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Improving Mathematical Problem-Solving Ability through Project-Based Learning in Elementary Linear Algebra: A Study of Mathematics Education Students

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Abstract
Elementary Linear Algebra covers the study of matrices and vectors. One practical application of matrix concepts in daily life and technology is the Hill Cipher cryptosystem. Cryptography is the science of securing confidential messages, while the Hill Cipher is a cryptographic method that uses matrices in the encryption process. The Hill Cipher can be applied as a project in Project-Based Learning (PjBL) for the Elementary Linear Algebra course, particularly in the topic of matrices, with the aim of improving students' problem-solving abilities. This approach serves as an alternative to the conventional learning methods commonly used. Through the implementation of PjBL, it is expected that the course learning outcomes can be achieved and that students will become more creative and innovative in solving problems. This study is a quantitative research with one group pretest–posttest design conducted on third-semester students of the 2023/2024 academic year in the Mathematics Education (Tadris Matematika) program, Faculty of Tarbiyah and Teacher Training, UIN Sulthan Thaha Saifuddin Jambi. Observation sheets were used to examine the implementation of the PjBL model, including the alignment between the learning process and the syntax and principles of PjBL, as well as the effectiveness of the projects used. Tests were administered to measure students' mathematical problem-solving ability after the implementation of the PjBL model, in the form of essay questions referring to indicators of mathematical problem-solving ability. The effect of the effectiveness of the PjBL implementation to improve students problem-solving ability was analyzed using the N-gain test on the results of the mathematical problem-solving ability test. The obtained N-gain score was 0.5786, which falls into the moderate category, indicating that the PjBL model is moderately effective to improve problem solving ability.

Keywords: Elementary Linear Algebra, Effectiveness, *Project Based Learning* (PjBL).

Introduction

The Project-Based Learning (PjBL), according to (Ngalimun, 2012), is a learning model that involves students in problem-solving activities and provides opportunities for them to construct their own learning, resulting in valuable and realistic products. The advantages of this learning model, as stated by (Education, 1999), include enabling students to develop a framework, identify problems, design processes by managing the information collected, and conduct continuous evaluation. This learning approach can be implemented either in groups or individually and plays a role in creating an atmosphere that is tolerant of mistakes and change(Thomas, 2000).

Elementary Linear Algebra is one of the pure mathematics courses whose study is closely related to matrices and vectors. The matrix topic covers the definition of matrices, matrix operations, the definition of determinant functions, various methods for determining determinants, and the properties of determinants. One application of matrix material in daily life and technology is the Hill Cipher cryptographic system(Anton & Rorres, 2014; Lay et al., 2016).

Cryptography is the science that studies how to maintain the security of confidential messages. Security refers to ensuring that confidential messages are not accessed by unauthorized parties, that the content of the messages is not altered during transmission, and that the messages are genuinely created by the original sender rather than by others impersonating them(Tuti, 2015). There are several components in cryptography(Haris, 2020), including encryption (the transformation of the original message into coded form), decryption (the transformation of the coded message back into its original form), keys, ciphertext (coded messages), and plaintext (original messages). In particular, a cryptanalyst is a person who is able to break encrypted messages without using a key, commonly known as a hacker. One hacker who has recently attracted public attention is an individual using the pseudonym BJORKA, who leaked the personal data of several officials to the public domain(Stallings, 2017).

The Hill Cipher is a cryptographic method that uses matrices in the encryption process. The original message is converted from alphabetic form (A–Z) into numerical form (0–25), after which the message is arranged into a matrix. This matrix is then multiplied by a specific key matrix to produce the ciphertext. The ciphertext is converted back into the original message using the concepts of determinants, matrix inverses, and matrix multiplication(Schneier, 2015; Trappe & Washington, 2006).

The theory of the Hill Cipher is considered applicable as a project in the Elementary Linear Algebra course, particularly in the matrix topic, and is expected to enhance students' problem-solving abilities. This approach serves as an alternative to the conventional learning methods commonly used. Through the implementation of PjBL, it is expected that the Course Learning Outcomes (CPMK) can be achieved, and that students will become creative and innovative in solving problems and possess competencies aligned with the current demands of the workforce(Bell, 2010; Kokotsaki et al., 2016; Polya, 1973).

