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The Role of Virtual Laboratory Facilities and Infrastructure in Developing Student Competence in Engineering Education

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ABSTRACT
This study investigates the impact of Virtual Reality (VR)-based virtual laboratory facilities and infrastructure on students' competencies in the Department of Electronic Engineering Education at the Faculty of Engineering, Makassar State University. With the increasing integration of digital technology in education, virtual laboratories have become pivotal in enhancing students' technical and conceptual understanding, especially in technical fields such as electronics. The research employs a quantitative survey method, distributing questionnaires to 31 students. Data analysis includes descriptive and inferential statistics, including regression analysis to examine the relationship between the adequacy of virtual laboratory facilities, student motivation, and their academic competencies. The results reveal a significant positive influence of the sufficiency of virtual laboratory infrastructure and student motivation on their competencies. Specifically, the study finds that improvements in the adequacy of virtual laboratories contribute to a notable improvement in students' practical and conceptual skills. Moreover, higher student motivation correlates with better academic performance. This research underscores the importance of upgrading virtual laboratory facilities and fostering student engagement to maximize learning outcomes in technical education.

Keywords: Virtual Laboratory Infrastructure, Student Motivation, Competency Development, Engineering Education.

I. Introduction

Quality education is not only determined by the material taught, but also by the Virtual Laboratory Facilities and Infrastructure available to support the learning process (Jaya, 2012), where educational technology such as virtual laboratories has been proven to increase accessibility and flexibility in engineering learning. (Wahyudi et al., 2024), As well as improving students' conceptual understanding and practical skills (Triejunita et al., 2021); in the context of engineering education, the use of Virtual Laboratory (VL) allows for more in-depth interactive simulations to replace the limitations of physical laboratories (Sellberg et al., 2024), providing safer exploratory experiences and supporting pedagogical effectiveness in engineering learning (Zhang et al., 2024). However, challenges such as limited interactivity and technical constraints still need to be overcome (Sasongko & Widiastuti, 2019).

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The Department of Electronic Engineering Education, Faculty of Engineering, University of North Sumatra, as an educational institution focusing on developing students' technical competencies, greatly benefits from virtual laboratory technology, which has been proven to improve students' academic achievement through digital experiment-based learning. However, the effectiveness of using this technology in improving students' competencies still needs to be explored further, because although it can improve conceptual understanding and practical skills, there are still limitations in terms of interactivity and real physical experience. (Wahyudi et al., 2024). The availability and sophistication of virtual laboratories are also significant determinants of their effectiveness in engineering learning, where accessibility and infrastructure support greatly influence the application of this technology in higher education (Zhang et al., 2024). In addition, student learning motivation is also an important factor that can be influenced by the design of an interactive and engaging virtual laboratory, so that it can increase student involvement in the learning process (Byukusenge et al., 2022). Therefore, although virtual laboratories provide significant benefits in engineering teaching, further research is needed to optimize their use in improving student competencies in various aspects of learning.

II. Literature Review and Hypothesis Development

2.1. Concept of Virtual Laboratory Facilities and Infrastructure in Education

Educational facilities and infrastructure play an important role in supporting an effective and efficient learning process, where educational facilities include various tools and facilities used in the teaching and learning process, such as classrooms, laboratory equipment, and learning technology (McCallum, 1981). Meanwhile, infrastructure includes supporting infrastructure such as internet networks, laboratories, and hardware that increase the accessibility and effectiveness of learning (Cimino, 1998). In engineering education, adequate Virtual Laboratory Facilities and Infrastructure are essential to support the understanding of complex technical concepts and improve students' practical skills (Mahajan & Suresh, 2017). Physical and virtual laboratories are crucial in engineering teaching because they allow students to apply theory in real experiments or digital simulations. (Omae et al., 2017). Thus, the development and maintenance of educational facilities and infrastructure must be a priority to ensure optimal effectiveness of engineering learning.

