

Exploring Learning Gaps And Support Needs In Differentiation And Integration Topic

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Article History : Received 081005; Revised 051105; Accepted 191105;

ABSTRACT – The purpose of this research was to explore any learning difficulties faced by students enrolled in Differentiation and Integration under the course DBM20173 of Engineering Mathematics 2. The aim was to pinpoint possible reasons that affected students' comprehension and utilization of concepts of calculus, especially for questions related to interpretation, selection of methods, visualization, and problem-solving. This was accomplished using a combination of methods, namely, pre-test results, error identification, survey from students, interview or focus group discussion and observation by lecturer. The results revealed that students experienced difficulty only with the unfamiliar and application-based questions rather than direct procedural ones. According to the pre-test results, volume of bounded regions represented the highest number of difficulties among the participants with 25 out of 30 participants (83.3%), while trigonometric, exponential and reciprocal integration involved 24 students (80.0%) and area under a curve involved 23 students (76.7%). As many as 248 errors occurred during the process; formula error was found to be the most common type of errors occurring in 58 cases (23.4%), while visualisation error occurred in 43 cases (17.3%), followed by method-selection error with 42 occurrences (16.9%). The questionnaire results revealed that the level of readiness to engage in digital and immersive learning assistance was very high, as the mean score equaled 4.39, while need for visualisation and application-based assistance was also very high (mean score 4.34).

KEYWORDS : *Differentiation and Integration; Engineering Mathematics; Learning Difficulties; Error Analysis; Self-Learning, Instructional*

1.0 INTRODUCTION

Engineering Mathematics 2 covers core calculus topics that are relevant to engineering problems [1]. It begins with basic rules for indices and logarithms before moving into differentiation and integration. The goal seems to be building skills for real problem solving but not everyone picks it up smoothly from lectures alone [2]. Differentiation includes standard rules along with parametric and implicit methods plus second-order derivatives for trig log and exponential functions. Applications like rate of change or maximum and minimum problems come up too. Integration deals with algebraic, trig, exponential and reciprocal types and then uses them for areas and volumes. That part often needs good visualization of regions which adds another layer.

Students usually manage the worked examples in tutorials yet many lose confidence when a question asks for choosing the right approach or interpreting something unfamiliar. Graphs and bounded areas especially cause issues because it is hard to see what the problem wants without extra practice [3]. Some people handle routine calculations fine but then struggle when things shift slightly [4]. The needs analysis was carried out in order to identify the challenges that students face while studying Differentiation and Integration, especially regarding understanding the concept, choosing a proper method to solve problems, visualization, problem-solving confidence and independent learning. The results indicate that the learning support needed by students should be closer to how they learn in the contemporary digital world [5]. This means that the suggested way forward is to create learner-centred learning materials aimed at self-directed study which will have to be visual, interactive, accessible and convenient for review. Examples of these could include video tutorials, interactive notes, visual explanations, problem-solving exercises, self-assessments and chatbot-led hints. Using such resources, learners will be able to review

challenging concepts, practice on their own, get help when necessary and gradually gain confidence in using Differentiation and Integration in new contexts [5].

2.0 METHODOLOGY

In order to conduct the needs analysis studies, a mixed-methods research design was adopted to enable the researcher to have a holistic view regarding the learning needs of the students in Differentiation and Integration [6]. Quantitative and qualitative data were collected to make sure that there is no exclusive focus on only the performance of the students in tests as a way of conducting the analysis. The collection of quantitative data involved the administration of a pre-test and the Student Needs Analysis Questionnaire. Pre-test helped in assessing the level of knowledge of the students in the topic whereas the needs analysis questionnaire captured students' perceived problems, understanding, visualization problems, engagement in learning activities and willingness to be engaged in the use of the technology-enhanced learning process.

The questionnaire had a total of 25 items and each was ranked using the five-point Likert scale (1= Strongly Disagree to 5 = Strongly Agree) [7]. On the other hand, the quantitative data collected were subjected to descriptive analysis. Questionnaire responses were tallied to calculate the frequency, percentage and mean score per item [8]. Frequency and percentage reflected the response distribution across the five categories. The questionnaire items were categorized into the following constructs: Learning difficulty, Conceptual understanding, Visualization and Application, Engagement and Motivation, and Readiness for digital and immersive learning support. The average scores for each construct were computed to determine the major areas of students' learning needs. These scores were further analyzed using predetermined levels, from very low to very high.

The qualitative data were collected through students' error analysis, interviews or focus group discussion, the lecturer's observation and previous assessment performance. Error analysis involved checking the students' written solution in the pre-test for common errors in concepts, formulae, procedures, algebra, applications and visualization. On the other hand, qualitative content analysis entailed looking for themes that recur during the interviews of students and lecturer observation regarding students' learning difficulties, confidence, engagement and learning support [9], [10]. It was possible to triangulate the findings using both quantitative and qualitative approaches [6]. It means that the identified learning problems from the pre-test and questionnaire results could be validated based on the students' errors, class observations and feedback from them. As a consequence, the needs analysis would serve as a stronger foundation for devising an instructional strategy that will assist immersive student learning of the topic.

In order to give an overview of the methodologies involved, the methods used for conducting the needs analysis can be classified according to the purpose served and the analysis output generated. It becomes possible to highlight how each method was instrumental in identifying the learning problems, perceptions, behaviors and needs of the students. These are summarized in Table 1.

Table 2.1. Data Collection Methods and Analysis Outputs.

Method	Purpose	Analysis/Output
Pre-test	To assess students' prior knowledge before enhancing instruction.	Baseline and hard questions
Error analysis	To analyze the students' errors found in their work.	Error patterns and explanation for the learning gap
Questionnaire	To assess students' difficulties in learning, their attitudes and readiness.	Frequency, percentage, mean score, and construct mean
Focus group	To get more feedback about the learning process from students.	Themes and student voice

Lecturer observation	To observe the behavior of students during the lectures and tutorials.	Observation themes and instructional issues
Previous assessments	To substantiate results using academic performance evidence.	Trend and consistency of the problem area

To show how the needs analysis was conducted, the data collection and analysis process was summarized in a process flow. This flow in Figure 2.1 illustrates how each source of information contributed to identifying students' learning difficulties and instructional support needs.