Previous studies have extensively discussed the implementation of the PjBL model in mathematics learning; however, the application of the PjBL model in the Elementary Linear Algebra course, specifically using Hill Cipher cryptography theory as the project theme, has not yet been conducted(Hmelo-Silver, 2004). A study entitled "The Effect of the Implementation of Problem-Based Learning (PBL) and Project-Based Learning (PjBL) on Students' Problem-Solving Abilities Based on Self-Efficacy" (Resdiana et al., 2021) reported differences in students' problem-solving abilities when taught using the PBL and PjBL models. Furthermore, the study explained the interaction between PBL, PjBL, self-efficacy, and students' problem-solving abilities.

The similarity between this study and previous research lies in the use of Problem-Based Learning models and the focus on mathematical problem-solving ability as the measured outcome. The difference is that this study is specifically conducted in the Elementary Linear Algebra course, particularly on matrix topics. In addition, the designed project is related to a contemporary theme, namely basic cryptography using the Hill Cipher. This learning approach serves as a means to introduce students to the application of abstract theories from algebra courses in real-life contexts. Based on these considerations, this study is entitled "Improving Mathematical Problem-Solving Ability through Project-Based Learning in Elementary Linear Algebra: A Study of Mathematics Education Students at UIN Sulthan Thaha Saifuddin Jambi."

Method

This study is a quantitative research with one group pretest–posttest design aimed at examining the implementation of Project-Based Learning (PjBL) on students' mathematical problem-solving abilities(Creswell & Creswell, 2018; Sugiyono, 2019). The study was conducted with third-semester students in the 2023/2024 academic year from the Mathematics Education (Tadris Matematika) program, Faculty of Tarbiyah and Teacher Training, UIN Sulthan Thaha Saifuddin Jambi.

Data collection techniques in this study included observation, documentation, and tests. Observation was used to examine the overall implementation of the PjBL learning model, specifically to assess the alignment between the learning process and the syntax and principles of PjBL, as well as the effectiveness of the projects employed. The instrument used was an observation sheet developed based on indicators of learning implementation.

Constructivist theory states that learning becomes more meaningful when students are directly involved in the process of constructing knowledge through active engagement, discussion, and reflection (Bell, 2010; Kokotsaki et al., 2016; Moursund, 2003; Thomas, 2000; Vygotsky, 1978). Therefore, student activeness is a crucial indicator in evaluating the effectiveness of the implementation of Project-Based Learning (PjBL) to improve problem solving ability. The indicators of learning implementation include activities such as identifying and understanding the project, developing a project plan, establishing the project schedule and time management, implementing and monitoring the project, testing and validating the project outcomes, as well as evaluation activities.The observation sheet was assessed using a Likert scale ranging from 1 to 5. The level of achievement of the implementation of the PjBL model based on observation results is presented in the table below:

Tabel 1. The Achievement Criteria

Criteria	The Achievement (%)	Category
1	$0 \leq Achievement(\%) < 55$	Very Poor
2	$55 \leq Achievement(\%) < 65$	Poor
3	$65 \leq Achievement(\%) < 80$	Fairly Good
4	$80 \leq Achievement(\%) < 90$	Good
5	$90 \leq Achievement(\%) \leq 100$	Very Good

The test was administered to assess students' mathematical problem-solving abilities after the implementation of the Project-Based Learning (PjBL) model. The test consisted of two essay-type questions. The test items were developed based on indicators of mathematical problem-solving ability. The scoring process was conducted using a predefined scoring rubric.

After obtaining the pretest and posttest scores, the researcher analyzed the scores obtained. The analysis employed was the normalized gain (N-gain) test. This test was used to determine the improving of the treatment provided. The formula used to calculate the normalized gain according to Meltzer is presented below.

