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ENHANCING STUDENTS' LEARNING OUTCOMES IN CLASSICAL CRYPTOGRAPHY THROUGH INTERACTIVE 3D SIMULATIONS

Wenda Novayani*[1], Iqbal Alhuda[2]
Teknologi Rekayasa Komputer, Politeknik Caltex Riau, Pekanbaru, 28265, Indonesia[1]
Teknik Informatika, Politeknik Caltex Riau, Pekanbaru, 28265, Indonesia[2]
wenda@pcr.ac.id*[1], iqbalalhuda1998@gmail.com[2]

Penulis Koresponden

ABSTRACT

Cryptography is the study of how to transform data or information into a form that is unreadable by others, thus ensuring the security of the data. Based on a questionnaire conducted among students of Politeknik Caltex Riau (PCR) who have studied classical cryptography, the Vigenere Cipher and Affine Cipher were found to be the most difficult algorithms to understand. This research aims to investigate the improvement in students' knowledge of classical cryptography through interactive 3D simulations. The experiment was conducted on 30 PCR students by comparing two learning groups: a control group (using textbooks) and an experimental group (using 3D simulations). The results showed that the average post-test score for the control group was 67.33 point, while the experimental group achieved an average score of 83.33 point. Thus, learning with 3D simulation media can serve as an effective alternative medium, with a confidence level of 95%, to enhance students' understanding of classical cryptography. Meanwhile, the satisfaction level indicates that 86.75% of students are satisfied with learning through interactive 3D simulation media. This indicates that the use of classical cryptography learning media through 3D simulations provides a significant improvement in student learning outcomes.

Keywords: *3D Simulation, Cryptography, Effective, Interactive, Student Learning Outcomes*

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1. INTRODUCTION

Developments in multimedia computing and networking have significantly enhanced the importance of 3D models in engineering applications [1, 2]. One field significantly influenced by technological advances is higher education, particularly technical courses such as cryptography. Cryptography, as the study of techniques for securing information[3], plays a crucial role in today's digital age.

However, cryptography concepts are often seen as abstract and difficult to grasp[4], especially for newcomers, due to the complex, mathematically intensive nature of the material. Common challenges in learning cryptography include understanding algorithmic functions, especially in algorithms like the Vigenère Cipher. A survey of Caltex Riau Polytechnic (PCR) students who have studied cryptography found the Vigenère Cipher and Affine Cipher to be the most challenging, aligning with previous studies[5]. Mastery of these ciphers can provide students a foundational understanding for developing new modern cryptographic algorithms and foster logical thinking skills.

To address these challenges in cryptography education, innovative and engaging learning approaches are needed. Simulations offer a range of practical opportunities and represent one of the most effective approaches to creating learning environments in higher education [6]. One promising alternative is the use of interactive learning media, specifically 3D simulations. Simulations are commonly utilized to enhance knowledge and skills related to interacting with mechanisms or abstract systems, or to gain a deeper understanding of complex concepts and their interrelationships [6]. 3D simulation enables students to adaptive visual effects[7] of abstract cryptographic concepts in a more concrete and accessible way, allowing for active engagement and deeper comprehension.

However, most previous research has focused on using conventional learning media, such as textbooks or PowerPoint presentations. Efforts to support cryptography learning include using tools like cryptool [7–9] , visual programming [10], web-based [8–11], flash-based media [15], and games[13,14]. Abstract learning in subjects such as physics (e.g., the density of objects) [18], math (conditional probability)[19] has successfully increased user engagement through the use of simulation media. Yet, prior studies have not successfully provided visual simulation of cryptographic processes. While many studies have explored the effectiveness of interactive learning media in various fields, research specifically on using 3D simulation to improve students' understanding of cryptographic concepts remains limited.

Based on this background, this study aims to examine the effectiveness of interactive 3D simulation media in enhancing students' comprehension of cryptographic concepts compared to conventional textbook-based learning. The interactive 3D simulation used in this research is an application developed in previous studies [20], deemed suitable as an alternative learning tool. This study's findings are expected to contribute to the development of more effective learning media for cryptography courses and provide recommendations for educators in selecting appropriate media to improve instructional quality.