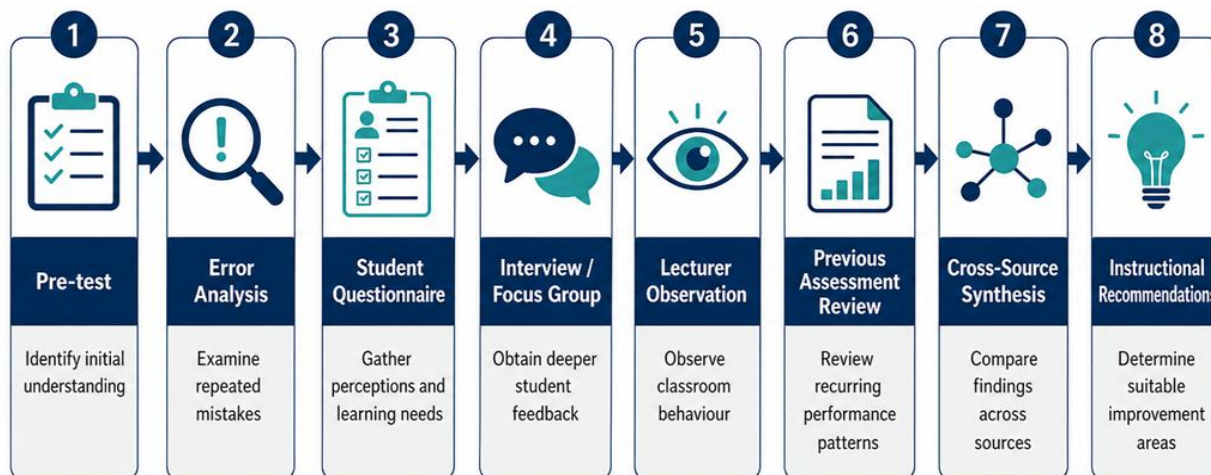


Figure 2.1. Need Analysis Process Flow.

The research methods were done in a step-by-step manner to enhance understanding of the students' needs. The first step involved conducting a pre-test to determine students' initial level of comprehension and identify the areas of challenging questions. The second method was error analysis where an examination of students' written responses identified their common errors in answering the questions. Following this, a questionnaire was administered to gather students' opinions concerning their learning challenges and ability for self-study. Thereafter, the focus group discussion method was employed to gain more insights into the students' learning experiences. These findings were analyzed collectively to determine learning problems and the type of self-learning aids required.

2.1 Pre-Test Method

A pre-test was administered in order to determine the level of knowledge of Differentiation and Integration amongst students before the introduction of the support mechanism [11]. In other words, the pre-test would enable to identify the existing knowledge amongst the learners, what type of questions they can answer and what extra help they need. The questions administered in the pre-test covered all the sub-topics involved in Differentiation and Integration. They were arranged from questions that require basic procedural work to those that involved the application and visualization of the concept. Topics covered include basic differentiation, applications of differentiation, basic integration, integration of trigonometry, exponential and reciprocals, area under curve and volume of bounded regions.

Questions involved finding of values including derivatives, integrals, velocity, minimum or maximum values, area under the curve and volume of bounded regions. Questions also required setting up the correct formulas, choosing the correct method and determining the limits of integration. This is important since the needs analysis would not only identify if students can calculate, but also if they understand what is required of them and the correct method and concept [12]. The responses from the students were analyzed by topic. The total number of students who found themselves having difficulties in answering questions on any topic was counted as students

who needed assistance. The percentage of students who needed assistance was then computed using the formula:

There were two primary outcomes from this type of analysis. First, it determined the initial understanding level of students regarding Differentiation and Integration. Second, it pointed out the hard question topics, which are the topics with high percentages of students needing assistance. Such results were then used in selecting the topic areas to include in the suggested self-learning materials.

2.2 Error Analysis Method

Error analysis was done after the pre-test to look into the solutions of the students further. Error analysis is done to determine the nature of errors that students make and the possible reasons why they had problems in Differentiation and Integration [13]. Error analysis does not only concern itself with whether the answer provided by the students was right or wrong, but also the way they chose formulas, arranged the process of solutions, understood the problem, manipulated symbols and related diagrams or information to the solution [14]. The error analysis involved 30 students who were assessed using 12 pre-test questions. The test questions included topics like basic differentiation, applications of differentiation, basic integration, trigonometry integration, exponential and reciprocal integration, area under a curve, bounded regions, and volume of bounded regions. The test questions asked the students to find derivatives, velocity, maximum/minimum value, indefinite integrals, area under a curve, area between curves, and volume of a bounded region. Some test questions required students to formulate the right formula, use suitable limits and apply the correct approach before finding the answer.

The answers of the students were examined based on a question-by-question analysis. Each mistake and lack of answer in the students' answers was categorized according to the nature of the mistake. The mistakes were categorized into seven different types of errors. They are conceptual error, formula error, procedural error, algebraic error, application error, visualization error and method selection error [13], [15]. For instance, using an improper formula in integration would be classified as a formula error. Not being able to relate a graph or a region to its corresponding integral would fall under the visualization error category. Being confused regarding the method to apply after changing the form of the question is called method selection error.

In order to analyze the data obtained from the students' answers, each type of mistake was counted based on frequency. The questions that caused the most problems were determined accordingly. This aided in determining whether the errors made by the students are due to a lack of knowledge in the concepts, confusion in using formulas, improper sequence of steps, poor algebraic skills, difficulties in interpreting application problems, or problems in visualizing the math relationship. The results that came out from this process include the major categories of errors, the frequency of the errors, the topics associated with the errors and the possible reasons behind the gaps in the students' learning. These data were used in determining the appropriate self-learning aid that should be provided [14].

2.3 Student Questionnaire Method

The student questionnaire was employed to capture the students' perceptions of their learning experience of Differentiation and Integration. The goal of employing the student questionnaire was to determine students' difficulties in learning, learning confidence, preferences for learning tools and willingness to access self-learning materials. The questionnaire instrument was designed using a five-point Likert Scale, such that 1=Strongly Disagree, 2=Disagree, 3=Not Sure, 4=Agree and 5=Strongly Agree [7]. Overall 30 students completed the questionnaire. The questions were divided according to five major construct concepts of learning difficulty, conceptual understanding, visualization and applications, engagement and motivation and readiness for digital and self-learning support. Some of the questions in the student questionnaire referred to some general areas of learning Differentiation and Integration. This included difficulty in

comprehending mathematical formulae, difficulty in applying proper methods, application-based problem solving, area under a curve visualizing, bounded regions and volume-related issues. Other questions included preference for example-oriented learning, visual learning, video-based learning and interactive learning among others.