Normalized Gain Test Score:

$$N\ Gain = \frac{S_{POST} - S_{pre}}{S_{\ maks} - S_{pre}}$$

Where:
$N\ Gain$: Normalized Gain Test Score

S_{POST} : pretest score

S_{pre} : posttest score

$S_{\ maks}$: maximal score

The improving problem solving ability criteria based on the normalized gain values according to Meltzer are shown in the table below (Hake, 1999; Meltzer, 2002).

Tabel 2. Normalized Gain Test Score

No.	Normalized Gain Test Score (n)	Category
1	$0{,}70 \leq n \leq 1{,}00$	High
2	$0{,}30 \leq n < 0{,}70$	Moderate
3	$0{,}00 \leq n < 0{,}30$	Low

Result and Discussions

The implementation of learning was aligned with the PjBL syntax, which includes project determination, project planning, scheduling, project monitoring, project product testing, and evaluation. The initial stage of determining the learning project was conducted online, in accordance with the Rector's instructions. At this stage, the lecturer explained the project topic to be implemented, namely a modified Hill Cipher cryptography. The Hill Cipher is one of the basic cryptographic methods and is relatively simple. Therefore, this project required students to design a new algorithm that combines the Hill Cipher with another cryptographic method, with the aim of making the resulting formula more difficult to decipher. The class was divided into small groups, and each group was assisted by a senior student in determining the project title(Bell, 2010; Kokotsaki et al., 2016; Thomas, 2000).

The project planning stage was also carried out in the first meeting. The lecturer asked students to review the required materials, search for references, divide tasks, and perform other preparatory activities. In the scheduling stage, each group was required to create a realistic project timeline. Furthermore, students were asked to complete a table containing the activities to be carried out along with their implementation dates.

The fourth stage involved monitoring project progress. Each group was asked to report the progress of their project. In addition, students presented the obstacles or problems they encountered and discussed the best possible solutions. Each group was also required to prepare a project progress table consisting of the topics that had been discussed, the results obtained, and documentation.

The fifth stage was testing the project outcomes, which was conducted in the form of group presentations. Each group was allotted 20 minutes, consisting of 13 minutes for presentation and 7 minutes for a question-and-answer session. One of the objectives of this project was to develop students' creativity and analytical skills in discovering new ideas that differ from existing articles or previous studies. The assessment of assignments and presentations emphasized the novelty of the formula and the originality of the work.

The final stage was evaluation. At this stage, a test was administered to assess students' problem-solving abilities in accordance with the learning objectives.

The research instruments used were observation sheets and tests. The observation sheets were used to examine the implementation of the learning process. The initial step was to develop the instruments, which were then validated by experts in education and language. After being revised according to the validators' suggestions and feedback, the instruments were deemed ready for use.

The observation sheet was used to assess the extent to which the steps of the Project-Based Learning model were implemented. The results of the observation on the implementation of the Project-Based Learning model are presented as follows:

