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[Research Article]

TEACHING MATERIAL DESIGN FOR SOLVING 2 & 3 LOOP ELECTRICAL CIRCUITS USING THE GAUSS-JORDAN ELIMINATION METHOD

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ABSTRACT

This research aims to teaching materials for solving 2 and 3 loop electrical circuits using the Gauss-Jordan elimination method as an innovative alternative in physics learning. The research method used is non-experimental research with a quantitative descriptive approach. Literature studies were conducted to analyse the theory of simple n-loop electrical circuits and develop new solutions using the Gauss-Jordan elimination method. The design of teaching materials that had been made was then validated by 2 expert validators and 3 user validators. The validation results showed that the designed teaching materials received an average score of 4.53 with a percentage of 90.6% from expert validators, as well as an average score of 4.34 with a percentage of 86.6% from user validators, both with very valid criteria. The overall average validation percentage of 88.6% indicates that this teaching material is suitable for use in physics learning activities.

Keywords: Teaching materials, Electrical circuits, Gauss-Jordan Elimination, Physics learning.

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1. INTRODUCTION

Learning in the 21st century emphasises the development of critical thinking skills, creativity, collaboration, and effective communication (Lestari, S. 2021). In this context, students are not only expected to understand academic material, but also be able to apply the knowledge gained to solve real problems. The quality of 21st century learning can be achieved if teachers are able to shape students' skills well. To support more effective and efficient learning, adequate infrastructure is needed, including quality and appropriate teaching materials (Ridho et al., 2020).

Teaching materials include various instruments used in the learning process to support teaching and learning activities (Rahmawati et al., 2019). The study conducted by Mulyana et al. (2021) showed that teaching materials have an impact on students' concept understanding, with an average Effect Size value of 2.16. These results indicate that teaching materials are effective in helping high school students understand physics concepts. In addition, research by Miftahurrahmi et al. (2021) revealed that teaching materials contribute significantly to physics learning outcomes, as evidenced by the Effect Size value of 1.1308 which is classified as high.

One of the teaching materials that are often used in learning is learning modules. The application of modules by teachers allows for two-way communication with students, so that teachers can act as facilitators and understand the extent of students' understanding of the material (Kosasih, 2020: 18). Research conducted by Mulyana et al. (2021) shows that the module has the highest Effect Size value compared to LKS and video, which is 2.55. This proves that learning modules can improve students' understanding in physics. Yani & Wahyudi (2021) also confirmed that the use of LKS alone is still not effective in improving understanding of physics concepts, so it is necessary to develop a module-based LKS that is more detailed in its explanation.

Physics is one of the subjects that requires good teaching material support, considering that many students find it difficult. This is in line with the research of Patandean et al. (2023) which revealed that students' lack of interest in learning physics is caused by the perception that this subject is difficult and less interesting. The difficulties faced by students include understanding concepts, analysing problems, linkages between materials, and applying appropriate formulas in solving problems.

One of the physics topics that students find difficult is dynamic electrical circuits (Mandang & Tulandi, 2020). Their difficulty in solving two-loop electrical circuit problems is caused by several factors, such as determining the direction of the loop, compiling variables in equations, understanding the laws of electrical circuits, and the limitations of teaching materials that are incomplete and not supported by interesting illustrations (Solihudin et al., 2023). In addition, many students experience misconceptions related to electric current, Ohm's law, and Kirchhoff's law. Erly's research (2020) also shows that student learning outcomes on dynamic electrical circuit material tend to be low.

One of the methods used in solving linear systems in electrical circuits is the substitution-elimination method. This solution can also be expressed in the form of matrix multiplication. Several studies have proven the effectiveness of this method, such as the research of Supriadi et al. (2024) who used the Cayley-Hamilton theorem to solve two- and three-loop electrical circuits, where the results showed that this theorem can be an alternative in solving electrical circuits with more than two loops. In addition, research by Wahyudianti et al. (2023) found that 62.77% of respondents agreed that Cramer's rule combined with the minor-cofactor method can be used as an alternative in solving two-loop electrical circuits.
The Gauss-Jordan elimination method is one of the mathematical techniques that can be used in the calculation of matrix functions. This method is used to solve a system of linear equations with

many variables (Afri & Lestari, 2021). Various studies have applied this method, such as in the analysis of simple triangular truss structures, which show fairly accurate calculation results compared to exact analysis (Nasmirayanti et al., 2022). In addition, this method can also be applied in solving two-loop electrical circuits and more complex circuits. The Gauss-Jordan elimination method is also used to obtain the matrix inverse, which helps in determining the value and direction of electric current in a circuit with the help of Scilab software (Anam & Arnas, 2019).