2.2. Virtual Laboratories in Engineering Education

Virtual laboratories are a technology that allows students to conduct experiments or practices digitally using computer simulations and virtual hardware, which has been shown to increase accessibility and flexibility in engineering learning (Wahyudi et al., 2024). According to Vásquez-Carbonell (2022), virtual laboratories provide opportunities for students to interact with technological devices without having to be in a physical laboratory, as well as providing a more immersive experience through the use of Virtual Reality (VR) (Vásquez-Carbonell, 2022). In engineering education, VR-based virtual laboratories allow students to understand complex concepts better than conventional learning methods (Zhang & Aslan, 2020). Several studies have shown that virtual laboratories can improve students' understanding of technical materials and provide hands-on experiences that are close to reality, thereby increasing the effectiveness of learning in engineering (Try et al., 2021). Another study found that using VR in virtual laboratories can increase student engagement and accelerate the learning process due to its interactive and immersive nature (Di Lanzo et al., 2020).

2.3. The Influence of The Advanced Virtual Laboratory Facilities and Infrastructure on Student Competence

The sophistication of Virtual Laboratory Facilities and Infrastructure in engineering education is vital in enhancing student competencies, primarily by applying the latest technologies that support industry-based learning (Hussaini, Abbas, & Manzoor, 2023). A meta-analysis study found that the use of technology in engineering education has a significant positive impact on student learning outcomes, with a moderate effect on cognitive enhancement. (Michko, 2008). In addition, recent studies have shown that applying technologies such as augmented reality (AR) and project-based learning (PBL) significantly improves students' engineering design and systems analysis skills. (Yin & Sarmiento, 2024). Thus, improving educational infrastructure and technology is critical in preparing engineering students to face challenges in the global industrial world (Ayokanmbi, 2011). Learning motivation is an important factor in improving student competence, where high motivation can encourage students to participate more actively in the learning process and improve the quality of their learning outcomes (López-Fernández, Alarcón, & Tovar, 2015). Intrinsic motivation, which comes from within students to achieve learning goals, significantly improves competence because it increases student independence and learning resilience (Siddique, Hardré, & Altan, 2015). Research shows that students with high learning motivation master learning materials more successfully and develop practical skills needed in engineering education (Doulougeri & Bombaerts, 2019). Therefore, learning strategies that increase student motivation are key to improving their academic and professional competence. (Makarova, Shubenkova, Tikhonov, & Buyvol, 2017).

2.4. The Influence of Virtual Laboratory Facilities and Infrastructure on Student Competence

Virtual Reality (VR) technology in engineering education is gaining popularity due to its ability to create interactive and realistic learning experiences (Han, 2023). VR in engineering learning allows students to visualize concepts that are difficult to explain through theory alone, improving their understanding and practical skills (Jain & Soni, 2024). Furthermore, studies have shown that the application of VR in engineering education contributes significantly to increasing students' learning motivation and improving their technical skills (Alhalabi, 2016). With VR, students can perform practical simulations without needing expensive physical equipment or large laboratory spaces, making it a more flexible and economical solution in engineering training (Lai et al., 2020). For research to be focused, it is necessary to formulate estimates first. First of all, regarding the problem being studied, namely the hypothesis. The hypothesis is a temporary answer to the formulation of the research problem. The research hypothesis is as follows:

1. The adequacy level of Virtual Laboratory Facilities and Infrastructure influences the competence of the Electronic Engineering Education Department, FT UNM students.
2. learning motivation influences Virtual Laboratory Facilities and Infrastructure on the competence of Students of the Department of Electronic Engineering Education, FT UNM.
3. There is a significant influence on the adequacy of Virtual Laboratory Facilities and Infrastructure, and motivation to learn together on students' competence in the Department of Electronic Engineering Education, FT UNM.