a. Identifying and Understanding the Project

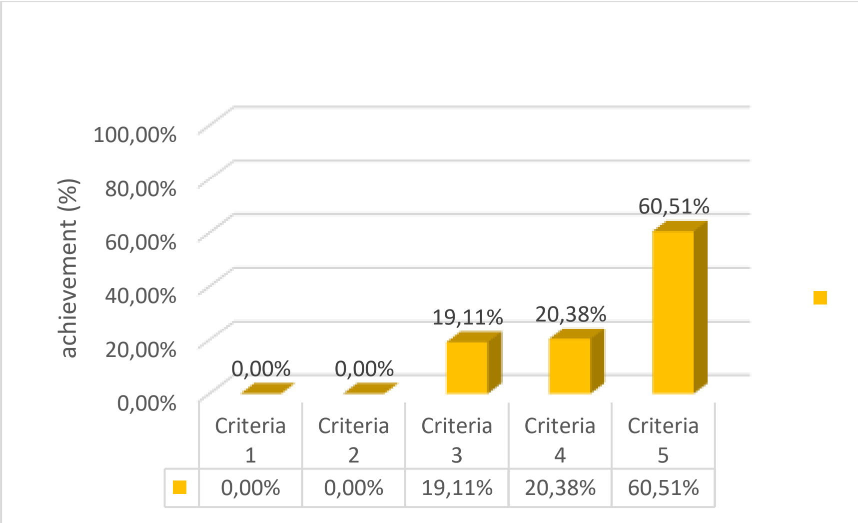

Figure 1. Graph of Identifying and Understanding the Project

Based on the graph above, it can be observed that for the project determination indicator, no students fall within the assessment ranges of criteria 1 and 2. Meanwhile, 19.11% of students are in criterion 3, 20.38% in criterion 4, and 60.51% in criterion 5. Overall, the assessment of the activity of determining and understanding the project reached 80.89%, which falls into the good category.

This activity illustrates that students identified a linear algebra problem to be used as a project, namely a modified Hill Cipher cryptography project, posed relevant questions, and demonstrated an understanding of the objectives and context of the assigned project. According to (Thomas , 2000), a well-designed project should begin with a challenging and meaningful problem. Students' active engagement in understanding the purpose of the project indicates the presence of intrinsic motivation and cognitive readiness.

b. Activities of Developing a Project Plan

In the context of Elementary Linear Algebra learning using a modified Hill Cipher cryptography project, this activity assists students in organizing abstract concepts into systematic solution procedures. The following section presents the results of observations on project planning activities.

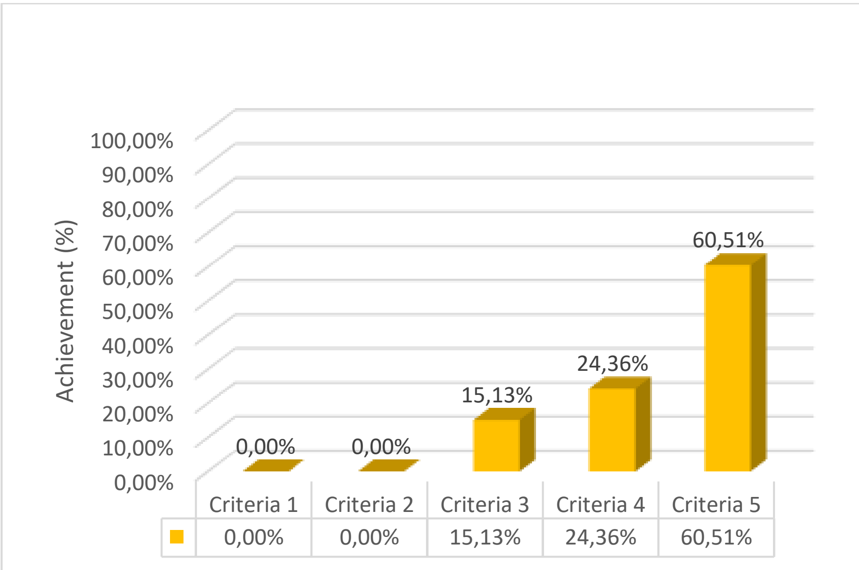

Figure 2. Graph of Project Developing a Project Plan

Based on the graph above, it can be observed that for the project planning indicator, no students were rated in criteria 1 and 2. Meanwhile, 15.13% of students were rated in criterion 3, 24.36% in criterion 4, and 60.51% in criterion 5. Overall, the project planning activity achieved a score of 84.87%, which falls into the good category. According to (Bell, 2010), Project-Based Learning encourages students to independently and responsibly design problem-solving strategies.

c. Scheduling and Time Management Activities

Students' activities in scheduling and time management indicate a sense of responsibility toward the learning process as well as the ability to organize realistic strategies for project completion. The following presents the results of observations on scheduling and time management activities in the modified Hill Cipher cryptography project.