The analysis of results involved frequency, percentage, and mean scores. Frequencies and percentages showed the extent to which students selected scales. The mean score indicated the average students' level of agreement regarding each item and construct. Mean scores were arrived at through the multiplication of each Likert Scale option by the total number of students who selected each option and dividing the total by the number of participants [16]. To obtain the mean score of each item, the product of the Likert scale and the number of students who chose that particular scale was determined and divided by the total number of respondents. This can be mathematically represented as follows (1):

$$\text{Mean Score} = \frac{(1 \times f_1) + (2 \times f_2) + (3 \times f_3) + (4 \times f_4) + (5 \times f_5)}{30} \quad (1)$$

where f_1 , f_2 , f_3 , f_4 and f_5 are the number of students who selected scales 1, 2, 3, 4 and 5 respectively.

Interpretation of the resulting means was carried out using a predetermined scale of Very Low to Very High. It made it possible to establish constructs that exhibited high learning needs. Among the outputs of such an approach would be the perceived level of difficulty by students, their confidence in comprehending the subject matter, need for visual/audio/video teaching aids, and willingness to engage in self-help activities [16], [17].

2.4 Student Interview / Focus Group Method

The interview/focus group of students was carried out in order to get more information about students' learning experience in Differentiation and Integration. The interview/focus group was chosen as a means of reinforcing results gathered via questionnaires, allowing students to discuss problems and their learning needs in their own words [18]. A focus group was held after the pre-test and student questionnaire in order to discuss issues identified on the basis of students' results and answers to questions asked in the questionnaire. A small number of students were selected to participate in the discussion, representing different learning levels and ranging from top performers in the pre-test to poor performers [18], [19].

At least 6 to 8 participants are involved in a focus group in order to gather diverse opinions while the number is not too big to prevent participants from being shy. Individual interviews require an even smaller sample size; at least 5 participants should be interviewed. Six semi-structured questions were asked in the interview/focus group. Open-ended questions were used so that the students can give detailed explanations about their answers [19]. The questions revolved around:

- the most challenging aspect of Differentiation and Integration;
- questions that were challenging to comprehend;
- reasons behind their challenges with some questions;
- sources that made it easier for them to learn;
- help required when they study individually; and
- if visual or interactive or any other form of learning materials can assist them.

Thematic analysis was used to analyze the data collected through these questions [20]. First, students' answers were read and grouped according to similarity. Then, recurring ideas were coded into thematic areas including method selection, visualization, step-by-step learning, independent learning and interactive learning. These thematic areas guided the identification of the form of self-learning support that should be provided to the students. The output generated through this approach includes recurring feedback patterns, voices of representative students and a qualitative explanation of the students' learning challenges.

2.5 Lecturer Observation Method

Observation of the lecturer was performed in the lecture and tutorial classes to obtain information on students' actual learning behavior while learning Differentiation and Integration [9]. The observation was performed in order to validate the results obtained from the pre-test, questionnaire and focus group through the examination of students' behavior in the classroom environment [20]. This was performed after exposing the students to the selected topics and during the practice of solving questions in the class and tutorial sessions. The entire class was observed, which comprised 30 students, in order to observe the general behaviors of the students while learning in the classroom environment.

A checklist for observing a lecturer was used in conducting the observation. The checklist included six major observation areas such as participation, independent attempt, repeated explanation, reasoning, visual aid and feedback. These observation areas were chosen due to their relationship with students' self-confidence and the capability of independent learning. The observation was based on questions such as:

- How do students behave during problem-solving exercises?
- Are students capable of attempting problems following demonstrations?
- What subtopics need repetition?
- Are students capable of explaining why a specific formula is used?
- Do students behave better when diagrams are shown?
- Do students require confirmation or feedback while attempting problems independently?

In the process of observation, students' behavior was documented through the lecturer's comments. The lecturer observed whether students were participating actively, waiting for complete explanations, seeking clarification, reacting to diagrams, discussing among themselves or becoming passive when faced with difficult problems. The observations provided information about whether students were capable of working independently or required assistance from the lecturer [20], [21]. Qualitative data obtained from lecturer observations were analyzed through the use of a simple thematic analysis [9]. Initially, observation notes were repeatedly reviewed to note recurring behavior. Next, recurring behaviors were categorized according to similarities. For instance, learners who waited until the lecturer had completed his/her demonstration before attempting the questions were categorized under low independent attempts, whereas those who kept asking whether their processes were right were categorized under need for feedback. Such categories were further analyzed into themes like passivity, lecturer dependency, poor reasoning, visual support and need for instant feedback.

The above themes from lecturer observations were then cross-referenced with pre-test results, questionnaire results, and focus group discussions. This process helped determine whether the behaviors noted in the classroom correlated with learner performance, errors, and learning difficulties. Output from this process was in the form of themes, behaviors and instructional strategies for supporting self-learning among learners.

2.6 Review of Previous Assessment Performance Method

A review of past assessment performance was carried out to find out whether the learning difficulties encountered during the needs analysis were one-off cases or common trends among the students [22]. This process was employed to validate the conclusions drawn from the pre-test, error analysis, questionnaire, focus group discussion and lecturer observations [24]. This review was conducted following the analyses of the pre-test and questionnaire data. The documents

reviewed were past quizzes or test scores, coursework exercises and notes by the lecturers regarding the performance of the students in Differentiation and Integration. The review concentrated mostly on the past assessments which tested the students on method selection, concept application, visualization, area under a curve, volume of bounded regions and multi-step problem solving. The main aim of this review was to find out whether there have been any common difficulties exhibited by the students in the past. For instance, this included finding out whether the students had consistently received low scores in application questions involving integration, committed many formula or algebraic mistakes or needed explanation in area and volume problems.

The data analysis used for this task involved simply analyzing the documents for any patterns [23]. To begin with, the assessment records were studied to determine the areas where students had difficulties. Thereafter, the identified patterns were categorized according to the type of difficulty faced by the students, such as poor performance in applying concepts, making mistakes with formulas and algebra and problems with topics based on visualization. In addition, the results of this needs analysis were compared with those from other sources such as the pre-test, error analysis, questionnaire, and lecturer observations [24], [6]. This helped to validate the results of the needs analysis as far as the identification of learning needs is concerned. The outcome of this method involved recurring patterns of poor performance and possible causes of these difficulties.

3.0 RESULTS AND FINDINGS

Conclusions drawn from the results of the needs analysis are explained in terms of evidence obtained throughout the investigation. These sources are pre-test, error analysis, student questionnaire, student interview or focus group, lecturer observation and evaluation of prior performance. All of them offered a different view of the learning needs of students in relation to the topics of Differentiation and Integration. Pre-test provided basic data about students' knowledge, while error analysis was useful in identifying specific errors made by students when solving tasks. The questionnaire revealed their opinions, preferences concerning learning style and their preparedness to use visual and digital learning resources. Lecturer observation and prior performance evaluation contributed valuable qualitative data on issues encountered by students during learning. Findings are analyzed separately for each type of evidence used. This makes it easier to organize the analysis process. At the same time, findings are considered together to see how they connect to each other and what conclusions can be made as a result of this consideration. Thus, the conclusion will help define the most appropriate instructional strategies taking into account real students' needs.