2. METHOD

This study uses an experimental research design, The experimental design is a two-group pretest-posttest design. The pretest-posttest design explains how this design is used to measure the changes that occur as a result of a treatment or intervention [21]. The experimental design involves dividing students into two groups:

i) Experimental group: receives learning through interactive 3D simulation media.
ii) Control group: receives learning through textbooks.

The research sample consists of 15 students in the control group and 15 in the experimental group, like prior research samples [7]. The experimental design diagram is presented in Figure 1.

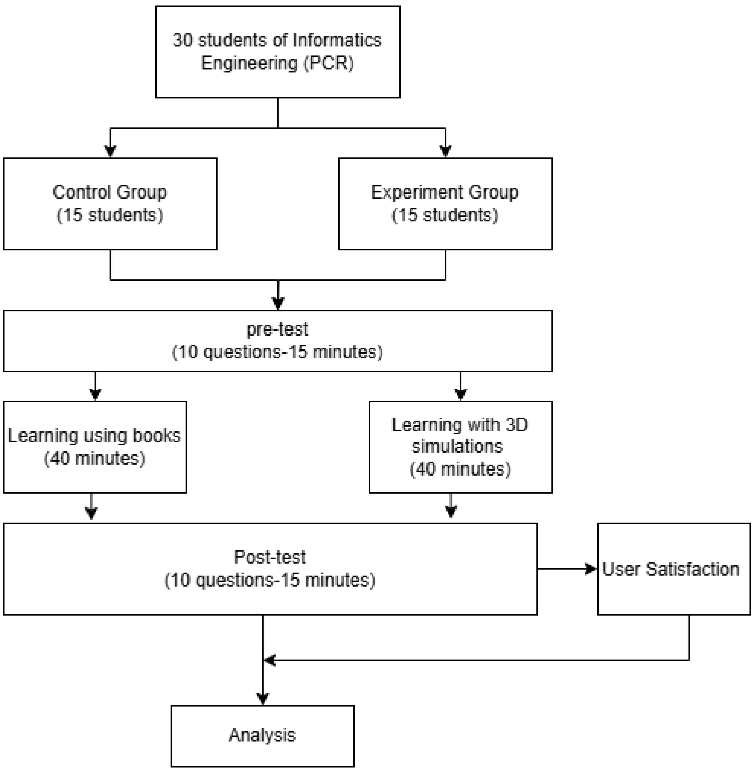

Figure 1. Experimental Design for Comparing Two Cryptography Learning Methods

The testing scenario for the two groups is as follows:

i) Experimental Group: The process begins with a pretest administered to students to assess their initial knowledge of the subject matter. Afterward, students engage with the application to study classical cryptography, specifically the Vigenère Cipher and Affine Cipher, for 40 minutes. They are then given a post-test with the same questions.

ii) Control Group: The testing scenario starts similarly with a pretest to gauge students' initial knowledge. Subsequently, students read a textbook on classical cryptography, including the Vigenère Cipher and Affine Cipher, for 40 minutes, followed by a post-test with the same questions.

The scheme used to evaluate the effectiveness of the simulation application on students' achievement in learning cryptography from both groups is illustrated in Figure 2.

