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Students' Procedural Errors in Solving Differential Equation Problems Based on Newman Error Analysis

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Abstract

Students' ability to solve problems in Differential Equations (DE) keep miscalculate, especially in homogeneous DE, exact DE, and integration factors, thus requiring an in-depth analysis of these errors. This study aims to identify the types of errors made by students in solving problems in DE based on Newman Error Analysis (NEA) theory. This research used qualitative approach with a case study design as a method. The subjects of this research was nine students who took the DE course. The research instrument was taking from students' midterm exam answer sheet for two selected descriptive questions. The result shared three types of errors made by students: transformation errors, process skill errors, and encoding errors. Those indicates students were lacking in process skills, which include algebraic operations, algebraic manipulation, and integration techniques in solving PD problems. Based on the result, this study implies the importance of strengthening prerequisite calculus learning and using NEA-based diagnostic strategies as the next improvement effort. Furthermore, the research suggested specific DE diagnostic instruments development and integrated warning examples into learning to address procedural errors while training students to think critically.

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INTRODUCTION

Differential Equations (DE) is one of the courses that students must take, especially students majoring in mathematics education. DE is a core content in the mathematics education curriculum (Zill, 2024). DE provides a strong foundation for students in solving various problems in other subjects and also serves as a basis for understanding various advanced concepts in applied mathematics. In addition, DE also plays an important role for students in developing critical thinking skills (Syaputra et al., 2024). For prospective mathematics teachers, mastery of DE is not only essential for problem solving, but also for building a deep understanding that they will teach in the future (Aisha et al., 2017). However, despite its importance, DE has complex and multi-layered procedural characteristics, so that resolving a DE involves a series of interdependent algorithmic steps, such as identifying the type of DE, selecting methods, integration techniques, and synthesizing the final answer (Habibi & Yusuf, 2020). This procedural complexity makes DE highly prone to layered errors, which are errors in the early stages that can continue and exacerbate errors in subsequent steps. Therefore, it is important for students to master the DE course well. The importance of mastering this course makes understanding its concepts and solution procedures a competency that cannot be ignored.

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Despite its central role, DE course are often considered challenging for students (Habibi & Yusuf, 2020). This challenge arises not only because students do not understand the instructions in the questions, but more because of the difficulty in carrying out the solution procedure in a logical, accurate, and precise manner. In addition, Ariawan et al. (2025) state that the course present difficult material and require a good command of prerequisite material. When these prerequisites are not firmly established, students often struggle to follow the logical flow of solving DE, from identifying the type of equation, choosing the right method, to carefully executing a series of calculus steps and algebraic manipulations (Sari & Oktaviana, 2021). Thus, the error lies in the application of conceptual knowledge to procedural actions. It is this procedural challenge that then gives rise to various systematic errors when students work on DE questions, as also found in the study Simanjuntak et al. (2024). Due to this procedural complexity, error analysis becomes a crucial step in diagnosing specific points of error. The following are concrete examples of such errors.

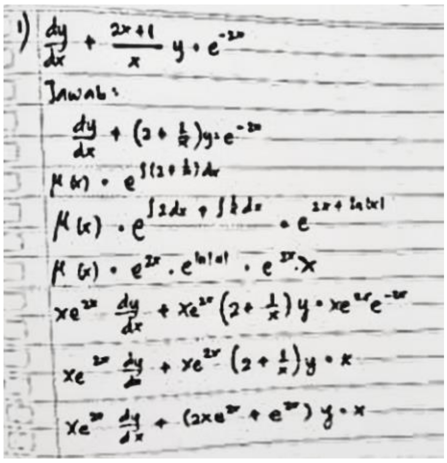

Figure 1. Student answer in determining integration factors

Base on Figure 1 above, students made errors in rearranging differential equations, even though they determined the integration factors correctly, he made errors in the next two critical stages. First, a procedural error (transformation error) occurred when rearranging the form of the differential equation after multiplying it by the integration factor. Second, an algebraic manipulation error (process skill error) occurred in simplifying the mathematical expression in the next step. In line with Mardiani (2018), errors in technical and operational steps such as these often result in the entire solution being incorrect. This example illustrates how a solution can be wrong not because of a lack of understanding of the big picture, but because of weaknesses in the execution of sequential procedures.

