Jurnal Ilmiah Pendidikan Fisika
https://ppjp.ulm.ac.id/journals/index.php/jipf/index
e-ISSN: 2549-9963 p-ISSN: 2549-9955
Vol 9 No 1 2025
DOI: https://doi.org/10.20527/jipf.v9i1.14718

First-Year Students' Understanding of the Use of Differential and Integral in Solving Kinematics Problems

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Article Info

Article history:
Received: January 29, 2025
Accepted: February 26, 2025
Published: March 8, 2025

Keywords:
Initial understanding
Kinematics
Mathematics
Physics

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Abstract

A good interconnection between mathematical ability and understanding of physics concepts is needed to solve physics problems. This study aims to analyze students' initial understanding of differential and integral concepts and students' understanding of using differential and integral in solving kinematic problems. This study involved 23 first-year Chemistry Education Study Program students taking a General Physics Course. The study was conducted in May 2024. This study was a descriptive study with a quantitative approach. Test was used to collect data with essay questions as an instrument. The instruments used are valid and reliable, with a reliability coefficient 0.74. Data were analyzed using descriptive statistics. The results showed that the number of students who understood the concept of differential was twice as many as those who understood the concept of integral. The results also showed that the number of students who could apply the concept of differential in solving physics problems was much greater than the number of students who could apply the concept of integral in solving physics problems. Even so, there was the much greater number of students who did not understand mathematical concepts and could not apply them in solving physics problems. This indicates the importance of strengthening mathematical concepts to support the implementation of physics learning. This can be conducted by involving students in problem-solving learning using real-life physics problems. Students must use their mathematical abilities and appropriate physics concepts to find the solutions. It will help students understand the interconnection between mathematics and physics so that they can see both as one inseparable part.

To cite this article: Sarkity, D., Fitriani, R., & Kurniawan, B. R.(2025). First-year students' understanding of the use of differential and integral in solving kinematics problems. *Jurnal Ilmiah Pendidikan Fisika*, *9*(1), 76-90.

INTRODUCTION

Mathematics has an important role in various branches of science. This is what makes mathematics said to be the mother of various knowledge (Russell, 2020). Mathematics is very much needed to solve various problems, especially problems related to natural sciences (Harefa et al., 2023; Maass et al., 2019; Weyl, 2021). Mathematics can provide modeling and a framework to facilitate problem-solving so that the problem-solving process can be carried out optimally to find solutions to problems (Abramovich et al., Grinshpan, & Milligan 2019; Kaiser 2020; Rizki & Priatna, 2019).

Among the parts of natural science that use mathematics as a tool for problem-solving is physics. Physics is inseparable from mathematics because mathematics is the best tool for solving various physics problems (Branchetti et al., 2019; Islami & Wiltsche, 2020; Serbin & Wawro, 2024). Take modern physics, for example, whose field of study is microscopic; the study of which cannot be done empirically but through a mathematical approach (Anastopoulos, 2020; Rosaler & Harlander, 2019).

Not only in the realm of modern physics, classical physics, whose studies can be done empirically, also uses mathematics dominantly, and it cannot be separated from physics to solve problems. Classical physics still requires mathematical modeling to determine various physical quantities observed in nature (Chow, 2024; Levi, 2023; Wyld & Powell, 2020). Newton's laws, fundamental in classical physics, are also described through mathematical modeling (Leinaas 2024; Mandal et al., 2022; Mongan et al., 2020; Qin et al., 2019).

Among the topics in classical physics that require mathematics to be used in solving problems is kinematics. Kinematics is a part of mechanics, which studies motion without knowing why objects can move (Eisner et al., 2022; Luo et al., 2021; Sarkity et al., 2022). Solving kinematics problems is identical to determining various physical parameters such as position, velocity, acceleration, and other parameters (Ekrem & Aksoy, 2023; Fomin et al., 2021; Pöppl et al., 2023; Sarkity et al., 2022; Sarkity & Sundari, 2020, 2022; Do Tran et al., 2018). In solving kinematics problems, some understanding of mathematical concepts is needed, such as integrals, differentials, algebra, etc (Haug, 2022; Lee et al., 2018; Pappalardo & Guida, 2018).