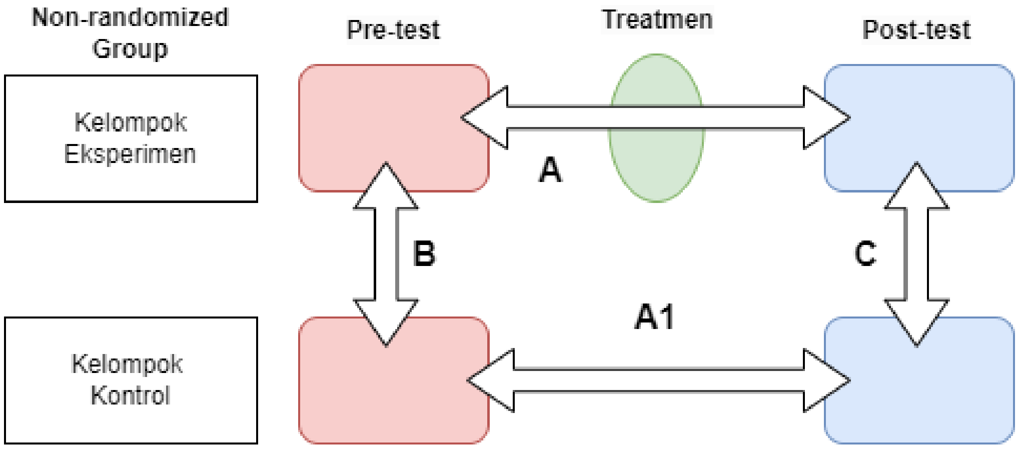

Figure 2. Design of Analysis for Pre-test and Post-test Results in Cryptography

Image explanation:
A = Comparison of pre-test and post-test scores for the experimental group
A1 = Comparison of pre-test and post-test scores for the control group
B = Comparison of pre-test scores between the experimental group and the control group
C = Comparison of post-test scores between the experimental group and the control group

Before comparing the post-test results of both groups, a test for the equivalence of capabilities between the two groups was first conducted by statistically comparing the pre-test results. If there are no significant differences in the pre-test scores, it indicates that both groups are balanced, allowing for the subsequent comparison of their post-test learning outcomes.

The pre-test scores of students not using simulation 3D will be compared with the post-test scores of those who did use simulation 3D. Similarly, the pre-test results of students using conventional learning methods will be compared with the post-test results of those who also employed conventional methods. The basis for decision-making in this testing is as follows:

i) Hypothesis for the Experimental Group
H0: There is a significant difference between the learning outcomes of pre-test and post- test data using 3D simulation.
H1: There is no significant difference between the learning outcomes of pre-test and post-test data using 3D simulation.
The decision-making basis for this test is as follows:
- If the significance value (2-tailed) < 0.05, then accept H0.
- If the significance value (2-tailed) > 0.05, then reject H0 and accept H1.

ii) Hypothesis for the Control Group
H0: There is a significant difference between the learning outcomes of pre-test and post-test data using conventional methods.
H1: There is no significant difference between the learning outcomes of pre-test and post-test data using conventional methods.
The decision-making basis for this test is as follows:
- If the significance value (2-tailed) < 0.05, then accept H0.
- If the significance value (2-tailed) > 0.05, then reject H0 and accept H1.

Then, the n-gain score[22] is used to interpret the interactive 3D simulation, which is employed to strengthen the analysis of the effectiveness of using interactive 3D simulations in improving learning outcomes.

$$n - gain = \frac{posttest - pretest}{\max score - pretest} \quad (1)$$

Description:
post-test : the score obtained after the intervention.
pre-test : the score obtained before the intervention.
max score : the maximum score that can be achieved on the test

Table 1. N-Gain Score Index

Improvement Category	N-Gain Score Range
Low	< 0.30
Medium	0.30 - 0.69
High	>= 0.70

According to the gain score criteria, 3D simulation media is deemed effective if students achieve an n-gain score greater than 0.3, with a classification of either moderate or high. As the n-gain score has also been used to measure the effectiveness of game[23] media and mobile applications[24] as learning tools.

3. RESULTS AND DISCUSSION

The interface of the interactive 3D cryptography learning media used in the experimental group features three learning menus: learning through video, simulation, and quizzes. The application menu interface is as follows:

(a) (b)

Figure 3. Interface of the cryptography learning application menu

Meanwhile, the simulation menu interface for cryptography learning is shown in Figure 3(a), and the learning interface with the converter is depicted in Figure 3(b) below:

(a) (b)

Figure 4. Interface of the interactive 3d cryptography learning simulation application

In Figure 4(a), users can select from several examples of plaintext/ciphertext and keys from the four cases provided for simulation, then press the encryption/decryption button to display the simulation. An info button is available to provide explanations regarding each input. In contrast, Figure 4(b) shows the interface for performing encryption and decryption conversions. Students can input text and keys as desired, and the application will display an explanation based on the inputs, with the output being either ciphertext or plaintext. The encryption and decryption processes in this converter can be performed dynamically according to user inputs.