To prevent students from repeating their errors, it is necessary to conduct an in-depth analysis of the types of errors made. According to Farhan and Zulkarnain (2019), error analysis is a process of examining, identifying, and categorizing errors based on predetermined criteria or rules. This analysis is very important in learning differential equations because the solution is systematic and procedural. In the steps of solving DE, an error that occurs in a particular step can invalidate the entire solution (Tall, 2013). Therefore, error analysis can be used as a vital diagnostic tool to identify critical points where students' understanding or skills begin to fail. Through error analysis in solving mathematical problems, especially in DE, lecturers can reassess the effectiveness of the

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learning process that has taken place and make the necessary improvements (Alfisyahra et al., 2022).

Student performance in solving mathematical problems, especially in DE, needs to be analyzed so that student errors can be identified. One of the tools that can be used is Newman Error Analysis (NEA) (Utami, 2016). White (2010) explains that NEA is a simple diagnostics framework that includes five stages, there are (1) reading or decoding, (2) comprehension, (3) transformation, (4) process skills, and (5) encoding. The suitability of NEA lies in the alignment between the procedural and sequential characteristics of DE completion and the structure of the stages in NEA. DE completion involves a logical sequence, namely reading and interpreting the question, understanding the concept being asked in the question, transforming it into a mathematical model, applying certain procedures (such as integration or algebraic manipulation), and writing the answer. Therefore, this method is designed to help identify categories of errors that arise, especially in essay test answers.

NEA is a tool used to thoroughly examine various types of errors made by learners when working on math problems or questions, including the reasons behind these errors (Kania et al., 2024). In addition, NEA also serves as a diagnostic method that helps reveal the fundamental errors in students' answers when they solve mathematical problems (Syawali & Mulyawati, 2024). Thus, NEA was chosen to thoroughly diagnose the location and source of students' errors in solving differential equation problems.

Based on the above description, authors need to analyze students' errors in solving differential equation problems, such as homogeneous differential equations, exact differential equations, and finding integration factors in determining the solution of a differential equation. More than just identifying types of errors, the objectives of this study are to: (1) map dominant error patterns based on the NEA framework; (2) analyze the causes of these errors; and (3) formulate implications of the findings for improvements in differential equation learning. Thus, this study is expected to provide an in-depth analytical contribution to the diagnosis of learning difficulties and the development of pedagogy in differential equation learning.

METHODS

This study follows research conducted by Elsa and Suhendra (2022), using the case study method with a qualitative approach. The focus of this study is to identify and analyze students' errors in solving problems on the topics of Homogeneous DE, Exact DE, and integration factors. The analysis was conducted using the Newman Error Analysis (NEA) framework to obtain an in-depth explanation of the types of errors and their sources. The subjects in this study were nine students in the Mathematics Education Study Program in their seventh semester who were enrolled in the Differential Equations course at a private university in Bandung City, West Java Province. Therefore, it is important to emphasize that the findings and analysis in this study are contextual and interpretive. The results of the study primarily reflect the learning dynamics and error patterns in the specific population and topics studied. Thus, generalizing these findings to a broader context requires caution and further study.

The instruments used in this study were the researcher himself as the main instrument and the students' midterm exam answer sheets as supporting instruments. Two procedure-based questions were selected for in-depth analysis: Question 1 (homogeneous differential equations) and Question 2 (exact DE and integration factors). The procedural nature of both questions requires sequential steps, from identification to execution, thereby aligning with the NEA framework. Specifically, such problems tend to reveal errors that are dominant in the transformation stage and process skills stage, thereby directly affecting the distribution of errors across all NEA categories. The following are the two exam questions given to students, as presented in Figure 2 and Figure 3 (questions are presented in Indonesian).