2. METHOD

This research applies a non-experimental method with a quantitative descriptive approach. This approach aims to present research results systematically and plays a role in describing, explaining, and validating the phenomenon under study (Ramadhan, 2021: 7-8). The main focus of this research is a literature review on simple n-loop electrical circuits by analysing existing theories and examining relevant variables to find new solutions using the Gauss-Jordan elimination method. After the new solution in solving the electrical circuit was obtained, the researcher designed teaching materials so that it could be applied in learning.

This research was conducted in the odd semester of the 2024/2025 academic year at one of the public high schools in Jember Regency. The analysis method used was empirical analysis, namely validation of the design of teaching materials based on the Gauss-Jordan elimination method in solving n-loop electrical circuits. The validation process was carried out through expert judgement by Physics Education lecturers FKIP University of Jember and public high school teachers in Jember Regency. The validity test in this study included four main aspects, namely content feasibility, material presentation, language, and graphics. Assessment of teaching material design using a Likert scale as shown in Table 3.1.

Table 3.1 Scoring Guidelines on the Validation Sheet Questionnaire

Value	Criteria
5	Very Good
4	Good
3	Quite Good
2	Less Good
1	Not Good

The equation for processing the score data that has been obtained in the form of expert and user validation percentages can be seen in equation 3.1 below.

$$(x) = \frac{Number\ of\ Score\ Pbtained}{Maximum\ Score} \times 100\% \qquad 3.1$$

The calculation results obtained are converted into categories in Table 3.2 below.

Table 3.2 Percentage criteria for suitability

Frekuensi Persentase(%)	Kategori Kesesuaian
$80\% < x \leq 100\%$	Very Valid
$60\% < x \leq 80\%$	Valid
$40\ \% < x \leq 60\%$	Quite Valid
$20\% < x \leq 40\%$	Less Valid
$0\% < x \leq 20\%$	Invalid

(Modified from Elisa et al., 2023)

Based on the criteria of Table 3.2, the design of teaching materials for the Gauss-Jordan elimination method in solving 2 & 3 loop electrical circuits is declared valid if x≥60%.

3. RESULT AND DISCUSSION

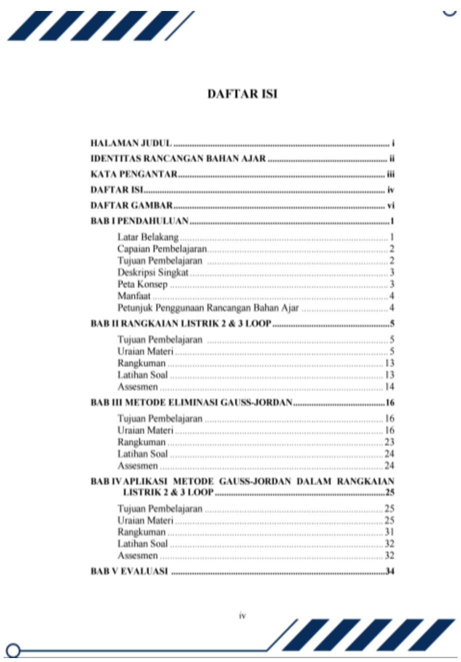
Teaching materials on two- and three-loop electrical circuits generally use substitution and elimination methods to solve systems of linear equations (SPL) obtained from the application of Kirchoff's first and second laws. Mathematically, there are several methods that can be used to solve SPL with two or three variables, one of which is the Gauss-Jordan elimination method.

This method has been proven effective in solving n-loop electrical circuit problems, both analytically and numerically. However, this method has not been widely developed in the form of teaching materials or applied in learning. Therefore, the use of the Gauss-Jordan elimination method in analytically solving two- and three-loop closed circuits can be an alternative. The procedures and stages of solving two- and three-loop electrical circuits with this method are explained in detail in the design of teaching materials, which are designed to help students understand the material and its application in solving electrical circuits.