3.1 Pre-Test Method

A pre-test was carried out to find out how much students knew about Differentiation and Integration before the development of the self-learning aid proposed for the students. This pre-test was done on 30 students and it included several topics such as Basic Differentiation, Applications of Differentiation, Basic Integration, Trigonometric, Exponential and Reciprocal Integration, Area under a Curve, and Volume of Bounded Regions. Questions asked in the test included several levels of difficulty, including procedural, application and visualization questions. This analysis will concentrate on finding out the number and percentage of students who needed extra help in the various topics. Students were regarded as needing help when they had problems choosing the right method, working through their solutions completely, applying the wrong formulae, misunderstanding the questions, and having difficulties in formulating the right solutions. The percentage of students needing help was computed using the total number of students involved in the pre-test, using the formula (2):

$$\text{Percentage of Students Requiring Support} = \frac{\text{Number of Students Requiring Support}}{30} \times 100 \quad (2)$$

The results obtained from the pre-test indicated that students scored higher on direct procedural questions than on those involving application and visualization questions. The percentage of students who needed help was the least in basic differentiation, with 14 out of 30 students (46.7%) requiring extra help. This indicates that students were relatively more comfortable with differentiation questions that only required them to do simple procedures. However, the percentage was higher for subjects that required interpretation and choice of methods to solve the problem. Basic integration had 18 students (60.0%) needing extra help, whereas in the application of differentiation, 20 students (66.7%) required assistance. This shows that although some students could do simple calculations, many of them found it difficult to answer questions that required them to use different formats.

The most difficult topics were those that involved the integration of functions and visualization. There were 24 students (80.0%) who required guided learning support in the topics of trigonometric, exponential and reciprocal integration, indicating that students had problems in identifying function types and using the appropriate integration formulae. In the topic of area under a curve, there were 23 students (76.7%) who required guided learning support, while 25 students (83.3%) required guided learning support in the topic of volume of bounded regions, which is the most difficult among all other topic areas. These results indicated that students experienced more difficulty when they had to integrate the concepts of equation, graph, limits, shaded regions and three-dimensional representation. In general, 22 out of 30 students (73.3%) required guided learning support in the pre-test topics. It means that the primary problem encountered by students is not merely computation but involves conceptual understanding, method selection, visualization and application. In order to present the findings more comprehensively, the pre-test results were summarized based on the topic area in Table 3.1. Table 3.1 includes information on the topic area covered, pre-test question focus, students' performance and interpretation of students' performance.

Table 3.1. Pre-test Findings by Area Assessed.

Topic Area Examined	Pre-test Question Related to Topic Area	Performance	Interpretation of Performance
Basic differentiation	Direct differentiation of algebraic, trigonometric or exponential functions	Students demonstrated moderate comprehension.	Students were able to use their knowledge to solve problems directly if the problems were not complex.
Application of differentiation	Rate of change, maximum-minimum or contextual problem-solving	Students had poor performance in applying concepts to problem-solving.	Students could not understand the problem before applying a procedure.
Basic integration	Direct integration based on the rules of integrations	Students performed well in simple questions while struggling with more complex ones.	Students had conceptual knowledge but were unsure about solving questions in new formats.
Trigonometric, exponential and reciprocal integration	Integration of various function types	Students were hesitant and made mistakes while trying to integrate.	Students had trouble recognizing which function was used and selecting the best rule for solving the problem.
Area under a curve	Based on graphing, limits, and regions bounded	Students were having difficulties comprehending visual information.	Students were unable to link graphs to the equation that describes them.

Volume of a bounded region	Integration applied to find volumes of three-dimensional bounded areas	Students were struggling to understand three-dimensional objects from equations.	Students had difficulty visualizing the 3D shape and linking it to the correct volume formula and limits.
Overall performance	Combination of procedural, conceptual and application questions	Students required additional guided learning support.	Students need structured learning experiences that combine explanation, visualization, interaction, practice, and feedback.

As illustrated in Figure 3.1, the largest number of students needing help was observed in bounded regions (83.3%), followed by trigonometric, exponential and reciprocal integration (80.0%) and area under a curve (76.7%). These three topics have something in common in that they need visualization of mathematical concepts and selection of methods before proceeding with problem-solving. Conversely, the smallest number of students who needed assistance was observed in basic differentiation (46.7%), indicating that students felt more comfortable with straightforward computation questions. This suggests that the pre-test results show that students' challenges were conceptual in nature.

In summary, the difficulties faced by the students in Differentiation and Integration seem to be more apparent in questions that require application of knowledge, appropriate method choice and visualization. While some students managed to answer simple procedural questions well, the data indicates that many still needed help in solving questions involving different functions, area under a graph and volume of bounded regions. Students who needed the most help were found in volume of bounded regions, followed by trigonometric, exponential and reciprocal integration and area under a curve. This implies that students' weaknesses in differentiation and integration may not only involve calculations but also concepts, visualization and applying appropriate methods in different situations.

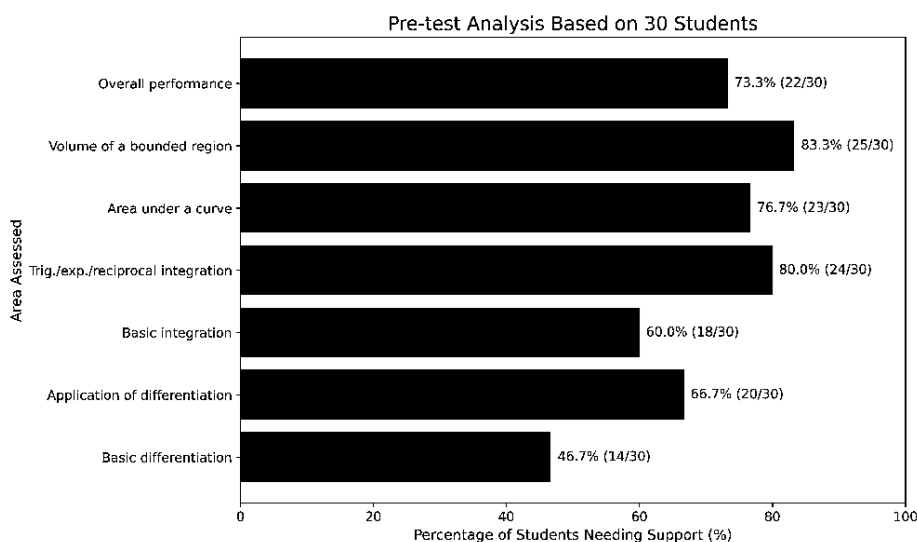


Figure 3.1. Pre-test Analysis Based on Students Requiring Additional Support

3.2 Error Analysis

Error analysis was performed through the examination of the written answers by 30 students in the pre-test. This error analysis was done in order to find out what kinds of mistakes were made by students in Differentiation and Integration and also the possible reasons why the