III. Research Method

The research used in this study is quantitative research with a descriptive survey method approach. Quantitative research uses instruments (questionnaires), uses numbers, and processes deductively (from general to specific) to produce conclusions that are theory-testing. At the same time, the descriptive survey method is used as a tool to obtain data. According to Sugiyono (2018:4), the definition of survey research is a method used to obtain data from certain natural places (not artificial). However, researchers carry out

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treatment in data collection, for example, by distributing questionnaires, tests, structured interviews, and so on. Based on the explanation and opinion above, this quantitative research is to test the theory, while the purpose of the research is to determine whether or not there is an influence of the adequacy of Virtual Laboratory Facilities and Infrastructure, as well as learning motivation, on the competence of Electronic Engineering Education Department Students, FT UNM. The research was conducted in the PTA Department, FT UNM, from December to January 2025, focusing on the condition of Virtual Laboratory Facilities and Infrastructure.

This study aims to measure the motivation and interest in learning mechatronics students using samples from the 2021 and 2022 intakes. The population of this study was all mechatronics students, while the sample was taken using the probability proportionate random sampling technique. Data were collected through a questionnaire containing a series of written questions to obtain information from respondents. The instrument was a closed questionnaire with a Likert scale with four alternative answers. This study used data analysis with the help of SPSS 23, where the analysis techniques used included descriptive analysis, validity testing, reliability testing, and hypothesis testing. Descriptive analysis includes calculating the average, standard deviation, and grouping value categories using the Ideal Mean (Mi) and Ideal Standard Deviation (SDi). For the validity test, Pearson correlation was used to measure the extent to which items in the questionnaire were related to the total score. Items that have a correlation value of more than 0.3 are considered valid. The reliability test used the Cronbach Alpha formula, showing that the instruments for the peer variables and learning interest were reliable. Furthermore, normality, linearity, and multiple linear regression tests were used to test the relationship between variables. A simple linear regression test is used to test the hypothesis of whether there is a significant influence between independent variables (E.g., the adequacy of virtual laboratory facilities and infrastructure, and motivation) on the competence of Electronic Engineering Education Department Students FT UNM. Validity and reliability testing of the instrument were conducted before distributing the questionnaire to respondents, and the results showed that the instrument was valid and reliable. Based on the validity and reliability tests, the instrument used in this study was declared feasible and reliable for data collection.

IV. Results and Discussion

4.1. Research result

Research conducted by JPTA FT UNM revealed a relationship between the adequacy of virtual laboratory facilities and infrastructure and the level of student competence. This study involved 31 students as samples, with data collected through questionnaires and documentation during the research process. Two statistical approaches were used to analyze the data: descriptive and inferential statistical analysis.

4.1.1. Descriptive Analysis Results

4.1.1.1. Descriptive Adequacy of virtual laboratory facilities and infrastructure (X1)

Data on the adequacy of virtual laboratory facilities and infrastructure were obtained through a questionnaire with 31 students as respondents. Based on the results of the data analysis obtained from respondents, the peer variable obtained the highest score of 48 and the lowest score of 18 with a Mean (M) value of 36.65, a Median of 36, and a Standard Deviation of idea (SDi) of 6,785.

Table 1. Frequency of Categories: Adequacy of virtual laboratory facilities and infrastructure

No	Interval Class	Frequency	Frequency (%)	Category
1	$X \geq 38$	12	39%	Very Enough
2	$33 \leq X < 38$	13	42%	Enough
3	$28 \leq X < 33$	4	13%	Not Enough

No	Interval Class	Frequency	Frequency (%)	Category
4	X < 28	2	6%	Not Enough
Amount		31	100%	

The results in Table 1 show that the frequency of peers in the very high category is 39%. The frequency of peers in the high category is 42%. The frequency of peers in the low category is 13% and the frequency of peers in the very low category is 6%.

4.1.1.2. Description of learning motivation (X2)

Learning motivation data was obtained through a questionnaire with 31 students as respondents. Based on the results of the data analysis that had been obtained from the respondents, the learning motivation variable obtained the highest score of 68 and the lowest score of 29, with a Mean (M) value of 49.90, a Median of 49, and a Standard Deviation (SDi) of 9,843.

Table 2. Frequency of Learning Motivation Categories

No	Interval Class	Frequency	Frequency (%)	Category
1	X ≥ 57	9	29%	Very high
2	49 ≤ X < 57	12	39%	Tall
3	42 ≤ X < 49	7	23%	Low
4	X < 42	3	10%	Very Low
Amount		31	100%	

The results in Table 2 show that the frequency of learning motivation in the very high category is 29%. The frequency of learning motivation in the high category is 39%. The frequency of learning motivation in the low category is 23% and the frequency in the low category is 10%.