Data collection was conducted through a literature study on the application of the Gauss-Jordan elimination method in electrical circuits. In addition, data was also obtained from SMA Negeri Ambulu in Jember Regency through observation of the teaching materials used, the method of solving two- and three-loop electrical circuits, and interviews with teachers related to obstacles and student understanding of the material. Documentation of teaching materials used in schools was also reviewed as a reference in the preparation of the design of physics learning teaching materials for the topic of two- and three-loop electrical circuits. After the design of teaching materials was prepared, validation was carried out by two Physics Education lecturers from Jember University as expert validators and three physics teachers from one of the public high schools in Jember Regency as user validators.

The analysis results from the literature study related to the application of the Gauss-Jordan elimination method in electrical circuits are used as the basis for developing physics teaching materials for two- and three-loop electrical circuits. The design of the developed teaching materials includes various components, such as cover, instructions for use, learning outcomes, learning materials, practice questions, summary, assessment, reflection, glossary, and index. In addition, some additional components include teaching material identity, preface, table of contents, list of images, concept map, evaluation questions, and bibliography. These components are compiled based on previous research, as stated by Magdalena et al. (2020), Prastowo (2014:28), as well as regulations from the Ministry of Education and Culture No. 21 of 2023. The display of the components of this teaching material design can be seen in Figure 4.1.

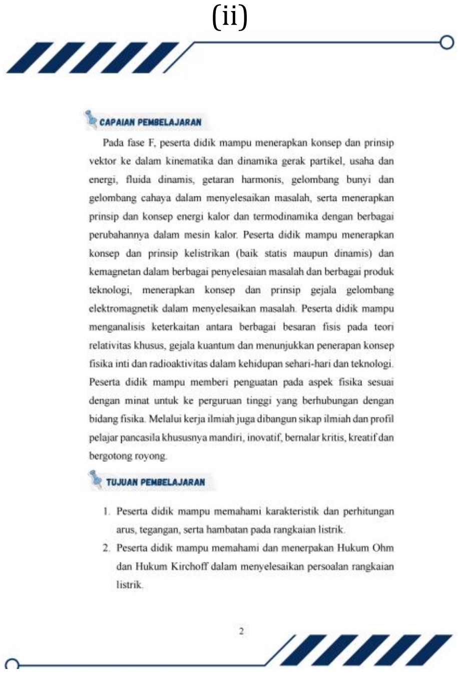
(i)



DAFTAR ISI

iv

(ii)



CAPAIAN PEMBELAJARAN

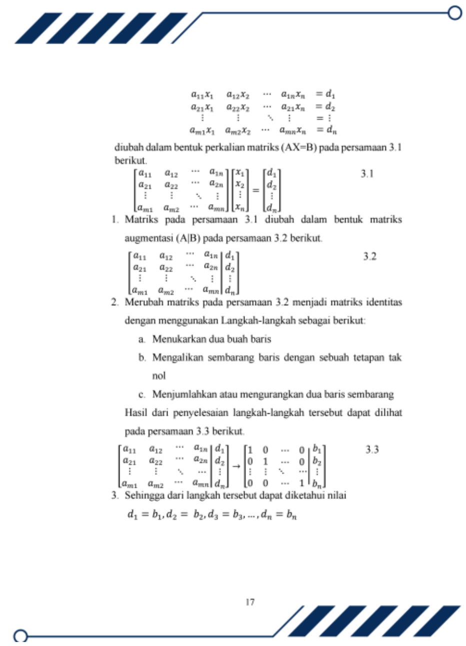
Pada fase F, peserta didik mampu menerapkan konsep dan prinsip vektor ke dalam kinematika dan dinamika gerak partikel, usaha dan energi, fluida dinamis, getaran harmonis, gelombang bunyi dan gelombang cahaya dalam menyelesaikan masalah, serta menerapkan prinsip dan konsep energi kalor dan termodinamika dengan berbagai perubahannya dalam mesin kalor. Peserta didik mampu menerapkan konsep dan prinsip kelistrikan (baik statis maupun dinamis) dan kemagnetan dalam berbagai penyelesaian masalah dan berbagai produk teknologi, menerapkan konsep dan prinsip gejala gelombang elektromagnetik dalam menyelesaikan masalah. Peserta didik mampu menganalisis keterkaitan antara berbagai besaran fisis pada teori relativitas khusus, gejala kuantum dan menunjukkan penerapan konsep fisika inti dan radioaktivitas dalam kehidupan sehari-hari dan teknologi. Peserta didik mampu memberi penguatan pada aspek fisika sesuai dengan minat untuk ke perguruan tinggi yang berhubungan dengan bidang fisika. Melalui kerja ilmiah juga dibangun sikap ilmiah dan profil pelajar pancasila khususnya mandiri, inovatif, bernalar kritis, kreatif dan bergotong royong.