Given that mathematics is needed to solve physics problems, mathematical ability is something that must be possessed, of course, in addition to understanding the concept of physics itself. In several studies, many students have problems in mathematics (Febriyanti et al., 2021). Among the problems is that students find it difficult to connect mathematics and the problems they want to solve (Kenedi et al. 2019; Retnawati et al., 2020; Sarkity et al., 2016). In addition, the problem experienced is the inability to understand the mathematical concept itself, such as in the topic of differentials (Säfström et al., 2024; Sijmkens et al. 2024) and integrals (García-García & Dolores-Flores 2021; Viberg et al., 2023).

Several previous studies have explored students' difficulties in applying mathematics in learning. Among them are students' difficulties in understanding mathematical symbols used in physics (Badmus & Jita, 2024; Begg & Pierce, 2021; Johansson & Österholm, 2023; Redish 2021). Another problem is that students struggle to make mathematical models to solve problems (Ye et al., 2024). But it is also important to examine how students understand the concept of mathematics itself, not just how students use mathematics to solve physics problems. Students could be good at mathematics but confused when applying it to solve problems.

Concerning the use of mathematics in solving physics problems, first-year students in science group study programs, such as the chemistry education study program, are required to take general physics courses. Students' understanding of mathematical concepts is the main capital of this course. The understanding referred to here is students' initial knowledge from prior education (Bond et al., 2021). For example, to take lectures on kinematics topics, students must understand the concepts of differential and integral. Several previous studies have explored students' difficulties in solving problems in graphs (Sarkity et al., 2022) or student difficulties in kinematics topics in general (Sarkity & Sundari, 2020, 2022). In those studies, it was found that there were difficulties in understanding physics concepts. The inability to understand physics concepts will cause students to be unable to solve problems (Banda & Nzabahimana, 2021; Docktor et al., 2016; Lestari et al., 2021; Simanjuntak et

al., 2021b). Some studies only focus on students' difficulties in understanding physics concepts but do not explore their difficulties in using mathematics to solve physics problems. Students' difficulties in applying mathematics when solving physics problems do not necessarily indicate that students are weak in mathematics. This could be because students do not know how to apply mathematics to solve various problems. Based on this background, researchers conducted a study to analyze students' initial understanding of the concept of differential and integral students and analyze students' abilities in applying differential and integral concepts to solve kinematics problems.

METHOD

This research is a descriptive study with a quantitative approach. This research was conducted in May 2024 at Universitas Maritim Raja Ali Haji. This study involved 23 first-year students in the Chemistry Education Study Program. Chemistry education students were chosen because chemistry is part of the natural sciences, which is closely related to physics. Students in the first year must understand chemical concepts and physics well, even at a basic level. This study was conducted to analyze students' initial understanding of the concept of differential and integral and students' understanding of applying the concept of differential and integral in solving kinematics problems in physics. The data collected in this study is quantitative data from students' conceptual understanding. Research data were collected through tests. The instrument used to collect data was an essay question. The questions used are valid and reliable, with a reliability coefficient of 0.74, which shows the instrument has high reliability (Arikunto, 2021). The grid of the research data collection instrument can be seen in Table 1.

Table 1 Data collection instrument grid

No.	Indicators	Number of questions
1	Differential in mathematics	1
2	Application of differential in solving kinematic problems	1
3	Integrals in mathematics	1
4	Application of integrals in solving kinematic problems	1
	Total	4

The research data were analyzed descriptively. The data collected from the first question (differential of a function) and the third question (integral of a function) will be presented as tables or graphs by grouping the data based on Correct Answers, Wrong Answers, and No Answers at All. For question number 2 and question number 4, the data were analyzed using a problem-solving rubric modified from the rubric of Docktor et al., (2016) but only focused on assessing aspects of the physics approach, specific application of physics, and mathematical procedure to see how students' abilities are in applying differentials and integrals in solving kinematics problems. The assessment rubric is presented in Table 2.