The scenario for measuring the effectiveness of the interactive 3D cryptography simulation application involves two groups, following the experimental design scenario illustrated in Figure 2. The testing was conducted with 30 students divided into two testing groups: the control group and the experimental group. Using the Paired Sample t-Test, it can be concluded that there is a difference in the average scores of the students between the pre-test of the experimental group and the post-test of the experimental group, as well as between the pre-test of the control group and the post-test of the control group. The results of the pre-test and post-test for the two learning groups are described as follows:

Table 2. Statistical description of pre-test and post-test scores in cryptography

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound	Min	Max
Pre-test	Control	15	28.00	13.202	3.409	20.69	35.31	10	60
	Experiment	15	26.00	12.421	3.207	19.12	32.88	10	50
Post-test	Control	15	67.33	10.998	2.840	61.24	73.42	50	90
	Experiment	15	83.33	8.165	2.108	78.81	87.85	70	100

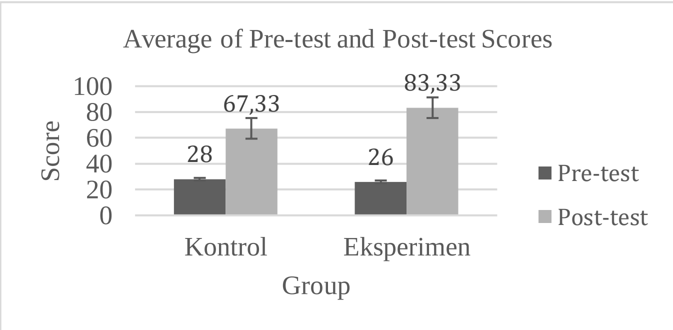

Figure 5. Graph of Pre-Test and Post-Test Scores of Research Groups

The initial test conducted was to assess the equivalence of the initial capabilities of the two groups by comparing the pre-test scores of the control group and the experimental group. This test was performed using SPSS software with the independent sample t-test method, as was also done in previous research [25]. The results of this test are presented in Table 3.

Table 3. Statistical test results for the difference between pre-test and post-test scores

		Levene's Test for Equality of Variances: F	Sig.	t-test for Equality of Means: t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference: Lower	Upper
Pre-tes	Equal variances assumed	.039	.844	.427	28	.672	2.000	4.680	-7.587	11.587
	Equal variances not assumed			.427	27.897	.672	2.000	4.680	-7.589	11.589
Post-test	Equal variances assumed	.843	.366	-4.524	28	.000	-16.000	3.537	-23.245	-8.755
	Equal variances not assumed			-4.524	25.837	.000	-16.000	3.537	-23.272	-8.728

Based on the results presented in Table 2, the pre-test scores of the experimental group and the control group yielded a significance (2-tailed) value of 0.672, which is greater than 0.05. Thus, it can be concluded that there is no significant difference between the pre-test scores of the experimental group and the control group, indicating that both groups are equivalent and suitable for comparison. For the post-test results of both groups, a significance (2-tailed) value of 0.000 was obtained, which is less than 0.05. This indicates that there is a significant difference in the average scores between the post-test of the experimental group and the post-test of the control group with a confidence level of 95%.

Furthermore, based on the average scores in Table 2 and the graph in Figure 5, it can be observed that the learning outcomes achieved through simulation-based learning are higher compared to conventional teaching strategies. The pre-test scores indicate that the average score of students in the control group, who utilized conventional learning, is mean = 28 and SD = 13.202, which is higher than the simulation-based learning group (mean = 26, SD = 12.421). The post-test scores show that the average score of students in the experimental group, who used simulation-based learning, is mean = 83.33 and SD = 8.165, higher than the group that used conventional learning (mean = 67.33, SD = 10.998).

In the experimental group, there was an increase of 57,33 point from pre-test to post-test scores, while the control group experienced an increase of 39.33. Based on the calculation of the n-gain score, the experimental group has an n-gain score of $(83.33 - 26)/(100 - 26) = 0.77$, which falls into the high category. This indicates that the use of classical cryptography learning media through 3D simulations provides a significant improvement in student learning outcomes. Meanwhile, the control group has an n-gain score of $(67.33-28)/(100-28) = 0.54$, which is categorized as medium. This indicates that conventional media provides a moderate improvement in student learning outcomes.

This data indicates that although both groups experienced significant improvement, the experimental group showed a more substantial increase compared to the control group. This suggests that the use of interactive 3D simulations as a learning medium can serve as an effective alternative for enhancing student motivation and understanding of cryptography concepts. This finding is in line with previous research, which suggests that the use of simulations in abstract subjects such as STEM [6], physics [18], and conditional probability [19] is effective in enhancing students' knowledge and providing practical experience for both teachers and students.