TUJUAN PEMBELAJARAN

1. Peserta didik mampu memahami karakteristik dan perhitungan arus, tegangan, serta hambatan pada rangkaian listrik.
2. Peserta didik mampu memahami dan menerpakan Hukum Ohm dan Hukum Kirchoff dalam menyelesaikan persoalan rangkaian listrik.

2

(iii)



$$\begin{matrix} a_{11}x_1 & a_{12}x_2 & \cdots & a_{1n}x_n & = d_1 \\ a_{21}x_1 & a_{22}x_2 & \cdots & a_{21}x_n & = d_2 \\ \vdots & \vdots & \ddots & \vdots & = \vdots \\ a_{m1}x_1 & a_{m2}x_2 & \cdots & a_{mn}x_n & = d_n \end{matrix}$$

diubah dalam bentuk perkalian matriks (AX=B) pada persamaan 3.1 berikut.

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{bmatrix} \quad 3.1$$

1. Matriks pada persamaan 3.1 diubah dalam bentuk matriks augmentasi (A|B) pada persamaan 3.2 berikut.

$$\left[\begin{matrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{matrix}\middle| \begin{matrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{matrix}\right] \quad 3.2$$

2. Merubah matriks pada persamaan 3.2 menjadi matriks identitas dengan menggunakan Langkah-langkah sebagai berikut:
   a. Menukarkan dua buah baris
   b. Mengalikan sembarang baris dengan sebuah tetapan tak nol
   c. Menjumlahkan atau mengurangkan dua baris sembarang

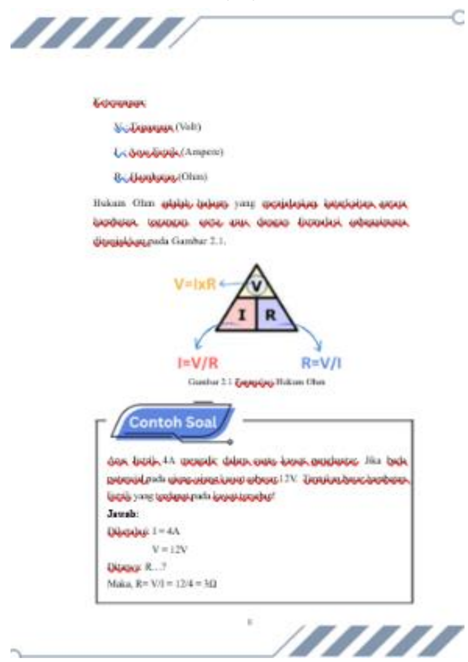
   Hasil dari penyelesaian langkah-langkah tersebut dapat dilihat pada persamaan 3.3 berikut.

$$\left[\begin{matrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \cdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{matrix}\middle| \begin{matrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{matrix}\right] \rightarrow \left[\begin{matrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \cdots \\ 0 & 0 & \cdots & 1 \end{matrix}\middle| \begin{matrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{matrix}\right] \quad 3.3$$

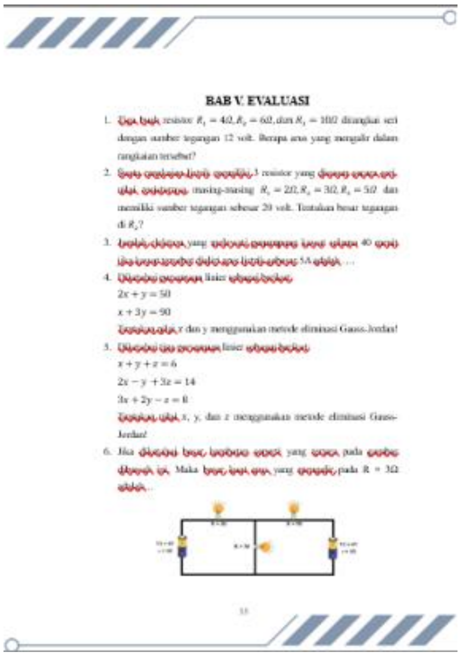
3. Sehingga dari langkah tersebut dapat diketahui nilai $d_1 = b_1, d_2 = b_2, d_3 = b_3, \ldots, d_n = b_n$

17

(iv)



(v)



(vi)

