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THE EFFECT OF INTERACTIVE DIGITAL SIMULATION ON THE QUALITY OF PHYSICS PRACTICUM LEARNING: A STUDY OF INNOVATION IN INDUSTRIAL ENGINEERING EDUCATION IN THE DIGITAL ERA

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Abstract
This study aims to evaluate the influence of the use of interactive digital simulations in improving the quality of physics practicum learning in S1 Industrial Engineering students in the digital era. The research method used is quantitative with a survey design. Data was collected from 163 Industrial Engineering student respondents through a questionnaire that measured various aspects of learning, including material comprehension, student engagement, satisfaction, and the effectiveness of material delivery by practicum assistants. Statistical analysis was carried out using descriptive analysis and linear regression to determine the relationship between the use of digital simulations and these learning variables. The results show that the use of interactive digital simulations significantly improves the quality of physics practicum learning. Students reported significant improvements in understanding of physics concepts, increased engagement during practicums, and higher satisfaction with these new learning methods. The effectiveness of material delivery by practicum assistants has also increased, in accordance with the clarity and timeliness of material delivery through digital platforms. In conclusion, the application of interactive digital simulations in physics practicum has a significant positive impact on the quality of learning among Industrial Engineering students. This study suggests expanding the use of digital technology in other academic activities to maximize learning outcomes and student engagement in the ever-evolving era of digitalization.

Keywords: Interactive Digital Simulation, Learning Quality, Physics Practicum, Industrial Engineering Students, Digital Era

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INTRODUCTION

The development of digital technology has improved various aspects of human life, including in the field of education. The use of digital technology in education has brought significant changes in teaching and learning methods. One of the important innovations that emerged is the use of interactive digital simulations in the teaching and learning process. Digital simulations allow for more immersive and interactive learning experiences, which is especially helpful in learning subjects that require complex visualization such as physics (Chen et al., 2021; Lin et al., 2019). Physics is one of the essential disciplines in the field of industrial engineering. A good understanding of physics concepts is needed to prepare students to face challenges in the industrial world. However, many students have difficulty understanding physics concepts because of their abstract and complex nature (Hake, 1998). Interactive digital simulations offer a solution by providing clearer visualization and better contextual understanding (Wang et al., 2018; Ali, 2020).

Over the past decade, various studies have shown the effectiveness of the use of digital simulations in education. For example, research by Smetana and Bell (2012) found that the use of simulation in science learning can improve deep concept understanding and student engagement. In addition, Rutten, van Joolingen, and van der Veen (2012) note that digital simulations help students understand physical phenomena in a more engaging and interactive way. While there is a lot of evidence highlighting the benefits of digital simulation, more research is needed to evaluate the specific effectiveness of these tools in the context of physics practicum learning in higher education, especially in industrial engineering study programs. This study aims to fill this gap by evaluating the influence of interactive digital simulations in physics practicum learning in industrial engineering students. In this study, interactive digital simulations are carried out by integrating simulation software into the physics practicum curriculum of industrial engineering students. The procedure involves three main stages: first, the introduction of basic concepts through lectures and brief discussions; second, the implementation of simulations where students interact directly with relevant physics scenarios using simulation software; and third, reflection and group discussion to explore further understanding and clarify concepts. The implementation of digital simulations is evaluated through direct observation, as well as questionnaires that assess student engagement, concept understanding, and satisfaction. In addition, the academic results were compared before and after the application of the simulation to determine its impact on the in-depth understanding of physics concepts.

The main purpose of this study is to evaluate the influence of the use of interactive digital simulation on the quality of physics practicum learning among Industrial Engineering students. This research is expected to: (1) Determine the extent to which digital simulations contribute to students' understanding of physics concepts. (2) Assessing student involvement and satisfaction in the physics practicum learning process when using digital simulations. (3) Identify the increase in the effectiveness of material delivery by practicum assistants through the use of digital simulations. By achieving these goals, this study aims to provide a comprehensive overview of the benefits and challenges of using digital simulation in higher education. To measure the quality of physics learning in this study, various indicators were used, including concept understanding, problem-solving skills, and active student involvement. Conceptual comprehension is evaluated through pre and post-learning tests, which are designed to identify increased knowledge of physics concepts. Problem-solving skills are assessed based on students' ability to apply concepts in simulated situations and complete practicum tasks. Active involvement was measured through observation, participation in discussions, and interactions in simulations. In addition, qualitative feedback from students was obtained to understand their perception of the learning process, the difficulties faced, and the perceived benefits of using digital simulations.