4.1.1.3. Descriptive competency of students (Y)

Student competency data was obtained through a questionnaire with 31 students as respondents. Based on the results of the data analysis that had been obtained from the respondents, the Student competency variable obtained the highest score of 70 and the lowest score of 48 with a Mean (M) value of 61.87, a Median of 63, and a Standard Deviation (SD) of 4.801.

Table 3. Frequency of Student Competency Categories

No	Interval Class	Frequency	Frequency (%)	Category
1	X ≥ 63	13	42%	Very high
2	59 ≤ X < 63	6	19%	Tall
3	55 ≤ X < 59	11	35%	Low
4	X < 55	1	3%	Very Low
Amount		31	100%	

The results in Table 3 show that the frequency of student competencies in the very high category is 42%. The frequency of student competencies in the high category is 19%. The frequency of student competencies in the low category is 35% and the frequency of student competencies in the very low category is 3%.

4.1.2. Prerequisite Analysis Test

The normality test results show that the Kolmogorov-Smirnov Test's significance value is 0.200, greater than 0.05. This indicates that the residual values are normally distributed. Furthermore, the linearity

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test shows a linear relationship between the variables tested. For the relationship between Student Competence and the Adequacy of Virtual Laboratory Facilities and Infrastructure, the significance value of the deviation from linearity is 0.114, greater than 0.05, meaning the relationship is linear. Likewise, the relationship between Student Competence and Learning Motivation, which has a significance value of deviation from linearity of 0.308, also shows a linear relationship. Finally, the results of the multicollinearity test show no multicollinearity between the independent variables. This can be seen from the Variance Inflation Factor (VIF) value, which is less than 10 (2.059), and the tolerance value, which is greater than 0.1 (0.486), which indicates that there is no strong correlation between the independent variables. The data shows a normal distribution, linear relationships between variables, and no multicollinearity problems between independent variables.

4.1.3. Hypothesis Testing

Hypothesis testing in this study used simple and multiple linear regression tests.

4.1.3.1. Results of Hypothesis Testing of the Effect of Adequacy of Virtual Laboratory Facilities and Infrastructure (X1) on Student Competence (Y).

The first hypothesis states that the adequacy of virtual laboratory facilities and infrastructure significantly affects students' competence in the Department of Electronic Engineering Education, FT UNM.

HO: There is no significant influence between the Adequacy of Virtual Laboratory Facilities and Infrastructure on the competence of Students of the Electronic Engineering Education Department, FT UNM.

Ha: There is a significant influence between the Adequacy of Virtual Laboratory Facilities and Infrastructure on the competence of Students of the Department of Electronic Engineering Education, FT UNM.

Hypothesis testing using simple regression analysis.

Table 4. Hypothesis Testing 1

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	71,699	1,589		45.128	.000
Adequacy of Virtual Laboratory Facilities and Infrastructure	-.281	.039	-.797	-7.112	.000
a. Dependent Variable: Student Competence					

Based on the test results, the sig value is 0.000, and this value is smaller than the error degree value ($\alpha = 0.05$) or ($0.000 < 0.05$) at a significance level of 5%. This shows that Ha is accepted, namely, there is a significant influence between the Adequacy of Virtual Laboratory Facilities and Infrastructure on the competence of Students of the Department of Electronic Engineering Education, FT UNM. The regression equation of the Adequacy of Virtual Laboratory Facilities and Infrastructure influence on the competence of Students of the Department of Electronic Engineering Education, FT UNM can be expressed as Y = 71.699 - 0.281 X1. This equation shows that the regression coefficient value is -0.281. In this study, it can be stated that the Adequacy of Virtual Laboratory Facilities and Infrastructure significantly affects the competence of Students of the Department of Electronic Engineering Education, FT UNM. Every 1% Increase in the Adequacy of Virtual Laboratory Facilities and Infrastructure has an impact on decreasing Student Competence by 0.281 (28.1%).