Figure 4.1 (i) Cover (ii) Table of Contents (iii) Competencies to be achieved (iv) Content of Learning Materials (v) Sample Questions (vi) Evaluation

This physics teaching material design was developed for students of grade XII SMA and consists of three stages of learning. The first stage discusses the material of two- and three-loop electrical circuits, including Ohm's law, Kirchhoff's law, and the basic concepts of electrical circuits. The second stage explains the Gauss-Jordan elimination method, including its application to systems of linear equations of two variables (SPLDV) and three variables (SPLTV). The third stage focuses on the application of the Gauss-Jordan elimination method in solving two- and three-loop electrical circuits. Each learning stage is equipped with sample problems, summaries, exercises, and assessments to strengthen students' understanding.

After the design of teaching materials was prepared, an evaluation process was carried out by validators to ensure its feasibility and validity. Validation was carried out by two Physics Education lecturers from the University of Jember as expert validators and three physics teachers from one of the public high schools in Jember Regency as user validators. The validation assessment included four main aspects, namely content, presentation, language, and graphical feasibility. The validation instrument used a Likert scale with the criteria listed in Table 3.1. If the validation results show that the teaching materials have not met the eligibility standards, then revisions are made until they meet the specified criteria. This process takes place repeatedly until the teaching material design is declared valid and ready for use.

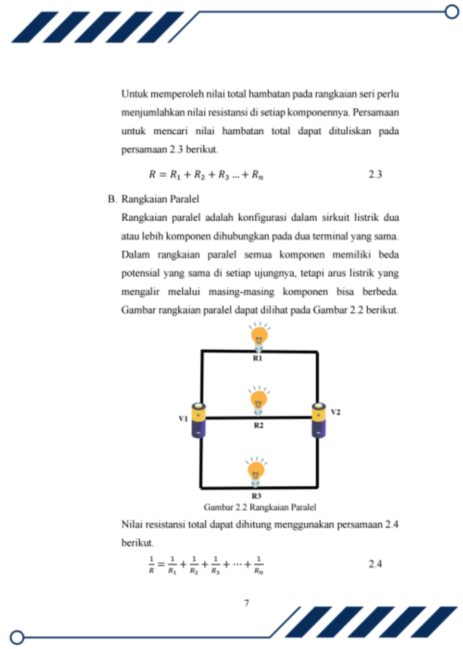
Validation was carried out by assessing the instruments that had been prepared by the researcher. The assessment results from the two expert validators were averaged and analysed to obtain the final validation score. A summary of the validation results is presented in Table 4.1 below.

Table 4.1 Results of validation of teaching material design by expert validators

No.	Aspect	Score		Average	Persentation	Criteria
		V1	V2			
1.	Content	4,8	4,4	4,6	92%	Very Valid
2.	Presentation	4,7	4,3	4,5	90%	Very Valid
3.	Language	5	4,4	4,7	94%	Very Valid
4.	Graphics	4,6	4,1	4,35	87%	Very Valid
Average		4,77	43	4,53	90,6%	Very Valid

The data in Table 4.1 shows that the assessment results from expert validators obtained an average score of 4.53 with a validity percentage of 90.6%. These results indicate that the design of teaching materials has a high level of validity. Teaching materials can be used in learning after making improvements in accordance with the revisions given by the validator. Some suggestions for improvement from expert validators include adding sample problems related to the application of the Gauss-Jordan elimination method in electrical circuits as well as illustrations of series and parallel circuits in the first activity. The subject matter has been prepared in accordance with the validation indicators assessed by the expert validators, so that the method used can be applied to solve two- and three-loop electrical circuit problems.

After going through the validation and revision process, the teaching material design is ready to be used in learning activities. Revisions were made based on input provided by validators to improve the quality and effectiveness of teaching materials in supporting the teaching and learning process. Some improvements in the teaching material design are shown in Figure 4.2 below.



Untuk memperoleh nilai total hambatan pada rangkaian seri perlu menjumlahkan nilai resistansi di setiap komponennya. Persamaan untuk mencari nilai hambatan total dapat dituliskan pada persamaan 2.3 berikut.

$$R = R_1 + R_2 + R_3 \dots + R_n \quad 2.3$$

B. Rangkaian Paralel

Rangkaian paralel adalah konfigurasi dalam sirkuit listrik dua atau lebih komponen dihubungkan pada dua terminal yang sama. Dalam rangkaian paralel semua komponen memiliki beda potensial yang sama di setiap ujungnya, tetapi arus listrik yang mengalir melalui masing-masing komponen bisa berbeda. Gambar rangkaian paralel dapat dilihat pada Gambar 2.2 berikut.