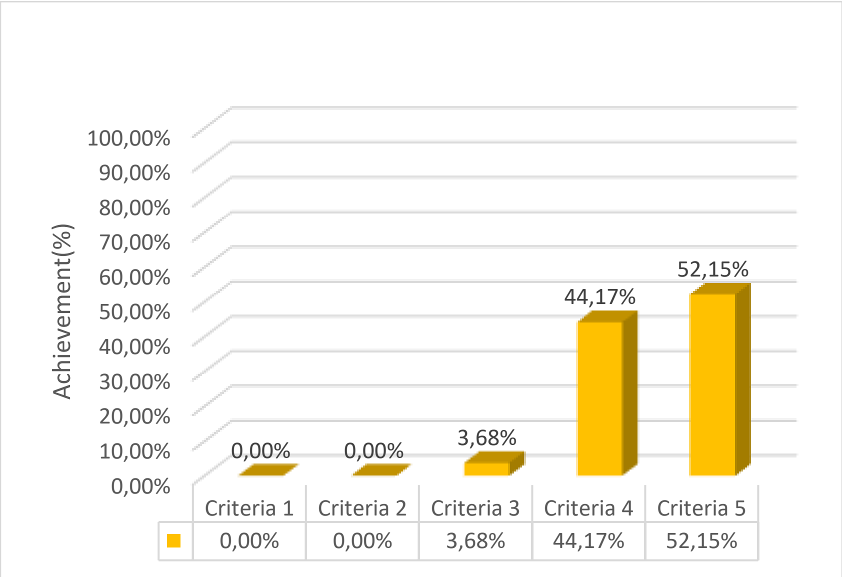

Figure 3. Graph of Scheduling Observation Results

Based on the graph above, it can be seen that for the scheduling indicator, no students were rated within criteria 1 and 2. Meanwhile, 3.68% of students were rated in criterion 3, 44,17% in criterion 4, and 52,15% in criterion 5. Overall, the scheduling activity indicator achieved a score of 96,32%, which falls into the very good category. Time management is part of 21st-century skills that can be developed through Project-Based Learning (Kokotsaki et al., 2016).

d. Project Implementation and Monitoring Activities

Project implementation and monitoring activities constitute the core of Project-Based Learning (PjBL). The following graph presents the results of observations of activities related to implementing and monitoring project development. These activities support both conceptual and procedural understanding through the direct application of mathematical concepts.

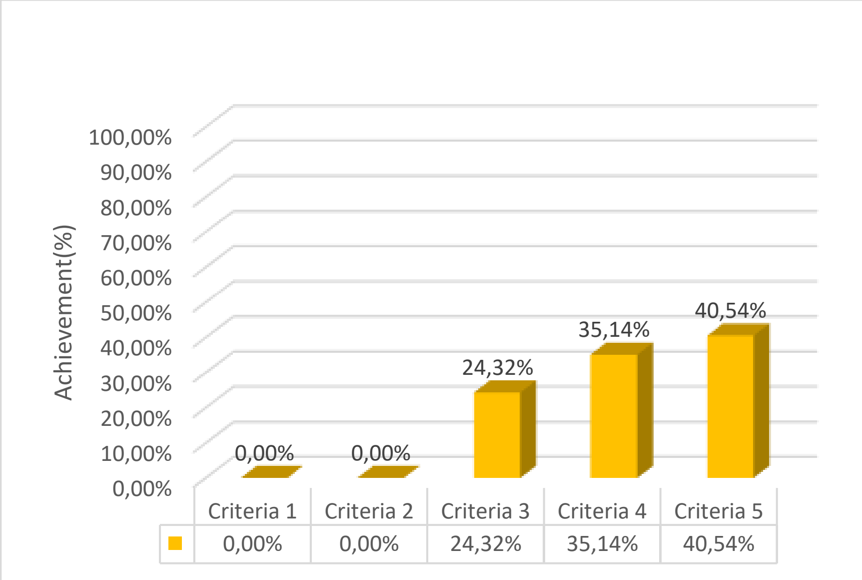

Figure 4. Graph of Observation Results on Project Implementation and Monitoring

Based on the graph above, it can be observed that for the indicator of implementing and monitoring project development, no students were rated within criteria 1 and 2. Meanwhile, 24,32% of students were rated in criteria 3, 35,14% in criteria 4, and 40,54% in criteria 5. Overall, the project monitoring activity indicator achieved a score of 75,68%, which falls into the fairly good category. According to (Moursund, 2003), students learn actively when they engage in exploration, computation, analysis, and continuous monitoring of ongoing processes.

e. **Project Testing and Validation Activities**

Project testing and validation activities reflect metacognitive processes, namely students' ability to evaluate and reflect on their own thinking outcomes.