students were having difficulty in the subject. Not only were the final answers examined, but also the working steps, formula, methods, algebraic manipulation, understanding of questions and even diagrams were analyzed. The error analysis involved 12 pre-test questions on differentiation and integration. These questions covered basic differentiation, application of differentiation, basic integration, integration of trigonometric functions, exponential and reciprocal integration, area under a curve, bounded region and volume of a bounded region. In the pre-test, students had to calculate the derivative, velocity, maximum/minimum values, indefinite integral, area under a curve, area between curves and volume of bounded regions. There were also some questions that required students to set up formulas and determine suitable limits and methods before solving. Each student's written solution was analyzed on a question-by-question basis. Each error committed was categorized based on its type, including conceptual error, formula error, procedural error, algebraic error, application error, visualization error and method-selection error. The frequency of each error was then determined so that the common types of errors could be identified. In all, there were a total of 248 errors committed by the 30 students in the pre-test.

Formula error is the most frequent type of error, with a total of 58 instances or 23.4% of all errors committed. This implies that most students have problems in using the right formula or rule, particularly those questions pertaining to algebraic, trigonometric, exponential and reciprocal integration. The second most common type of error is visualization error, having a total of 43 errors or 17.3%. Method-selection error follows with 42 instances or 16.9% and both errors are related to area under the curve, bounded regions and volume questions. Errors related to the application were noted, where there were 30 instances (12.1%) of errors that revealed that the students had trouble translating context or word problems to mathematical statements. Procedural errors had 27 instances (10.9%), while conceptual errors had 25 instances (10.1%). The lowest number of errors was the algebraic errors, where there were 23 instances (9.3%) that revealed that some students had problems with expanding, factorizing, simplifying, or rearranging expressions before differentiation or integration techniques can be used.

It should be emphasized that the students' errors were not random in nature. Rather, the errors exhibited repetitive patterns in various types of questions. While students were able to recall certain formulas, many of them were not able to determine when, why and how to apply them. It can thus be seen that the students' knowledge about formulas was mostly procedural and needed more help in terms of concepts, methods, visualization and problem-solving steps. Table 3.2 shows the summary of the error types made by the students based on their pre-test answers, including the question focus, frequency of occurrence, cause, and interpretation of the errors.

Table 3.2. Error Analysis Based on Students' Pre-test Responses.

Error Type	Related Question Area	Frequency, n (%)	Consequence / Reason	Critical Conclusion
Conceptual error	Differentiation and integration concept	25 (10.1%)	Lack of conceptual understanding other than formulae.	Students saw integration only as a formula but did not understand the concept of area, accumulation or reverse differentiation.
Formula error	Algebraic, trigonometric, exponential and reciprocal integration	58 (23.4%)	Incorrect use of formula or rule.	Students used formulas based on similarities rather than understanding the type of functions.
Procedural error	Differentiation, integration and applied calculus	27 (10.9%)	Omission or inappropriate sequence of work.	Students need more guidance in solving multiple-step questions.
Algebraic error	Pre-calculus operations prior to differentiation or integration	23 (9.3%)	Errors in expansion, factorization,	The poor algebraic skills impacted students' performance in calculus.

			manipulation and simplification.	
Application error	Contextual and word problems	30 (12.1%)	Unable to translate word problems into mathematical language.	Students were unable to determine the given, required and related concepts.
Visualization error	Area under a curve, bounded region and volume determination	43 (17.3%)	Inability to visualize regions, curves, boundaries and 3D shapes.	Students had difficulty relating equations, graphs, shaded regions and integral formulae.
Method-selection error	Questions that require technique selection	42 (16.9%)	Indecision in selecting the correct technique due to a question format change.	Students depend on the question pattern and lack the application of knowledge.

On the whole, the analysis of errors indicates that the most common errors were associated with formula selection, visualization and method selection. This indicates the fact that the issues experienced by students were not only associated with calculation but also involved certain problems with understanding the concepts, identifying the type of functions, interpreting visual data and making proper choices.

3.3 Student Questionnaire

A student questionnaire was also done to gather students' perceptions about their learning process in Differentiation and Integration. While the pre-test and error analysis yielded information regarding students' academic performance and writing errors, the questionnaire provided insight regarding how the students perceived themselves in terms of their difficulties, self-confidence, motivation and learning support. The questionnaire was given to 30 students and was composed of 25 statements based on a five-point Likert scale wherein 1 = Strongly Disagree, 2 = Disagree, 3 = Not Sure, 4 = Agree and 5 = Strongly Agree. These items were divided into five constructs: learning difficulty, conceptual knowledge, visualization and application, engagement and motivation and readiness for digital and immersive learning support.

The results of the questionnaire were analysed through frequency, percentage and mean scores. Frequency and percentage were used to determine how many students chose each category in the Likert scale, while mean scores were used to determine the degree of agreement per item and construct. The mean scores were further interpreted based on the predetermined scale presented in Table 5.3 below.

Table 3.3. Mean Score Interpretation Scale and Construct Analysis of Student Questionnaire Findings.

Mean Score Range		Interpretation	
1.00 - 1.80		Very Low	
1.81 - 2.60		Low	
2.61 - 3.40		Moderate	
3.41 - 4.20		High	
4.21 - 5.00		Very High	
Construct	Mean	Interpretation	Instructional Implication
Learning difficulty	4.11	High	Provide guided examples and method-selection activities.

Conceptual understanding	2.86	Moderate	Strengthen concept-based explanation, reasoning and independent problem-solving support.
Visualization and application	4.34	Very High	Use visual, interactive and immersive materials such as AR and dynamic diagrams.
Engagement and motivation	4.25	Very High	Include active learning, peer discussion and guided practice.
Readiness for digital and immersive learning support	4.39	Very High	Use digital tools to support student learning while keeping face-to-face learning central.

