments.

Learning motivation

Sardiman (2019) defines learning motivation as a psychological state that drives individuals to achieve learning goals through directed activities. This theory classifies motivation into two dimensions: intrinsic (originating from within) and extrinsic (influenced by external factors). According to Sardiman (2019), indicators of learning motivation include: perseverance, tenacity in the face of difficulties, interest in learning, depth of understanding, independence, and the ability to defend one's opinions. Learning motivation is a key factor determining the success of the

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

learning process. Without adequate motivation, students tend to lack enthusiasm, give up easily, and struggle to reach their optimal learning potential. Therefore, motivation also plays a key role in providing direction and sustaining learning behavior.

Based on Self-Determination Theory (SDT) proposed by Ryan and Deci (2020), learning motivation can be understood as a continuum consisting of varying levels of autonomy and self-regulation, ranging from intrinsic motivation, the internal drive to engage in an activity due to interest and enjoyment to extrinsic motivation, which is carried out to achieve goals external to the activity itself. According to this theory, improving the quality of motivation is strongly influenced by the fulfillment of three basic psychological needs: Autonomy, the feeling of having control over one's own actions; Competence, the belief in one's ability to complete a task; and Relatedness, the feeling of being connected to others in the learning environment.

In the context of this research, the Vernier Caliper Virtual Lab was designed to support these three aspects. This medium provides freedom to explore (autonomy), instant feedback that reinforces understanding (competence), and opportunities for collaboration and discussion (relatedness). Thus, the Virtual Lab not only has the potential to increase learning motivation but also encourages the maintenance of extrinsic motivation toward intrinsic motivation.

However, Ryan and Deci (2020) also emphasized that high motivation does not necessarily directly contribute to improved cognitive outcomes. Other factors, such as learning strategies, metacognition, and prior knowledge, also play a significant role. This could provide an analytical framework if it is later discovered that increased motivation does not have a direct, significant effect on students' mathematical problem-solving abilities.

Mathematical problem-solving skills

Mathematical problem-solving skills are defined as a student's ability to understand, analyze, and solve mathematical problems using systematic steps. Specifically, in Mechanical Engineering programs, these skills extend beyond calculations to include measuring with mechanical measuring instruments such as vernier calipers. Mastery of vernier calipers encompasses not only reading scales but also the ability to identify the correct type of measurement, select the appropriate tool, and interpret tolerance measurement results.

George Polya (1945) in his work "How to Solve It" outlined a mathematical problem-solving framework consisting of four fundamental stages: (1) understanding the problem, (2) developing a plan, (3) implementing the plan, and (4) looking back. The first stage acknowledges the importance of identifying variables and problem conditions, the second stage deals with discussing solution strategies, the third stage is the implementation of the plan, while the fourth stage includes evaluation and reflection on the results. This framework is highly relevant to the context of measurement using timeframes where students need to understand the types of measurements, plan calibration steps, perform measurements, and verify the results.

Theory integration in research

Based on the theoretical framework above, this research integrates three main pillars: (1) the virtual lab as an interactive learning medium, (2) the Polya framework as a basis for developing problem-solving skills, and (3) Sardiman's motivation theory as the foundation for learning engagement. The integration of these three elements creates a synergy where the virtual lab serves as a medium for implementing the Polya stages and also as a stimulus for learning motivation. This

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

theoretical configuration addresses a gap in previous research that has examined these three aspects separately.This research proposes that the effectiveness of the virtual lab is determined not only by the technological aspect, but also by the alignment between simulation design, Polya-based pedagogical strategies, and learning motivation management. This holistic theoretical framework is expected to make a significant contribution to the development of vocational mathematics education that is responsive to the challenges of the 21st century.

Methodology

Research design

This study used a quantitative approach with a one-group pretest-posttest design. According to Creswell (2017), a quantitative approach is appropriate when researchers want to test specific theories by collecting numerical data and analyzing it using statistical procedures. The one-group pretest-posttest design was chosen because it allows researchers to measure changes that occur within the same group after being given a specific treatment. As described by Campbell and Stanley (1963). In this design, one group of students was observed before and after being given the treatment, namely learning activities using an interactive simulation-based Vernier Caliper Virtual Lab. A pretest was conducted at the beginning to measure students' initial mathematical problem-solving ability, followed by the treatment in the form of Virtual Lab-based learning. After the treatment, a posttest was conducted to measure changes in students' problem-solving performance. The learning motivation questionnaire was also administered after the treatment to evaluate the influence of the Virtual Lab on students' motivation.