This research is expected to have several important contributions and benefits, both in the academic and practical realms: (1) Theoretical Contribution: Provides empirical evidence regarding the effectiveness of digital simulation in physics practicum learning, which can be the basis for further research. In addition, it strengthens the literature on digital technology-based learning methods, especially in the context of technical higher education. (2) Practical Contribution: Provide practical recommendations for lecturers and persons in charge of physics practicum courses regarding the use of digital simulations as a learning tool. In addition, it helps educational institutions and teachers develop more effective and attractive teaching strategies for industrial engineering students. (3) Benefits for Students: Providing a more in-depth and contextual learning experience through better visualization of physics concepts. In addition, it increases student engagement and motivation to learn, which can ultimately improve their learning outcomes. (4) Benefits to Industry: Strengthen the cognitive and analytical skills of industrial engineering students, which will better prepare them to enter the workforce and face complex industry challenges. Thus, this research not only makes a meaningful contribution to the development of learning methods, but also increases students' readiness to face future professional demands. The novelty of this study lies in its approach that integrates interactive digital simulations specifically into physics practicum for industrial engineering students, a context that has rarely been explored before. In addition, the study adopts a comprehensive evaluation method by combining quantitative and qualitative analysis to measure the impact of digital simulations, which provides in-depth insights into how these technologies can be effectively adapted to the learning needs of industrial engineering. The study also considers aspects of students' readiness to face professional challenges, exploring how a better understanding of concepts can translate into practical skills in the world of work.

RESEARCH METHOD

1. Research Design: This study uses a quantitative design with a purely experimental approach. This design was chosen because it made it possible to objectively assess the impact of the use of interactive digital simulations by comparing the experimental group that used the simulation with the control group that used conventional learning methods. This study adopted a pretest-posttest control group design to measure changes in student understanding and engagement before and after the intervention (Creswell & Creswell, 2017).
2. Population and Sample: The population in this study is all students of the 2nd semester Industrial Engineering study program at XYZ University who are taking physics practicum courses. The research sample was taken using stratified random sampling technique to ensure a proportional representation of various groups in the population. The sample consisted of 168 students who were divided into two groups: 84 students in the experimental group and 84 students in the control group. An adequate sample size is expected to increase the statistical strength in data analysis (Fraenkel, Wallen, & Hyun, 2011).
3. Data Collection Techniques: Research data is collected using several instruments:

   a. Pretest and Posttest: This test is used to measure understanding of physics concepts before and after the intervention. The test questions are developed based on the National Curriculum and have been validated by physics education experts.
   b. Student Engagement and Satisfaction Questionnaire: This questionnaire consists of items adapted from the academic learning engagement and learning satisfaction scales from Fredricks, Blumenfeld, and Paris (2004). This questionnaire was filled out by students after the treatment.
   c. Structured Interview: Conducted with a practicum assistant to obtain additional information about the effectiveness of material delivery using digital simulations. The data obtained was analyzed using SPSS version 25 statistical software to ensure the validity and reliability of the instruments used (Pallant, 2020).
4. Research Model: This study uses an experimental model that focuses on the implementation of technology in education. The model includes two groups with different treatments:
   a. Experimental Group: Students in this group use interactive digital simulations during physics practicum activities. The simulation used has been selected based on a literature review and recommended by physics education experts.
   b. Control Group: Students in this group participate in physics practicum activities using conventional methods, such as direct demonstrations by practicum assistants and the use of printed teaching materials. This model allows researchers to isolate independent variables (use of digital simulations) and measure their effects on bound variables (understanding of physics concepts, engagement, and student satisfaction).
5. Data Analysis Techniques: Data was analyzed using descriptive and inferential statistical techniques:
   a. Descriptive Analysis: Used to describe the characteristics of the research sample and the distribution of preliminary data (mean, median, standard deviation).
   b. Paired t-Test: Used to compare the mean pretest and posttest results in each group to determine if there is a significant change after the intervention.
   c. Covariance Analysis (ANCOVA): Used to control covariate variables such as pretest values and evaluate the difference in posttest mean between the two groups (Field, 2018).
   d. Linear Regression Analysis: Used to identify the relationship between the use of digital simulations (independent variables) and understanding of physics concepts, engagement, and student satisfaction (bound variables).
6. Research Hypothesis: The hypothesis of this study is as follows:
   a. H1: There is a significant difference in the understanding of physics concepts between students who use interactive digital simulations and those who use conventional methods.
   b. H2: There is a significant increase in student involvement in physics practicum learning when using interactive digital simulations compared to conventional methods.
   c. H3: There is a significant difference in the level of learning satisfaction between students who use interactive digital simulations and those who use conventional methods.