From the results of the questionnaire analysis, it emerged that the highest construct means occurred in the construct of readiness for digital and immersive learning support. The mean score for this construct was 4.39 which was interpreted as Very High. It means that the students had a high level of openness to the use of digital and self-access learning resources like short videos, chatbot support, augmented reality and interactive learning materials. In addition, items like "I would use short videos to revise difficult topics" had a mean score of 4.57 while "Interactive learning materials can help me understand this topic better" had a mean score of 4.50. Secondly, the construct of visualization and application had a mean score of 4.34 which was also interpreted as Very High. It means that the students had a high level of learning needs regarding the visualization of mathematical concepts like area under the curve, bounded regions and volumes. One of the items that received the highest item mean for this construct was "I understand better when mathematical concepts are shown visually" whose mean score was 4.50. The mean value for the construct engagement and motivation was found to be 4.25, which falls under the category of Very High. This indicates that the students had a good time engaging themselves in active learning. For example, the construct "I feel motivated when the lesson includes interactive activities" has a mean value of 4.40, while the construct "I can learn better if I am actively engaged in the lesson" has a mean value of 4.37.

When it comes to the construct of learning difficulty, its mean value was found to be 4.11, which falls into the category of High. This clearly shows that there were difficulties faced by the students in learning Differentiation and Integration due to remembering the formula, choosing the correct approach to solve questions and doing application-based questions. The mean value of "I find it difficult to solve application-based questions" was 4.37, while that of "I have problems choosing the right approach for solving questions" was 4.30. Conceptual Understanding showed the lowest mean value at 2.86, meaning Moderate. Even though this mean value was lower than the rest, it shows that the students were uncertain about the explanation of concepts, linking formulas to practical problems and solving problems without having to rely so much on the lecturer's assistance. In the item "I can solve questions without depending too much on the lecturer's guidance," the mean value was 2.60, indicating that the students needed more assistance to be able to become independent learners.

From the results obtained from the questionnaire, it is clear that students require learning assistance that is visual, interactive, guided and easily accessible by them for self-revision. From the data obtained, students are willing to use digital learning materials as long as the materials will help them visualize concepts, revise challenging concepts, practice independently and evaluate themselves. Thus, the data collected proves that there is a need for self-learning materials to be developed for the current learning behavior of the students. Overall, based on the results obtained from the questionnaire analysis, it is clear that the highest needs were those of learning support, visualization, application and engagement in learning. These constructs had high mean scores, which clearly show that learners would like to be exposed to learning materials that are more visual and interactive. On the other hand, the moderate mean score of conceptual understanding indicates that learners still have difficulties in explaining concepts and solving questions. This further reinforces the need for the development of self-learning materials.

3.4 Student Interview / Focus Group

The student interview/focus group was carried out on 8 students after carrying out the pre-test and questionnaire in order to gain insight into the students' learning process within Differentiation and Integration. The students included those who exhibited high, moderate and weak performance in the pre-test. This would ensure that the findings captured all experiences. In total, there were six semi-structured questions asked during the interview/focus group. These questions involved areas such as the most challenging areas of the topic, the type of questions that were difficult for the students, reasons why the students found the topic difficult, preferred learning resources, help required in independent study and use of visualization, interaction or digital tools in the learning process.

Thematic analysis was used to analyze the responses given by the students. The answers were reviewed, coded and categorized into recurring themes. The recurring themes from the data analysis included independent learning, visualization, method choice, application and interpretation, concept learning, repeated explanation, sequential learning and visual learning. The recurring themes were independent learning and visualization, each having been mentioned by 4 students (8.3%). These themes imply that the learners required assistance while working independently and also had difficulties comprehending visually oriented content like the area under the curve, bounded regions and volumes. The students noted that they would need to know how to check answers, ask questions, get step-by-step notes and diagrams for revision purposes.

Another prominent theme was the choice of method, which was mentioned in 3 responses (6.3%). According to the learners, they did not know what type of formula or method to use when the question format changed. This implies that they relied on the examples they knew and thus needed more guidance to identify question types and appropriate methods. Some of the supporting themes include application and interpretation, conceptual understanding, repeated explanation, step-by-step learning and visual learning, each being mentioned by 2 students (4.2%). These themes indicate that the students needed learning resources that could help them comprehend ideas, provide step-by-step solutions and connect formulas to graphs, limits, regions and situations. There was also evident interest in the use of digital and self-learning aids among the students interviewed. Some of the students indicated that videos, interactive diagrams, guided examples and instant feedback could help them learn more effectively on their own. It means that the students would appreciate the use of contemporary self-learning materials provided that they offer clear guidance rather than just solutions.

To summarize, the findings from the interview/focus group shown in Table 5.4 reveal that the students required learning support that is guided, visual, interactive and accessible outside the classroom hours. The findings point towards the creation of self-learning materials that will allow students to select appropriate methods, visualize mathematical concepts, practice step by step and verify their understanding independently. In conclusion, the interview/focus group results prove that the students' problems did not concern memorizing formulas only. The students also experienced challenges in selecting methods, visualizing, gaining confidence and practicing independently. The recurring theme of step-by-step learning, visualization and digital guidance implies that the self-learning materials should offer sufficient guidance and feedback outside class.

Table 3.4. Student Interview / Focus Group Findings.

Focus of Interview	Related Question	Feedback from Students	Theme Frequency, n (%)	Pattern of Critical Interpretation	Classroom Instructional Implications
Method selection	Which is the hardest part and why?	Students found difficulty in determining the	3 (6.3%)	Students depend on familiarity with example cases to	Prepare students on the method

		correct method or formula to apply.		answer the problem.	selection guide and the differences in problem types.
Visualization	Which is the toughest problem?	Students struggle in envisioning areas, bounded regions and volumes.	4 (8.3%)	Students find difficulties in relating formulas to graphical representations and shapes.	AR, diagrams, animation and visuals should be incorporated in instruction.
Step-by-step learning	What learning materials will aid you?	Students require a step-by-step explanation of answers.	2 (4.2%)	Students require a structured learning process and repetitive engagement with ideas.	Take students through the processes through instructional videos.
Independent learning	How can we make you understand better?	Students need help to ask questions when studying alone.	4 (8.3%)	Students require immediate assistance outside the classroom environment.	Leverage chatbots to facilitate the student learning process.
Interactivity	What makes you understand better?	Students prefer visual and interactive means of learning.	2 (4.2%)	Students find learning easy when they can see and relate to the subject matter.	Come up with active learning strategies for students.