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4.1.3.2. Results of Hypothesis Testing of the Influence of Learning Motivation (X2) on Student Competence (Y).

The second hypothesis states that Learning Motivation significantly affects Student Competence in the PTA Department, Makassar State University.

HO: There is no significant influence of learning motivation on the competence of PTA students at Makassar State University.

Ha: There is a significant influence between learning motivation and the competence of PTA students at Makassar State University.

Hypothesis testing using simple regression analysis.

Table 5. Hypothesis Testing

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	1 (Constant)	66,294	1,454		45,601	.000
	Motivation to learn	-.112	.028	-.602	-4.060	.000
a. Dependent Variable: Student Competence						

Based on the test results of Table 5, it is known that the sig value is 0.000, and this value is smaller than the error degree value (α = 0.05) or (0.000 <0.05) at a significance level of 5%. This shows that Ha is accepted, namely, there is a significant influence between Learning Motivation and the Competence of PTA students at Makassar State University. The regression equation of the influence of learning motivation on student competence can be expressed as Y = 66,294 - 0.112 X1. This equation shows that the regression coefficient value is -0.112. In this study, it can be stated that learning motivation significantly affects the competence of students majoring in PTA at Makassar State University. Every 1% increase in learning interest decreases learning motivation by 0.112 (11.2%).

4.1.3.3. Results of Hypothesis Testing of the Effect of Adequacy of Virtual Laboratory Facilities and Infrastructure and Learning Motivation (X2) on Student Competence (Y).

The third hypothesis states that Adequacy of Facilities and Infrastructure and Learning Motivation significantly influence the Competence of PTA students at Makassar State University.

HO: There is no significant influence between Adequacy of Facilities and Infrastructure and Motivation to Learn Together on the competence of PTA students at Makassar State University.

Ha: There is a significant influence between Adequacy of Facilities and Infrastructure and Motivation to Learn Together on the competence of PTA students at Makassar State University.

Hypothesis testing using multiple regression analysis.

Table 6. Hypothesis Testing

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	1 (Constant)	72,478	1,516		47,811	.000
	Adequate Facilities and Infrastructure	-.233	.042	-.661	-5,528	.000
	Motivation to learn	-.052	.022	-.280	-2,339	.027
a. Dependent Variable: student competence						

The regression equation of the influence of Virtual Laboratory Facilities and Infrastructure Adequacy and learning motivation on student competence can be expressed as Y = 72.478 + (-0.233) X1 + (- 0.052) X2. The equation shows that the constant value of student competence is 72.478. In this study, it can be stated that Virtual Laboratory Facilities and Infrastructure Adequacy and learning motivation have a joint effect on student competence. The correlation coefficient (R) results are 0.797, and the determinant coefficient (R2) is 0.636. These values indicate that Virtual Laboratory Facilities and Infrastructure Adequacy and learning motivation influence 63.6% of student competence. At the same time, the remaining 36.4% is influenced by other variables not examined in this study. This study also shows that the significant results of the Adequacy of Virtual Laboratory Facilities and Infrastructure and learning motivation show that the significance value of the Adequacy of Virtual Laboratory Facilities and Infrastructure is greater than learning motivation towards student competence, as seen from joint testing.

4.2. Discussion

This study aims to analyze the influence of virtual laboratory facilities and infrastructure on student competencies in the Digital Electronics course at the Department of Electronic Engineering Education, FT UNM. The research used in this study is quantitative research with a descriptive survey method approach. Quantitative research uses instruments such as questionnaires and numbers to process data deductively (from general to specific) to test theories. At the same time, the descriptive survey method is used to collect data from certain natural places, with specific treatments in data collection, such as distributing questionnaires, tests, or structured interviews (Sugiyono, 2018, p. 4).