The significant improvement in the experimental group can be attributed to the engaging nature of the interactive 3D simulation, which motivates students and facilitates a deeper understanding of concepts. The visualization offered by the 3D simulation allows students to better grasp abstract concepts, aligning with previous research indicating that visualization in cryptography supports effective understanding [26] and enhances student motivation [12-13], promoting interactivity and collaboration[29].

Validation results from a questionnaire by the data security course instructor at PCR indicate that this 3D simulation application aids student understanding and encourages learning interest, with an average Likert scale score of 86.75%, as presented in Figure 6.

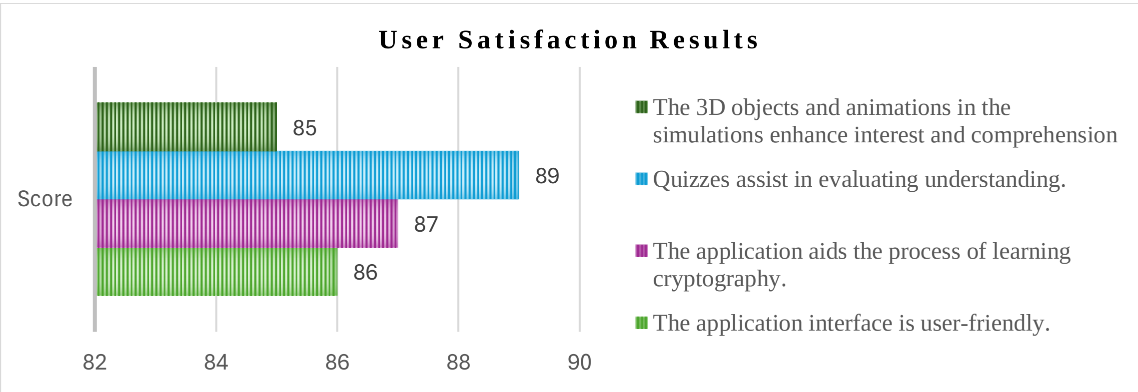

Figure 6. Graph of User Satisfaction Results

Moreover, students also expressed that the multimedia-based interactive 3D simulation application for classical cryptography encryption and decryption meets their learning needs. The learning model utilizing interactive 3D simulations is considered more effective and capable of increasing motivation to study cryptography compared to conventional methods. These findings are consistent with previous studies demonstrating that interactive applications or media [27-28] , animation, a 3D virtual approach supports more interactive and collaborative learning [29], enhancing learning outcome [32].

This research presents several limitations that should be considered in future studies. First, the sample size of 30 students from Politeknik Caltex Riau (PCR) is relatively limited, which affects the generalizability of the results; expanding the sample size and including participants from more diverse backgrounds could yield more comprehensive insights. Second, the study does not consider differences in students' prior knowledge, which may impact the effectiveness of the 3D simulations; future research should consider grouping participants based on their initial levels of expertise. Furthermore, the research focuses only on the Vigenère Cipher and Affine Cipher, leaving out other classical cryptography algorithms that could be included in future studies to evaluate the broader applicability of 3D simulations.

Additionally, the research evaluates only the immediate post-test outcomes without exploring the retention of knowledge over time, which is crucial for understanding the long-term effects of the learning method. The study also overlooks the potential benefits of combining 3D simulations with traditional textbook learning, which could provide a more holistic approach to teaching. While the level of student satisfaction is addressed, the research does not delve into how the design and usability of the 3D simulation tool contribute to the learning experience, an area worth further investigation. Lastly, cultural and cognitive factors that might influence student engagement and comprehension are not explored, leaving room for future studies to offer a more detailed analysis of the effectiveness of this learning medium in varied educational settings.

4. CONCLUSION

Interactive 3D simulation applications significantly enhance students' learning outcomes in classical cryptography by providing a more effective and engaging learning experience compared to traditional methods. The visual representation of abstract cryptographic processes, such as encryption and decryption, makes complex concepts easier to understand and more accessible. This approach not only improves students' grasp of classical cryptography but also maintains high levels of student engagement, as evidenced by the positive feedback and high satisfaction rates. The potential for expanding this method to other cryptographic techniques or related fields further highlights its effectiveness in enhancing learning. Ultimately, integrating 3D simulations into cryptography education offers a powerful tool for improving students' understanding and bridging the gap between theoretical concepts and practical application.

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