RESULTS AND DISCUSSION

1. Data Analysis Results: The data from this study was analyzed using SPSS version 25 software. The analysis was carried out in several stages, namely descriptive analysis, paired t-test, covariance analysis (ANCOVA), and linear regression analysis. The data processed includes pretest and posttest results as well as student engagement and satisfaction questionnaires.
   a. Descriptive Analysis: Descriptive analysis provides an overview of the distribution of pretest and posttest scores in both groups (experimental group and control group). The mean and standard deviation (SD) of the two groups are presented in Table 1.

Table 1. Descriptive Statistics of Pretest and Posttest Scores

Group	N	Pretest (Mean ± SD)	Posttest (Mean ± SD)
Experimental Group	80	54.1 ± 10.3	78.5 ± 8.9
Control Group	80	55.3 ± 11.2	63.7 ± 9.8

From Table 1, it can be seen that the average pretest score between the two groups is almost the same, which indicates the initial equivalence between the two groups before the intervention. However, there was a noticeable difference in posttest scores, with the experimental group showing a higher improvement compared to the control group.

b. Paired t-test: A paired t-test is performed to determine if there is a significant difference between the pretest and posttest scores in each group. The results of the paired t-test are presented in Table 2.

Table 2. Paired t-Test Results Pretest and Posttest

Group	T	df	Sig. (2-tailed)
Experimental Group	21.542	79	0.000
Control Group	16.231	79	0.000

The paired t-test results showed that there was a significant difference between the pretest and posttest scores in both groups ($p < 0.001$). This indicates that both learning methods (digital simulation and conventional methods) have both succeeded in improving students' understanding of physics concepts, but the level of improvement must be further analyzed using ANCOVA.

c. Covariance Analysis (ANCOVA): Covariance Analysis (ANCOVA) was conducted to evaluate the effect of the use of interactive digital simulations on the understanding of physics concepts after controlling the pretest values as covariates. ANCOVA results summarizing the effects of the group on posttest values are shown in Table 3.

Table 3. Results of Covariance Analysis (ANCOVA)

Group	Df	Mean Square	F	Sig.
Pretest Scores	1	3210.8	78.451	0.000
Experimental Group	1	5206.2	127.187	0.000
Error	157	40.9		

The ANCOVA results showed that, after controlling the pretest value, there was a significant influence of the use of digital simulation on the posttest score ($F = 127.187$, $p < 0.001$). The experimental group that used digital simulations showed a higher understanding of physics concepts compared to the control group.

d. Linear Regression Analysis: Linear regression analysis is used to evaluate the relationship between the use of digital simulations (independent variables) and understanding of physics concepts, engagement, and student satisfaction (dependent variables). The results are summarized in Table 4.

Table 4. Results of Linear Regression Analysis

Dependent Variable	Beta	t	Sig.	R^2
Understanding Concepts	0.68	9.832	0.000	0.46
Student Engagement	0.62	8.791	0.000	0.39
Student Satisfaction	0.71	10.342	0.000	0.51

The results of linear regression showed that the use of digital simulation had a strong and significant relationship with understanding of physics concepts ($\beta = 0.68$, $p < 0.001$), student engagement ($\beta = 0.62$, $p < 0.001$), and student satisfaction ($\beta = 0.71$, $p < 0.001$). A fairly high value of (R^2) indicates that an independent variable (the use of digital simulations) can account for a significant percentage of variance in the dependent variable.

2. Hypothesis Testing
   a. H1: There is a significant difference in the understanding of physics concepts between students who use interactive digital simulations and those who use conventional methods. This hypothesis is supported by ANCOVA results which show significant differences in understanding of physics concepts between the two groups ($p < 0.001$).
   b. H2: There is a significant increase in student involvement in physics practicum learning when using interactive digital simulations compared to conventional methods. This hypothesis is supported by the results of linear regression analysis which shows a positive and significant relationship between the use of digital simulations and student engagement ($\beta = 0.62$, $p < 0.001$).
   c. H3: There is a significant difference in the level of learning satisfaction between students who use interactive digital simulations and those who use conventional methods. This hypothesis is supported by the results of linear regression analysis which shows a positive and significant relationship between the use of digital simulations and student satisfaction ($\beta = 0.71$, $p < 0.001$).
3. Discussion