3.5 Lecturer Observation

Lecturer observation was carried out during lectures and tutorials in which 30 learners participated. Observation of students was carried out in order to identify their actual learning behavior in undertaking Differentiation and Integration assignments. Lecturer observation covered learner participation, learner's individual efforts, need for re-explanation, reasoning ability, reaction to visual explanation and feedback during practice. Observation data were collected using the checklist method. Learners' behaviors were identified based on their repeated classroom behavior such as their effort in answering questions independently, waiting for the lecturer to demonstrate, seeking re-explanation, responding to diagrams or seeking confirmation prior to continuing with their answers. These observations were quantified in terms of frequency and percentage in order to establish the level of occurrence of each behavior among the learners. From the results shown in Table 3.5, 22 out of 30 learners (73.3%) responded well to visual explanations like diagrams and other visual prompts. This was the most dominant observation among all the indicators, implying that visual explanation is a critical factor in understanding area, bounded region and volume questions.

Second to that, it was the need for feedback. A total of 17 respondents (56.7%) exhibited a high need for feedback when solving questions. This is because the majority of students needed some form of reassurance from the lecturer before they could continue their solutions, especially when they do not know how to start their solution. Another observation made was that 15 students (50.0%) could not solve questions by themselves after the examples had been done. Moreover, 15 students (50.0%) needed explanations several times. This is because most students still depend on the lecturer to demonstrate the answers and need repeated explanations before attempting to solve similar questions on their own.

With regards to the reasoning skills of the students, it was observed that 14 students (46.7%) demonstrated weak reasoning and did not understand why certain formulas and methods were used. On the other hand, 10 students (33.3%) demonstrated passive participation when solving difficult questions. This is an indication that apart from having problems with the subject matter, they also have issues with confidence and reasoning. On the whole, the results of the observation of the lectures demonstrate that the students need learning assistance which will enable them to visualize the concepts, practice independently, verify their solutions and review explanations after lessons. The results confirm the necessity of providing self-learning materials that will have diagrams, explanations, repetition, self-testing and feedback.

Table 3.5. Summary of Lecturer Observation Findings.

Focus of Observation	Guiding Question	Finding, n (%)	Interpretation	Self-Learning Support Implication
Student participation	How do students respond during problem-solving?	10 (33.3%)	Some students became less active when facing difficult questions.	Provide guided prompts and scaffolded problem-solving tasks.
Independent attempt	Can students attempt questions after examples are given?	15 (50.0%)	Students depended on the lecturer's demonstration before attempting questions.	Provide step-by-step self-learning activities and worked examples.
Repeated explanation	Which subtopics require repeated explanation?	15 (50.0%)	Students needed repeated exposure to concepts and procedures.	Provide short revision videos or repeatable digital notes.
Reasoning ability	Can students explain why a method is used?	14 (46.7%)	Students struggled to explain why a formula or method was used.	Provide "why" question prompts and concept-based explanations.
Visual support	What support improves students' participation?	22 (73.3%)	Students responded positively to diagrams and visual prompts.	Provide visual diagrams, sketches, interactive models or AR-based visuals.
Feedback need	What happens during independent practice?	17 (56.7%)	Students needed confirmation before continuing their solutions.	Provide self-checking exercises, answer prompts and chatbot-style guidance.

To conclude, based on the results of the lecturer observation, it can be stated that the most dominant pattern in the class is the students' positive reaction to visuals, then their requirement for feedback and reiteration. According to the results, it appears that many students have not yet developed the confidence to initiate questions independently or provide an explanation about why they chose a particular approach. Hence, the observation results confirm the necessity of creating self-learning materials with visual guidance and feedback.

3.6 Review of Previous Assessment Performance

An assessment of previous assessment performance was carried out to find out if the learning difficulties discovered through the needs analysis were singular cases or repeating trends. This assessment made use of 10 records regarding assessment which covered 30 students, including quiz/test scores, coursework/exercise records and lecture notes about Differentiation and Integration. The assessment concentrated on test questions that involved the use of integration in practical applications, area under a curve, volumes of bounded regions, basic

integration, trigonometry and exponential integration, maximum-minimum problems, problem solving during tutorials and questions involving both Differentiation and Integration. These types of assessment questions were chosen since they were relevant to the aspects of method selection, application, visualization, formula application and problem solving. The data collected were analyzed based on the number of students affected in each assessment record. The percentage of students affected was determined using the formula (3):

$$\text{Affected Percentage} = \frac{\text{Number of Students Affected}}{30} \times 100 \quad (3)$$

According to the findings shown in Table 5.6, the topic that was most affected was the Volume of Bounded Region, which was a challenge for 25 out of 30 students (83.3%). It was followed by Trigonometric/Exponential Integration, whereby 24 out of 30 students (80.0%) had difficulty in applying the appropriate integration rules to different functions. Regarding Area Under a Curve, there was a challenge for 23 out of 30 students (76.7%) in setting up the limits correctly from the graph. Other trends that were observed include integration application problems affecting 21 out of 30 students (70.0%), differentiation and integration application problems affecting 22 out of 30 students (73.3%), and lecturer notes indicating 22 out of 30 students (73.3%) requesting explanations in area and volume lessons. Other records included coursework and exercise records, where there were formula and algebraic problems affecting 18 out of 30 students (60.0%) in basic integration and 24 out of 30 students (80.0%) in trigonometric/exponential integration.

In summary, the previous review of the assessment showed that the learning problems identified during the needs analysis did not occur by accident. Such problems could be seen in quiz/test performance, coursework/exercise performance, and lecturer notes. The common problems among the students were those related to visualization, identification of formulas and algebraic expressions, application of questions, repetition of explanations, choice of methods, and confidence in problem-solving independently.

Table 3.6. Previous Assessment Performance Review.

Assessment Source	Assessment Item /Topic	Pattern Observed	Students Affected, n (%)	Interpretation	Self-Learning Support Direction
Quiz/Test Result	Application-based integration question	Below-average score in the contextual integration question	21 (70.0%)	Students had difficulty interpreting unfamiliar question formats.	Guided problem interpretation framework and worked examples.
Quiz/Test Result	Area under a curve	Students failed to set the correct limits from the graph	23 (76.7%)	Students struggled to connect the graph, limits and integral expression.	Interactive diagrams and step-by-step visual explanation.
Quiz/Test Result	Volume of bounded region	Low score in volume setup and wrong formula use	25 (83.3%)	Students had difficulty visualizing a three-dimensional representation.	Visual models, AR-based illustration or dynamic diagrams.
Coursework / Exercise	Basic integration practice	Frequent formula confusion and algebraic	18 (60.0%)	Formula recognition and prerequisite algebra need reinforcement.	Short formula revision notes and self-check exercises.