Soal 1
Apakah PD $(y^2 - x^2)dx + xy\,dy = 0$ merupakan PD homogen? Jika YA, carilah solusi dari PD tersebut!

Figure 2. Question 1 about homogeneous differential equations

Soal 2
Tentukan solusi dari PD $y(x + y + 1)dx + x(x + 3y + 2)dy = 0$ dengan menggunakan faktor integrasi!

Figure 3. Question 2 about exact DE and integration factors

The steps in this study included (1) examining the midterm exam results for the Differential Equations course; (2) classifying students' answers based on NEA; and (3) documenting students' work. The following are the types of errors and brief explanations used to classify errors made by students.

Tabel 1. Tipe Kesalahan Berdasarkan NEA

No.	Error Type	Explanation
1.	Reading	Students are unable to interpret the purpose of the problem, do not understand the symbols or terms in the problem.
2.	Comprehension	Students do not understand the instructions in the problem.
3.	Transformation	Students are unable to make assumption, determine the formula or strategy needed in the solution stage.
4.	Process Skill	Students are unable to carry out the solution stage in the steps that must be taken, such as integration techniques, performing algebraic operations, or algebraic manipulation.
5.	Encoding	Students are unable to write answers based on the instructions in the question or students are unable to write complete answers.

RESULT AND DISCUSSIONS

After examining the students' answers, one of the nine students made no errors, while the other eight students made errors in completing the questions. For more details, the grouping of students' answers is presented in Table 2 below:

Tabel 2. Categorization of Student Answers

Partisipant	The First Question	The Second Question
S1	Encoding error	Correct
S2	Process skill error	Correct
S3	Correct	Correct
S4	Transformation error	Process skill error

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S5	Transformation error	Correct
S6	Process skill error	Process skill error
S7	Process skill error	Process skill error
S8	Process skill error	Process skill error
S9	Process skill error	Process skill error

Based on Table 2, for question number 1, more than 50% of students made process skill errors. Meanwhile, only 2 out of 9 students made transformation errors. For question number 2, 4 out of 9 students answered the question correctly, although many students still made process skill errors. In addition, 4 out of 9 students still made process skill errors for both questions. This indicates that students consistently made process skill errors on both questions, reinforcing the assumption of a systemic weakness in their mastery of prerequisite skills. This pattern shows that the difficulty was cross-cutting and not caused by the conceptual complexity of a particular question. Based on an analysis of the eight students who answered incorrectly, the following frequency of errors was obtained:

Tabel 3. Recapitulation of Student Errors Based on NEA

No.	Error Type	Question		Total	Percentage
		1	2		
1	Reading	0	0	0	0%
2	Comprehension	0	0	0	0%
3	Transformation	2	0	2	15%
4	Process Skill	5	5	10	77%
5	Encoding	1	0	1	8%
	Total Errors	8	5	13	100%

Based on Table 2, in questions 1 and 2, there were 13 errors made by students. The three most common errors made by students were, in order, process skill errors, transformation errors, and encoding errors. A very striking pattern is the absolute dominance of process skill errors, which account for 10 of the 13 errors. Meanwhile, transformation errors only appear in Question 1 (2 errors), and Encoding errors only appear once. No reading or comprehension errors were detected. The following are some examples of errors made by students in solving problems about homogeneous differential equations, exact differential equations, and integration factors.

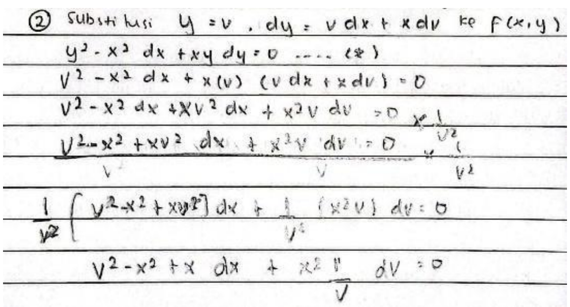

Figure 4. Transformation error made by S5 in question 1

Based on Figure 4, it appears that the student's answer contains a transformation error because the substituted function is incorrect. In the homogeneous ED solution stage, the substituted function is $y = vx$, which yields $dy = v\,dx + x\,dv$ to the original

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equation. Due to the error made by the student, the series of solutions to the problem to obtain the solution is incorrect.