This design was chosen because it is appropriate for preliminary studies that seek to identify potential effects of an intervention when a control group is not available. Although the absence of a control group limits the generalizability of the findings, this design provides sufficient evidence to examine whether the Virtual Lab intervention leads to measurable improvements within the same group of participants. In addition, the combination of test results, questionnaire responses, and observational data ensured that the study captured both the quantitative outcomes and supportive evidence of students' learning experiences during the intervention.

Research site and participants

This research was conducted at SMK, Cirebon, West Java, Indonesia, specifically in the Mechanical Engineering Department. The school was selected as the research site because it provides learning activities related to mechanical measuring instruments, including the use of vernier calipers, which aligns with the focus of this study. Moreover, the school faces challenges in implementing practical learning due to limited laboratory facilities, making it a relevant context for testing the effectiveness of Virtual Lab integration. The participants of this study were 42 students of Grade X Mechanical Engineering in the 2024/2025 academic year. The sample was determined using a purposive sampling technique, considering that the selected class had previously studied basic measurement concepts but had not yet received in-depth practice with vernier calipers. This ensured that students were at a similar starting point in terms of prior knowledge. The participants consisted of both male and female students, reflecting the typical demographic composition of vocational school students in mechanical engineering programs.

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

The involvement of students as participants in this research was also aligned with the study's objectives, namely to analyze the impact of interactive simulation-based Virtual Labs on learning motivation and mathematical problem-solving skills. By focusing on one intact class, the study was able to implement a pre-experimental one-group pretest-posttest design consistently and evaluate the effectiveness of the intervention in a natural classroom setting.

Data collection and analysis

The data collection process in this study was carried out using three types of instruments that were directly aligned with the research objectives and problem statements. First, a learning motivation questionnaire was administered to capture students' perceptions after the implementation of the Virtual Lab. The questionnaire was developed based on Sardiman's (2019) motivation indicators and used a 4-point Likert scale. Before being used, the instrument was validated through expert judgment and item-total correlation tests, and its internal consistency was confirmed with a Cronbach's Alpha value of 0.878, indicating high reliability. Second, an observation sheet was employed during the learning process to record students' motivational behaviors, such as persistence, interest, independence, and ability to express opinions. The observation data functioned as supporting evidence that complemented the quantitative questionnaire data. Third, a mathematical problem-solving test was administered in the form of a pretest and posttest, with questions developed based on Polya's (1945) four-stage problem-solving model. These questions focused on the application of real numbers in vernier caliper measurements, ensuring contextual relevance with vocational subjects.

Data analysis

The data analysis procedure was carried out in several stages according to the type of data and the research design employed. Descriptive statistics, including mean, minimum, maximum, and standard deviation, were used to describe students' learning motivation scores and their distribution across the sample. Observation data were analyzed using average scores across indicators to determine trends in student motivation during the learning activities. To address the first research question regarding students' motivation when using the Virtual Lab, both descriptive questionnaire analysis and observational results were synthesized.

For the second and third research objectives, inferential statistics were employed. Students' pretest and posttest scores on the problem-solving test were analyzed using normality tests to determine the appropriate hypothesis testing technique. When the data distribution met normality assumptions, a paired-sample t-test was used to test the difference between pretest and posttest means; otherwise, the non-parametric Wilcoxon Signed Ranks Test was applied. This procedure was used to evaluate whether there was a statistically significant improvement in students' problem-solving abilities after using the Virtual Lab. Furthermore, to answer the third research question, simple linear regression analysis was conducted to examine whether learning motivation, as measured by the questionnaire, significantly influenced the increase in students' problem-solving ability. The regression results provided insight into the predictive relationship between motivation and problem-solving in the context of Virtual Lab-based learning.

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

Findings

This section presents the key findings of the study, which are organized into three main parts based on the research objectives. First, the results of the descriptive and observational analysis regarding students' learning motivation after using the Vernier Caliper Virtual Lab are reported. Second, the outcomes of the inferential statistical analysis examining the improvement in students' mathematical problem-solving abilities are detailed. Finally, the results of the regression analysis investigating the influence of learning motivation on problem-solving ability are presented. The findings are supported by descriptive statistics and the results of relevant statistical tests. By structuring the findings in this manner, the study offers a comprehensive overview of the virtual lab's impact on both affective and cognitive learning outcomes.

Student learning motivation after using the virtual lab

Table 1: *Descriptive statistical test results of the learning motivation questionnaire*

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Total Motivation	42	10	30	14.83	4.828
Valid N (listwise)	42				

Based on the analysis of the learning motivation questionnaire completed by 42 students after participating in the Vernier Caliper Virtual Lab, an average score of 14.83 was obtained out of a maximum score of 40. Observations during the learning process indicated that the indicators of learning persistence (score 4), interest in learning activities (score 4), and learning independence (score 4) were consistent. However, the ability to maintain income still needed improvement (score 2). Overall, student learning motivation was in the good category, with an average observation score of 3.33 out of a scale of 4.