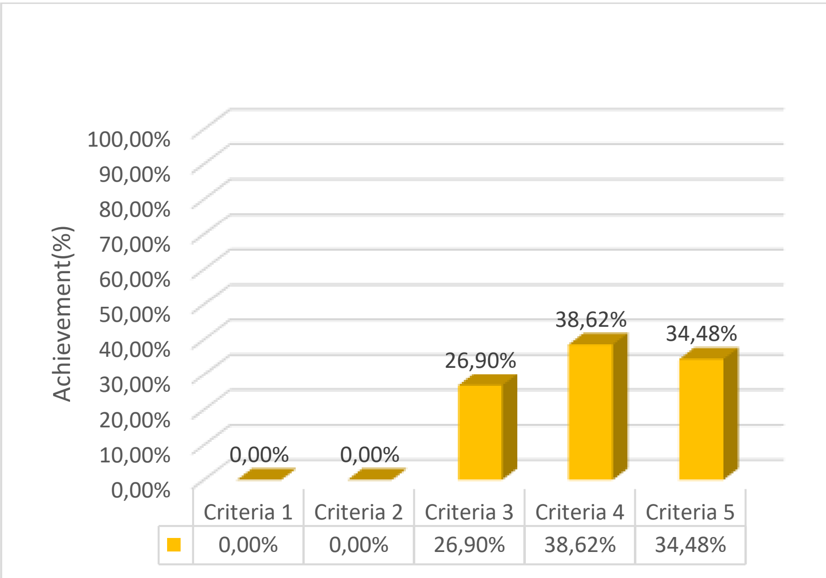

Figure 5. Graph of Observation Results on Project Testing and Validation Activities

Based on the graph above, it can be seen that for the project testing indicator, no students were rated within criteria 1 and 2. Meanwhile, 26.90% of students were rated in criteria 3, 38.62% in criteria 4, and 34.48% in criteria 5. Overall, the project testing indicator achieved a score of 73.10%, which falls into the fairly good category. Mathematical problem solving must involve a stage of reviewing the obtained solution. This finding indicates that students tend to lack carefulness in solving mathematical problems; therefore, project testing activities play an important role and need to be strengthened in mathematics learning (Polya, 1973).

f. Evaluation Activities

Evaluation activities strengthen students' conceptual understanding when solving mathematical problems, particularly in the modified Hill Cipher cryptography project, as well as enhance their mathematical communication skills. The figure below illustrates the results of observations of evaluation activities in the implementation of PjBL.