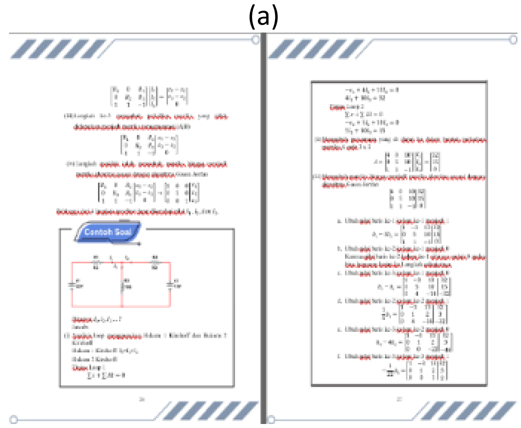
Gambar 2.2 Rangkaian Paralel

Nilai resistansi total dapat dihitung menggunakan persamaan 2.4 berikut.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad 2.4$$

7

(a)



(b)

Figure 4.2 (a) Addition of electrical circuit images (b) Addition of sample problems on the application of the Gauss-Jordan elimination method in solving electrical circuit problems.

The design of teaching materials that have been made is also validated by user validators, namely public high school physics teachers in one of the Jember districts. The validation process was carried out by assessing the validation instrument that had been prepared by the researcher. The assessment results from three user validators were then averaged and analysed to determine the final validation score. The final score is used to assess the validity level of the teaching material design that has been developed. The validity of teaching materials is measured based on predetermined criteria, with details of the results of the user validator assessment presented in Table 4.2 below.

Table 4.2 Results of validation of teaching material design by user validators

No.	Aspect	Score			Average	Persentation	Criteria
		V1	V2	V3			
1.	Content	4,1	4,4	4,5	4,3	86%	Very Valid
2.	Presentation	4,5	4,1	4,4	4,3	86%	Very Valid
3.	Language	4,7	4,1	4,4	4,4	88%	Very Valid
4.	Graphics	4,7	4,1	4,5	4,43	88,6%	Very Valid
Average		4,5	4,17	4,37	4,34	86,8%	Very Valid

The data in Table 4.2 shows that the assessment results from three user validators resulted in an average score of 4.34 with a validity percentage of 86.8%. These results indicate that the design of physics teaching materials is in the very valid category. Teaching materials can be applied in learning after improvements are made based on input from validators. Some of the suggestions given include improving the quality of the images to make them clearer and adjusting the cover design to be more in line with the material presented in the teaching materials.

The results of the validation analysis by expert validators showed that the design of teaching materials obtained an average score of 90.6%, which was categorised as very valid. In the aspect of content feasibility, with nine statements assessed, an average score of 4.6 and a percentage of 92% were obtained, indicating that the discussion and mathematical procedures in teaching materials were in accordance with the indicators of learning objectives. These results are in line with research conducted by Irawan et al. (2020) which states that the results of validation of teaching materials in the aspect of content feasibility reach 3.5 of the maximum score of 4 which is also included in the very feasible category. In addition, there is also research conducted by Prayoga et al. (2025) which states that the results of validation of teaching materials on content correctness get the maximum percentage of 100%. This shows that the suitability of the material to the competency standards and the accuracy of the material are important factors in assessing the feasibility of the content of teaching materials.

The results of the validation of the design of teaching materials in the aspect of graphics by expert validators in this study showed an average score of 4.35 with a percentage of 87% on 10 indicators that discussed layout, readability, and consistency of design and writing, all of which were in the valid category. This is in line with the research of Bahari et al. (2023) confirmed that graphic aspects, layout, and illustrations have an important role in increasing the effectiveness of teaching materials, where they found that teaching materials with simpler but attractive designs tend to be more easily understood by students.

4. CONCLUSION

Based on the results of the study, it is concluded that the validity of the design of physics teaching materials on the subject of two and three loop electrical circuits with the application of the Gauss-Jordan Elimination method is included in the very valid criteria with expert validation results of 90.6%, and user validation of 86.8%. Thus, the design of physics teaching materials for the application of the Gauss-Jordan Elimination method in solving two- and three-loop electrical circuits can be used as teaching materials in physics learning.

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