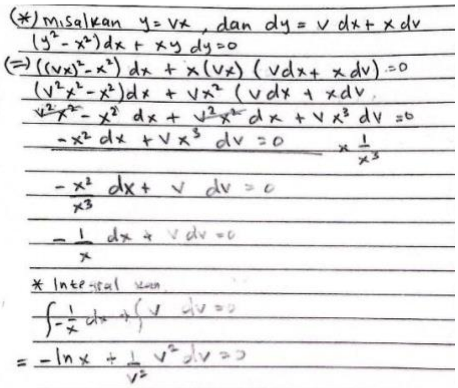
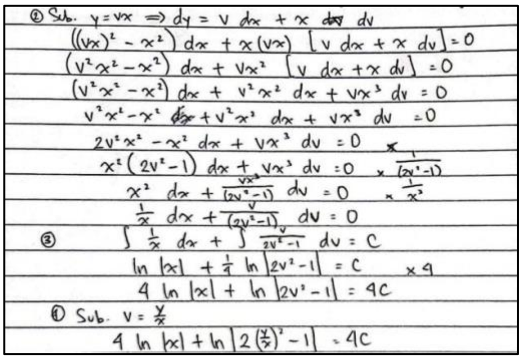


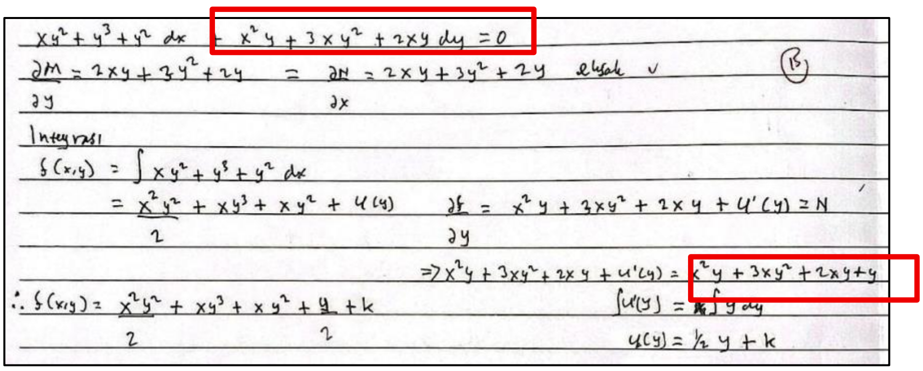
Figure 5. Process skill error made by S2 in question 1

Based on Figure 5 above, the student made a procedural error. This can be seen from the student's incorrect answer in performing the algebraic operation, namely when operating $v^2x^2 + v^2x^2$, the result should be $2v^2x^2$, not 0. Thus, the sequence of steps in determining the solution to the differential equation given in the question is incorrect.



Picture 6. Encoding error made by S1 in question 1

Based on Picture 6, the student's answer includes into the category of encoding error. Although the final result obtained in finding the solution to the given DE is correct, the student did not write down how he obtained the calculation result from $\int \frac{v}{2v^2-1} dv$. The result of the integral should use the algebraic substitution integral technique, where the student uses the substitution $u = f(x)$ to obtain $u' = f'(x)$.