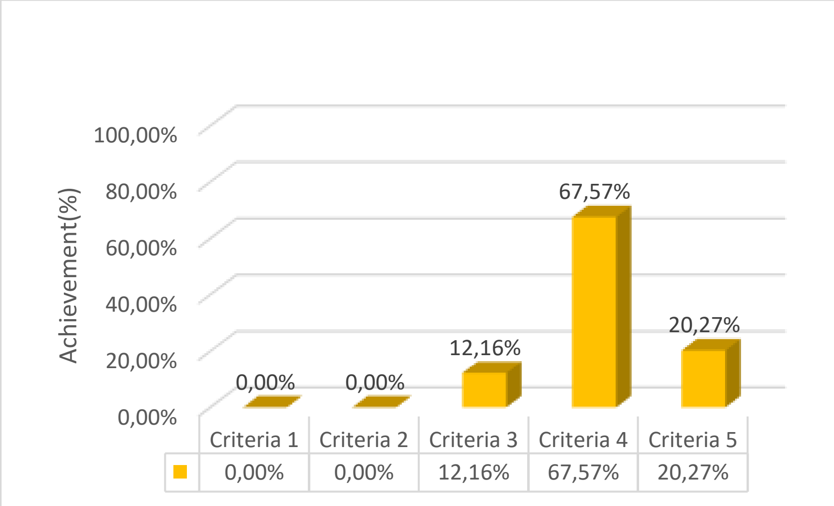

Figure 6. Graph of Observation Results on Evaluation Activities

Based on the graph above, it can be observed that for the evaluation indicator, no students were rated within criteria 1 and 2. Meanwhile, 12.16% of students were rated in criteria 3, 67,57% in criteria 4, and 20,27% in criteria 5. Overall, the evaluation activity indicator achieved a score of 87,84%, which falls into the good category. According to (Vygotsky, 1978)learning should emphasize the importance of social interaction. Through evaluation activities, students are able to construct knowledge more deeply and meaningfully(Prince & Felder, 2006).

The results of the analysis of the observation sheets showed scores of 80,89% for the project determination activity, 84,87% for the project planning activity, and 87,84% for the evaluation activity. All three indicators fall into the good category. This indicates that learning activities related to these activities were generally well implemented by the students. Project-Based Learning (PjBL) actively engages students from the early stages of instruction by immersing them in the exploration of authentic problems. Projects grounded in real-world contexts enable students to connect prior knowledge with project objectives, thereby fostering deeper conceptual understanding. Within the PjBL framework, structured group work supports meaningful discussion, effective task distribution, and collaborative knowledge construction. In line with social constructivist theory (Vygotsky, 1978), optimal learning is achieved through social interaction and collaboration within the zone of proximal development. The project evaluation stage was categorized as good, as students demonstrated the ability to reflect critically on their work. Furthermore, through presentation and feedback sessions, students were encouraged to evaluate the accuracy of their project outcomes and the effectiveness of the solutions proposed.Meanwhile there were still some students who obtained unsatisfactory scores. The observers' notes indicated that some students were not actively involved in discussions during the determination of paper titles, project planning, and scheduling within their groups. Some students remained passive, while others were occupied with their own activities.

The scheduling observation is 96,32% fall into very good category. It is suggests that students were able to organize project tasks systematically, set realistic deadlines, and coordinate responsibilities effectively within their groups. The high level of performance in scheduling reflects students' growing self-regulation and responsibility in managing the learning process, which are essential components of successful Project-Based Learning.According to (Thomas, 2000), effective scheduling is a critical element of PjBL because it enables learners to manage complex tasks over an extended period and ensures the timely completion of project activities. When students are actively involved in planning and scheduling, they develop ownership of the project, which in turn enhances engagement and accountability.

The project implementation monitoring activities obtained a score of 75,68% where is categorized as fairly good. This result indicates that the implementation of learning at this stage was generally fairly effective. Based on observers' notes and lecturers' monitoring results, several groups had not yet finalized their paper titles. The proposed titles were still limited to conventional Hill Cipher cryptography using 2×2 or 3×3 key matrices, indicating that they had not been modified by incorporating other cryptographic concepts. In addition, one group submitted an article written by another author as their paper. These two issues contributed to the lower scores obtained by some groups for this indicator. On the other hand, groups that achieved high scores had titles that met the required criteria, clear research formulations and objectives, and adequate theoretical foundations to complete the assigned tasks.

The project outcome testing and validation activities obtained a score of 73.10%, which falls into the fairly category. This indicates that the implementation of learning at this stage reached only a moderate level and did not attain the good category. Observers' assessments revealed that some students had limited understanding of the presentation material and tended to merely read what was displayed on the screen. This became more evident when the lecturer requested further explanations, as the students were unable to provide clear responses. Several students appeared confused, remained silent, or were unsure of how to answer, and some even asked other group members for help. This confirms that they did not fully master their own papers. In addition, during the discussion sessions, they were not actively engaged in asking or answering questions from participants of other groups.

The learning outcome test was used to examine improvements in students' problem-solving abilities after the implementation of project-based learning. The students' pretest and posttest scores are presented below.