Improvement in mathematical problem-solving ability

Table 2: *Statistik deskriptif pretest-postest*

Statistics			
		Pre-test	Pos-test
N	Valid	42	42
	Missing	0	0
Mean		68.95	79.74
Median		67.00	79.00
Std. Deviation		16.269	12.331

The results of the descriptive statistical analysis showed a significant improvement in students' mathematical problem-solving ability. The average pretest score of 68.95 increased to 79.74 in the posttest. The Shapiro-Wilk normality test showed that the pretest data were normally distributed ($p=0.405$), but the posttest data were not ($p=0.024$), so the Wilcoxon Signed Ranks Test was used. The Wilcoxon test showed a Z-value of -5.315 with a significance level of $p<0.001$, indicating a statistically significant improvement between students' mathematical problem-solving

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

abilities before and after using the Virtual Lab. Of the 42 students, 37 experienced an increase in their scores, 5 students remained stable, and no students experienced a decline in performance.

The effect of learning motivation on problem-solving ability

Prior to hypothesis testing, data analysis was conducted using a simple linear regression test to determine the effect of learning motivation on students' mathematical problem-solving abilities. This test aimed to identify the extent to which learning motivation contributes to improving students' abilities after using the interactive simulation-based Vernier Caliper Virtual Lab.

Table 3: *Correlation test results*

Correlations			
		N-gain	Total
Pearson Correlation	N-gain	1,000	,086
	Total	,086	1,000
Sig. (1-tailed)	N-gain	.	,294
	Total	,294	.
N	N-gain	42	42
	Total	42	42

Table 3 displays the results of the correlation test, a statistical method used to measure the linear relationship between two variables: N-gain (as the independent/predictor variable) and Total (as the dependent/outcome variable). The correlation value on the main diagonal of the table (1.000) indicates that each variable is perfectly correlated with itself, which is normal in correlation analysis. Meanwhile, the correlation value between N-gain and Total is 0.086, indicating a very weak and positive relationship. This means that an increase in N-gain is only accompanied by a very small increase in Total Motivation, and this relationship is almost insignificant.

The results of the correlation test show that the relationship between N-gain and Total Motivation is very weak ($r = 0.086$) and not statistically significant (one-tailed $p = 0.294$). This p-value far exceeds $\alpha = 0.05$, indicating the absence of sufficient statistical evidence to support a linear relationship between the two variables. Therefore, it is concluded that the increase in problem-solving ability (N-gain) is not linearly related to learning motivation (Total Motivation) in this study.

Discussion

Prior to conducting the classroom action research, the researcher conducted observations at the location that would serve as the research site. The data for this study involved 42 10th-grade vocational high school students. This data was collected using observation sheets, a learning motivation questionnaire, and a mathematical problem-solving ability test validated by experts. The mathematical problem-solving ability test was administered before (pretest) and after (posttest). The findings of this study confirm that the implementation of an interactive simulation-based Vernier Caliper Virtual Lab is effective in improving learning motivation and mathematical problem-solving skills of students in the Mechanical Engineering Vocational High School program. This increase in learning motivation can be seen in students' enthusiasm for operating

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

the Vernier Caliper simulation independently. According to Sardiman (2019), an interactive and enjoyable learning environment can stimulate students' intrinsic motivation to actively engage in learning.

This improvement in mathematical problem-solving skills aligns with Polya's (1945) theory, which emphasizes the importance of visualization in understanding problems. The Virtual Lab allows students to concretely visualize the measurement process, making it easier for them to understand problems, plan solutions, and evaluate measurement results. This finding aligns with research by Jaya & Haryoko (2010), which states that the dynamic and animated nature of virtual labs enhances students' conceptual understanding.

However, the lack of a significant effect between learning motivation and problem-solving skills indicates that other factors may play a more significant role in improving learning outcomes. According to Schukajlow et al. (2022), in the context of mathematics learning, learning strategies and metacognitive abilities play a more decisive role than motivation alone. These results are also supported by research by Widyastuti & Airlanda (2021), which found that a problem-based learning approach was more effective in improving mathematical problem-solving skills.

A similar finding was found by Siswanto & Meiliasari (2024), who explained that learning motivation may not directly impact problem-solving skills if it is not combined with a learning model that encourages active participation, such as the PBL approach. Their research emphasized the importance of implementing approaches that are not only structured (such as the Polya method) but also contextual to effectively train problem-solving skills, regardless of students' motivation levels.