Picture 7. Process skill made by S9 in question 2

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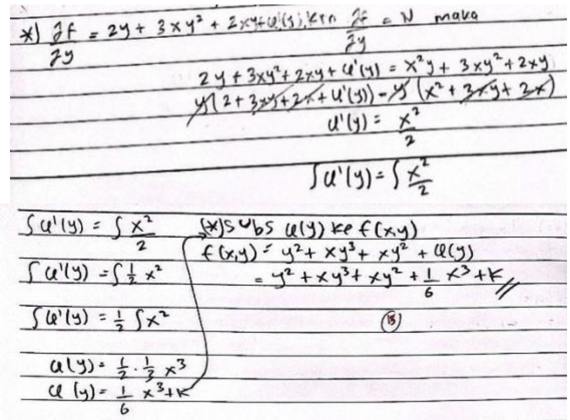
Base on Picture 7, the student made an error in the process of completing the given DE, namely when determining the function $\varphi(y)$ obtained from $\frac{\partial f}{\partial y} = N(x, y)$, the student incorrectly substituted the function $N(x, y)$ so that the function $\varphi(y)$ obtained was not correct. Therefore, the student's answer includes into the category of process skill errors.



Picture 8 Process skill made by S7 in question 2

Similar to the type of error described earlier, Picture 8 shows that the student made a error in performing algebraic operations when determining the function $\varphi(y)$, resulting in an incorrect solution. Thus, the student's answer falls into the category of process skill errors. However, the error is not apparent in all steps of the solution.

Based on the results described above, most students experienced errors in the process skills in the NEA, with a percentage of 77%. These errors appear in integration, function or algebraic operations, and mathematical manipulation after substitution. This is in line with the results of research by Simanjuntak et al. (2024), which shows that the most common type of error made by students is process skill errors. Although the topics of the DE materials studied were different, the errors made by students were predominantly of the same type, namely process skill errors. In addition, this is also in line with research conducted by Alfisyahra et al. (2022), which found that the types of errors often made by students in solving differential equations based on NEA include errors in process skills. This shows that, in general, students are still weak in carrying out the correct completion procedures.

In addition, errors in the transformation stage were also one of the prominent findings. These errors occurred when students did not correctly determine the method to be used, or made incorrect initial substitutions, which were key to solving homogeneous DE and exact DE. Transformation errors such as these reflect students' weak conceptual understanding of the characteristics of each type of differential equation. This is in line with research conducted by Kania et al. (2024), which shows that many students are weak in transformations to solve problems into mathematical models. In other words, students are not yet fully able to identify the specific properties of a DE and choose the appropriate solution strategy.

Another finding was encoding error, although the percentage was smaller. These errors occurred when students did not write down important steps in the solution, such as the integration process using substitution. This is not only related to neatness, but also shows that some students do not realize the importance of writing down the process as proof of understanding (Putri & Jupri, 2021). If the process is not written down, it is

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difficult for lecturers to assess whether students really understand the procedure or are just copying patterns without understanding the basics.

Overall, the results of the study indicate that the main problem lies in the process skills stage, particularly in using integration and function manipulation techniques and algebra. Weaknesses in basic concepts are one of the main factors that impact all stages of NEA, especially process and transformation skills. These findings also illustrate that mastery of theory alone is not sufficient; students need structured practice that emphasizes conceptual understanding as well as procedural accuracy.

CONCLUSION

Based on the previous discussion, it can be concluded that there are some students who make errors in solving differential equations, particularly in the material on homogeneous DE, exact DE, and integration factors. According to the Newman Error Analysis (NEA) framework, the most common errors are process skill errors, where students are not proficient in using integration techniques. This is because students have not fully mastered the prerequisite material, especially integral calculus. In addition, at the DE completion stage, students still make algebraic errors due to carelessness. Thus, these errors are procedural-conceptual in nature and are closely related to a weak grasp of the prerequisite material.

There are several suggestions that can be used for further research related to student error analysis, including: (1) developing and validating NEA-based diagnostic instruments specific to the topic of differential equations to help educators diagnose errors more efficiently; (2) implementing diagnostic tests at the beginning of the lecture to identify students' weaknesses in prerequisite skills, such as integration techniques and algebraic manipulation; (3) providing warning examples or examples of errors that may occur in learning, as well as inviting students to discuss the root causes of these errors, so that they can overcome procedural errors and train their critical thinking skills; and (4) provide drilling questions to students gradually based on their level of difficulty, especially to overcome the dominance of process skill errors, through strengthening integration, algebra, and procedural scaffolding in DE learning.

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