Table 3. Students' Test Results

No	Name	Pretest	Postest
1	AA	65	90
2	AR	35	55
3	DD	77,5	90
4	DA	85	92,5
5	FL	53,33	78
6	GA	48,33	50
7	HA	55	79
8	YC	88,33	89
9	MW	42,5	54
10	MP	33,33	60
11	NH	85	88
12	ON	25	68
13	QT	58,33	94
14	RT	62,5	100
15	SS	80	100
16	SJ	43,33	77
17	FF	85	98

No	Name	Pretest	Postest
18	MN	48,33	70
19	LD	86,67	87
20	AM	51,67	93
21	AF	20	52
22	BF	63,33	70
23	CF	58,33	84
24	FD	55	90
25	KE	53,33	86
26	LT	85	94
27	MU	85	94
28	MR	73,33	92
29	NK	63,33	90
30	NK	85	90
31	PR	45	90
32	QA	48,33	84
33	RS	51,67	98
34	SN	18,33	88
35	SH	50	92
36	SP	15	89
37	TA	51,67	77

Based on the table above, the table below shows the descriptive statistics of Students' Test Results.

Table 4. Descriptive Statistics of Students' Test Results

Score	Descriptive Statistics	Value
PRETEST	X_{max}	88,33
	X_{min}	15
	$\bar{x}$	57,59
	SD	20,80
POSTEST	X_{max}	100
	X_{min}	50
	$\bar{x}$	83,04
	SD	14,01

According to table 4 the average pretest score of the students was 57,59 while the average posttest score was 83, 04. This indicates an increase in the average students' problem-solving ability of 25, 45 points. The improving students' problem-solving abilities was calculated using the normalized gain (n-gain) formula as follows.

$$N\ Gain = \frac{S_{POST} - S_{pre}}{S_{\ maks} - S_{pre}} = 0{,}5786$$

The n-gain result of 0.5786 indicates that the improvement in students' problem-solving abilities falls into the moderate category. It's indicating that the PjBL model is moderately effective to improve problem solving ability. Although the implementation of Project-Based Learning (PjBL) has a positive impact on the learning of Elementary Linear Algebra, the N-gain results fall within the moderate category. This indicates that the improvement in students' mathematical problem-solving skills has not yet reached an optimal level. The Hill Cipher is a cryptographic topic that involves matrix operations, modular matrix inverses, modular arithmetic, and abstract algebraic modeling, all of which require a deep level of understanding for students in the early semesters. In addition, within the Project-Based Learning (PjBL) approach, students tend to be more oriented toward the successful completion of the project rather than toward a deeper understanding of the underlying mathematical concepts. In the modified Hill Cipher project, students' attention was often focused on the success of the encryption and decryption processes rather than on conceptual reflection regarding the matrix operations employed. As described by Thomas (2000), one of the challenges of PjBL is students' tendency to prioritize the final product, which may limit the transfer of conceptual understanding to formal evaluation contexts such as written tests. Furthermore, the implementation of PjBL requires a relatively extended period for exploration, discussion, and reflection. When the duration of implementation is limited, students may not fully reach the stage of deep conceptual understanding. According to Bell (2010), the effectiveness of PjBL is strongly influenced by the allocation of sufficient time for in-depth investigation and reflection. Limited instructional time may therefore result in suboptimal learning gains, leading to an N-gain that falls within the moderate category.

Conclusion

The implementation of the Project-Based Learning (PjBL) model in the Elementary Linear Algebra course involved the development of instructional materials and the execution of classroom learning activities. The learning process was conducted in accordance with the PjBL syntax and evaluated using observation sheets. The observation results showed good performance across key learning activities, including project identification, project planning, scheduling, monitoring of project activities, and evaluation of project trial outcomes, while the observation activity itself was categorized as fairly good.

The improving problem solving ability of the PjBL implementation in the Elementary Linear Algebra course was analyzed using the normalized gain (n-gain) test based on students' mathematical problem-solving ability test results. The obtained n-gain score was 0.5786 which falls into the moderate category, indicating that the PjBL model is moderately effective to improve problem solving ability.

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