A limitation of this study is the lack of a control group, making it difficult to compare the effectiveness of the Virtual Lab with conventional methods. Furthermore, the learning motivation questionnaire instrument may not have been able to fully measure students' intrinsic motivation in depth. For future research, it is recommended to use an experimental design with a control group and explore mediating variables such as student learning styles or creativity.

The findings of this study have practical implications for vocational high school mathematics teachers, particularly those in engineering programs. The Virtual Lab can be used as an alternative learning medium for mechanical measuring instruments, a topic often considered abstract and difficult by students. Teachers can utilize this interactive simulation to create more engaging and contextual learning tailored to the needs of the industrial world. Theese findings have important implications for vocational mathematics and engineering educators, as well as for school administrators. The use of Virtual Labs goes beyond being a technological trend it is a pedagogical innovation grounded in strong theoretical principles. From a theoretical perspective, Virtual Labs work effectively because they align with constructivist learning theory, which emphasizes active student engagement in building their own knowledge through exploration and discovery. The interactive simulation allows students to visualize abstract mathematical and technical concepts, thereby improving their conceptual understanding and problem-solving skills through experiential learning.

In terms of practical implementation, teachers can integrate the Vernier Caliper Virtual Lab into both mathematics and engineering measurement lessons. Before classroom use, teachers should ensure students have a basic understanding of measurement concepts, followed by guided exploration within the Virtual Lab. Teachers can design tasks that require students to read vernier scales, calculate tolerances, and analyze results directly in the simulation. Group discussions and reflection sessions should then be conducted to help students connect the virtual experience with

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

real-world applications. Collaboration between mathematics and engineering teachers is also recommended to create interdisciplinary learning activities that mirror actual industrial contexts.

To evaluate the impact of Virtual Lab implementation, teachers can employ a combination of formative and summative assessments. Formative evaluation can be done through observation of student engagement, self-reflection journals, and peer feedback during virtual experiments. Summative evaluation can involve pretests and posttests on problem-solving and conceptual understanding, supported by motivation questionnaires to capture changes in students' learning attitudes. School administrators can further monitor long-term outcomes by tracking improvements in student performance and interest in technical subjects.

However, practical challenges are likely to emerge. These may include limited digital infrastructure, a lack of teacher digital competence, and varying student access to devices or internet connectivity. To address these issues, schools should provide adequate technical support and training for teachers to develop digital pedagogical skills. Offline or hybrid Virtual Lab models can also be used to accommodate schools with limited internet access. Moreover, school leadership must promote a supportive policy environment that encourages innovation in teaching practices, including time allocation, access to resources, and recognition of teacher initiatives.

In summary, effective implementation of Virtual Labs requires not only access to technology but also pedagogical readiness, cross-disciplinary collaboration, and ongoing evaluation. When these elements are integrated systematically, Virtual Labs can transform mathematics and technical learning in vocational education into more engaging, relevant, and impactful experiences for students.

Conclusion and Recommendations/Implications

Based on the research findings, it can be concluded that the implementation of an interactive simulation-based Vernier Caliper Virtual Lab has proven effective in improving learning motivation and mathematical problem-solving abilities of vocational high school students in the Mechanical Engineering program. Students showed increased engagement, persistence, and independence during the learning process. Furthermore, their problem-solving skills, particularly in understanding measurement problems, planning solutions, and interpreting results, improved significantly after using the virtual lab. However, this study did not find a significant direct effect of learning motivation on improving mathematical problem-solving abilities. This suggests that although the Virtual Lab is a powerful tool for creating an interactive learning environment, improvement in problem-solving skills is likely more influenced by the hands-on learning experience with the simulation, the pedagogical approach, or other cognitive factors than by increased motivation alone.

Based on the limitations of this study, several recommendations can be put forward for further research. First, research with an experimental design involving a control group is needed to compare the effectiveness of virtual labs with conventional learning methods. Second, future research could explore mediator or moderator variables that might influence the relationship between virtual lab use and learning outcomes, such as cognitive style, spatial ability, or teacher support. Third, research that tests the effectiveness of virtual labs on different materials or at other educational levels is needed to determine the consistency of the findings. Fourth, longitudinal research could be conducted to measure the durability (retention effect) of improved problem-solving skills after using virtual labs. Finally, more sensitive research instruments are needed to

ISSN |2355-3669| E-ISSN |2503-2518|
Volume 12 | Number 2 | December 2025|

measure students' intrinsic motivation and metacognitive processes while using simulation-based learning media.

Disclosure statement

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