The sophistication of virtual laboratories significantly influences student learning outcomes in engineering education, in line with the opinion of Wahyudi (2024), who stated that virtual laboratories are permanent and play a role in supporting practical learning. A recent study by Balamuralithara & Woods (2009) showed that virtual laboratories provide benefits in cost-effectiveness, flexibility, and increased student involvement in the learning process. In addition, another study by Chan & Fok (2010) confirmed that virtual laboratories can improve students' conceptual and practical skills by providing a more inclusive learning environment. Furthermore, O'Dwyer (2009) stated that adequate virtual laboratory facilities are important in supporting the continuity of effective practical learning in the engineering field. This study's results indicate a significant influence of the Adequacy of Virtual Laboratory Facilities and Infrastructure, and learning motivation on student competence. This is indicated by the results of the F test obtained, the F count was 31.926 with a significant value of F of 0.000 or F <0.05. The results of multiple regression testing indicate that the correlation coefficient (R) is 0.797 and the determinant coefficient (R^2) is 0.636. These values indicate that the Adequacy of Virtual Laboratory Facilities and Infrastructure, and learning motivation, influence 63.6% of student competence. At the same time, the remaining 36.4% is influenced by other variables not examined in this study. The results of this regression test also show that the significant values of the two variables are smaller than when testing simple regression.

The Influence of Virtual Laboratory Facilities and Infrastructure Adequacy and Learning Motivation on Student Competence: The study's results indicate that the adequacy of virtual laboratory facilities and infrastructure and learning motivation significantly influence student competence. This means that the better the facilities and infrastructure provided in the virtual laboratory, the higher the students' learning motivation, and the higher the competence that students can achieve. Significance of Influence: The results of the F test show that the influence between the adequacy of virtual laboratory facilities and infrastructure and learning motivation on student competence is very significant, with an F significance value of 0.000 (less than 0.05). This means that these two factors have a strong relationship and influence student competence. Strength of Influence: With a correlation coefficient (R) of 0.797 and a determination coefficient (R^2) of 0.636, these results indicate that around 63.6% of student competence is influenced by the adequacy of virtual laboratory facilities and infrastructure and learning motivation. The rest, around 36.4%, is influenced by factors not examined in this study, such as individual factors or other environments. Multiple Regression and Significance of Variables:

Multiple regression testing shows that the influence of both variables (virtual laboratory facilities and learning motivation) on student competence is more significant than simple regression testing. This shows that both support each other and have a greater impact when analyzed together, compared to only one variable.

Based on the research data above, it is stated that learning motivation significantly influences student competence, where high motivation encourages students to learn actively, creatively, and innovatively, thereby improving their academic results and professional skills. This is in line with Holovko & Cherepakha (2021). The research of Dautkalieva & Ormanova (2020) found that intrinsic motivation contributes significantly to learning success by increasing student involvement in the academic process. Furthermore, Porwokerto et al. (2022) stated that a meta-analysis of the relationship between motivation and learning outcomes showed a strong correlation between the two variables, which confirms that students with high motivation tend to have better academic achievement. This is reinforced by Pertiwi, Sukarno, and Andra (2023), who state that learning motivation is a crucial factor in higher education that determines academic success and develops student competencies holistically. Based on the research data, it can be concluded that there is an influence of the availability of Virtual Laboratory Facilities and Infrastructure on student competence, this is in line with the opinion (Thannhauser (2015) which states that the availability of Virtual Laboratory Facilities and Infrastructure has a significant influence on increasing student competence in the field of engineering.

V. Conclusion

Based on the research results, it can be concluded that the adequacy of virtual laboratory facilities and infrastructure significantly influences student competence. Improving the quality of these facilities and infrastructure has been proven to improve students' technical and conceptual abilities in engineering education. In addition, the sophistication of virtual laboratory facilities and infrastructure also plays an important role in improving student competence. Newer and more sophisticated technology supports more effective and efficient learning, thus enriching students' learning experiences. Learning motivation also plays a key role in improving student competence. Students with high learning motivation tend to be more active in the learning process and better master the material. Simultaneously, the adequacy and sophistication of virtual laboratory facilities, together with learning motivation, have a significant effect on student competence. This study shows that around 63.6% of student competence is influenced by these two factors, while the rest is influenced by other factors not examined in this study.

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