		simplification errors			
Coursework / Exercise	Trigonometric/exponential integration	Students were confused about the integration rules for different function types	24 (80.0%)	Students selected formulas based on similarity rather than function structure.	Function-type comparison table and guided examples.
Coursework / Exercise	Maximum-minimum problem	Students were unsure which differentiation method to apply	20 (66.7%)	Students had difficulty choosing the correct method when the question format changed.	Method-selection checklist and decision tree.
Lecturer Notes	Tutorial: area and volume	Repeated requests for explanation in area and volume lessons	22 (73.3%)	Students needed repeated exposure after class.	Short step-by-step revision videos or digital notes.
Lecturer Notes	Tutorial problem-solving activity	Students asked for confirmation before continuing	19 (63.3%)	Students lacked confidence to validate their own steps.	Answer-checking prompts and formative self-test.
Coursework / Exercise	Multi-step differentiation application	Students skipped important steps in rate-of-change questions	20 (66.7%)	Students needed support in organising solution steps.	Scaffolded practice from simple to complex questions.
Quiz/Test Result	Combined differentiation and integration questions	Students answered direct questions better but struggled with combined application tasks	22 (73.3%)	Students showed limited transfer of learning to new contexts.	Guided mixed-question practice and reflection prompts

In conclusion, the review of the previous performance in assessments revealed that there were some recurring problems amongst the students when it came to their performance. The hardest areas were volume of bounded regions, trigonometric and exponential integration, and area under the curve. All these results agree with the results from the pre-test, error analysis, questionnaire and observations that suggest that students require help in visualization, recognition of formulas, choosing the right methods and problem solving.

4.0 CONCLUSION

According to the results of needs analysis, the challenges students have while studying Differentiation and Integration can be identified. In particular, poor conceptual understanding, inability to select an appropriate approach, poor visualization skills, lack of confidence in working independently and constant explanations are among the biggest problems. As seen from the

results of the research, the difficulties that students experience are not associated with poor calculations only. Indeed, such problems are related to deep issues that include weak conceptual comprehension, poor visualization, inappropriate applications of theoretical knowledge and lack of independent learning skills. While being able to work on examples provided by the lecturer, the learners tend to face certain difficulties in working with new tasks that involve different approaches, interpretation of diagrams and other tasks that need no instructions.

Thus, it is possible to conclude that students require a learning assistance that is organized, visual, guided and available out of the classroom. Such an approach may allow the students to go through major concepts, review the methods used for completing particular tasks, visualize mathematical relations between elements and practice solving problems independently. This analysis therefore forms the basis upon which appropriate learning assistance can be planned for the topic under discussion. The recommendations have been made after taking into consideration the students' results obtained from their pre-tests, common mistakes, questionnaire responses, interviews, lecturer observations, and assessments done previously.

REFERENCES

- [1] J. Stewart, *Calculus: Early Transcendentals*, 8th ed. Boston, MA, USA: Cengage Learning, 2016.
- [2] N. Hashemi, M. S. Abu, and H. Kashefi, "Undergraduate students' difficulties in solving derivative and integral mathematical problems," *Sains Humanika*, vol. 11, no. 2, pp. 19–27, 2019.
- [3] A. Arcavi, "The role of visual representations in the learning of mathematics," *Educational Studies in Mathematics*, vol. 52, no. 3, pp. 215–241, 2003.
- [4] L. L. Voon, N. H. Julaihi, and H. E. Tang, "Misconceptions and errors in learning integral calculus," *Asian Journal of University Education*, vol. 13, no. 1, pp. 17–39, 2017.
- [5] R. E. Mayer, *Multimedia Learning*, 2nd ed. Cambridge, U.K.: Cambridge University Press, 2009.
- [6] J. W. Creswell and J. D. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed. Thousand Oaks, CA, USA: SAGE Publications, 2018.
- [7] R. Likert, "A technique for the measurement of attitudes," *Archives of Psychology*, vol. 22, no. 140, pp. 1–55, 1932.
- [8] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, 8th ed. London, U.K.: Routledge, 2018.
- [9] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006, doi: 10.1191/1478088706qp063oa.
- [10] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative Data Analysis: A Methods Sourcebook*, 3rd ed. Thousand Oaks, CA, USA: SAGE Publications, 2014.
- [11] P. Black and D. William, "Assessment and classroom learning," *Assessment in Education: Principles, Policy & Practice*, vol. 5, no. 1, pp. 7–74, 1998, doi: 10.1080/0969595980050102.
- [12] B. S. Bloom, J. T. Hastings, and G. F. Madaus, *Handbook on Formative and Summative Evaluation of Student Learning*. New York, NY, USA: McGraw-Hill, 1971.
- [13] M. A. Newman, "An analysis of sixth-grade pupils' errors on written mathematical tasks," in *Victorian Institute for Educational Research Bulletin*, no. 39, pp. 31–43, 1977.
- [14] R. B. Ashlock, *Error Patterns in Computation: Using Error Patterns to Improve Instruction*, 9th ed. Upper Saddle River, NJ, USA: Pearson Prentice Hall, 2006.
- [15] P. Singh, A. A. Rahman, and T. S. Hoon, "The Newman procedure for analyzing primary four pupils' errors on written mathematical tasks: A Malaysian perspective," *Procedia - Social and Behavioral Sciences*, vol. 8, pp. 264–271, 2010, doi: 10.1016/j.sbspro.2010.12.036.
- [16] H. N. Boone and D. A. Boone, "Analyzing Likert data," *Journal of Extension*, vol. 50, no. 2, 2012.
- [17] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, 8th ed. London, U.K.: Routledge, 2018.
- [18] R. A. Krueger and M. A. Casey, *Focus Groups: A Practical Guide for Applied Research*, 5th ed. Thousand Oaks, CA, USA: SAGE Publications, 2015.
- [19] M. Q. Patton, *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*, 4th ed. Thousand Oaks, CA, USA: SAGE Publications, 2015.
- [20] E. C. Wragg, *An Introduction to Classroom Observation*, 2nd ed. London, U.K.: Routledge, 1999.
- [21] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, 8th ed. London, U.K.: Routledge, 2018.
- [22] G. A. Bowen, "Document analysis as a qualitative research method," *Qualitative Research Journal*, vol. 9, no. 2, pp. 27–40, 2009, doi: 10.3316/QRJ0902027.
- [23] J. W. Creswell and J. D. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed. Thousand Oaks, CA, USA: SAGE Publications, 2018.
- [24] Z. O'Leary, *The Essential Guide to Doing Your Research Project*, 3rd ed. London, U.K.: SAGE Publications, 2017.