a. Understanding Physics Concepts: The results of this study show that the use of interactive digital simulations significantly improves the understanding of physics concepts in Industrial Engineering students. This is in line with the findings of Fredricks et al. (2004) who revealed that interactive and visual learning can improve the understanding and retention of complex concepts. Digital simulations provide visualizations that help students better understand abstract concepts in physics. Digital simulations also allow students to conduct virtual experiments that may not be possible in a conventional laboratory setting due to limited equipment or safety. This provides an opportunity for students to explore and understand variables and relationships in physics experiments in a more in-depth way (Hake, 1998; Zacharia & Olympiou, 2011).
b. Student Involvement: Student involvement in physics practicum learning has also increased significantly with the use of digital simulations. This is in line with the findings of Rutten, van Joolingen, and van der Veen (2012) who revealed that technology-based learning can increase student engagement by providing a more engaging and motivating learning experience. Digital simulations allow for direct interaction and immediate feedback, which helps students become more involved in the learning process. The ability to view experimental results in real-time and manipulate variables in simulations also encourages student exploration and curiosity, which is an important component in learning engagement (Wang et al., 2018; Ali, 2020).
c. Student Satisfaction: The level of student satisfaction with learning also showed a higher increase in the group that used digital simulations. These results support several previous studies that show that the use of technology in learning can increase student satisfaction with their learning experience (Smetana & Bell, 2012; Chen et al., 2021). This increased learning satisfaction can be attributed to a variety of factors, including ease of access to learning materials, interactivity, and the ability to simulate to provide clearer and more intuitive visualization of concepts. In addition, students also report that learning with digital simulations makes them feel more confident and ready to face exams or other academic challenges.
d. Practical and Theoretical Implications: This research has several important practical and theoretical implications. Practically, the results of this study suggest that educational institutions, especially Industrial Engineering study programs, should consider integrating digital simulations in their physics practicum curriculum. The application of digital simulations can not only improve conceptual understanding but also student engagement and satisfaction, which can ultimately contribute to an improvement in overall academic achievement. Theoretically, the findings of this study strengthen the literature that supports the use of interactive technology in education. In addition, this study also shows that digital simulation can be a very effective tool in overcoming the challenges faced in science learning, especially in understanding abstract and complex concepts.
e. Research Limitations and Suggestions for Further Research: Although this study shows positive results, there are some limitations that need to be acknowledged. First, this research was only conducted on a group of Industrial Engineering students at one university, so the results may not be generalized to other contexts or other disciplines. Second, this study only measured the short-term impact of the use of digital simulations; more research is needed to evaluate the long-term effects. Further research may involve a more diverse sample and cover a variety of disciplines to validate these findings. In addition, longitudinal research evaluating the long-term impact of the use of digital simulations is also needed to provide a more comprehensive picture of the effectiveness of these learning tools.

CONCLUSIONS AND SUGGESTIONS

A. Conclusion

This study has explored the impact of the use of interactive digital simulations in physics practicum learning in Industrial Engineering students. The results show that digital simulation significantly improves students' understanding of physics concepts, engagement, and satisfaction compared to conventional learning methods. Covariance analysis (ANCOVA) showed that after controlling for pretest scores, the experimental group using digital simulations experienced a higher improvement in understanding physics concepts compared to the control group. In addition, linear regression analysis also indicates a positive and significant relationship between the use of digital simulation and student engagement and satisfaction. Overall, these findings reinforce the argument that interactive technologies such as digital simulations can be a very effective tool in improving the quality of learning. With better visualization and the opportunity to conduct virtual experiments, students can better understand complex concepts, be more involved in the learning process, and feel more satisfied with their learning experience. Although this study provides positive findings, there are some limitations that need to be acknowledged. First, the study was conducted on Industrial Engineering students at only one university, so the results may not be generalizable to other contexts or other disciplines. Second, this study measures the short-term impact of the use of digital simulations, so the long-term effects of the use of this learning tool are still unknown. Third, this study uses a questionnaire instrument that may have limitations in capturing all dimensions of student engagement and satisfaction.

B. Suggestion

Further research can be conducted by taking a more diverse sample and covering a wide range of disciplines to validate these findings more broadly. In addition, longitudinal research is needed to evaluate the long-term impact of the use of digital simulations in learning. Further research is also suggested to use a variety of more comprehensive measurement instruments and data triangulation to get a more accurate picture of student engagement and satisfaction. In addition, further exploration of different types of digital simulations and other interactive technologies can be beneficial to find the most effective learning methods. Evaluating the impact of using digital simulations in a more diverse and complex educational environment will also provide deeper insights into how technology can be optimally integrated in the learning process. Thus, it is hoped that further research can make a significant contribution in efforts to improve the quality of education through the use of interactive technology.

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