Table 2 Rubric for assessing students' understanding of implementing differential and integral in solving physics problems

No	Aspects	Score				
		4	3	2	1	0
1	Physics Approach (PA)	The AP used is appropriate and complete.	The PA used contains a few errors.	The PA used contains many errors.	The PA used is in-appropriate.	No PA found
2	Specific application of Physics (SAP)	The SAP used is appropriate and complete.	The SAP used contains a few errors.	The SAP used contains many errors.	The SAP used is in-appropriate.	No SAP found

No	Aspects	Score				
		4	3	2	1	0
3	Mathematical Procedure (MP)	The MP used is appropriate and complete.	The MP used contains a few errors.	The MP used contains many errors.	The MP used is in-appropriate.	No MP found

RESULTS AND DISCUSSION

The results are presented in two parts with the following descriptions.

Students Understanding of the Concepts of Differential and Integral in Mathematics

Measuring students' understanding of determining the differential and integral of a simple function is done with the questions shown in Figure 1.

1. Find the first derivation of the following function.
$f(x) = 3x^3 - 5x^2 + 3x + 8$

(a)

3. Find the indefinite integral of the following function.
$f(x) = 3x^2 - 4x + 10$

(b)

Figure 1 Questions to measure students' understanding in determining (a) the differential and (b) the integral of a function

The research data show that not all students are able to determine the differential or integral of a function. Students' answers are grouped into correct answers, incorrect answers, and no answers at all. The study's results based on the grouping can be seen in Figure 2.

In Figure 2, more students understand the concept of differential compared to integral. This can be seen from the percentage of students who answered correctly on differential questions, which is 60.87%, while the percentage of students who answered correctly on integral questions is only 30.44%. This shows that more than half of the research subjects understand the concept of differential but not integral.

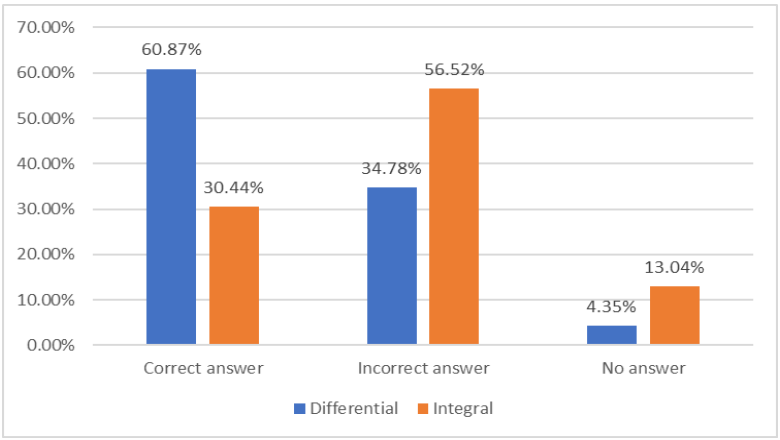

Figure 2 Grouping of answers to measure students' understanding in determining the differential and integral of a function

The results of this study are not surprising because several studies have also shown similar things. Several studies found that the application of integrals is more difficult and

challenging (Klappert et al., 2021; Lindell et al., 2021; Trager, 2022). The research also stated that the integral material was so difficult that it was categorized as a cognitive load in mathematics learning (Puspa et al., 2020). Integral has a more complicated calculation process (Chew et al., 2022; Liu & Ma, 2023). With the many uses of integrals in physics other than kinematics such as work and energy (Bai et al., 2023), Gauss's Law (Apruzzi et al., 2023; O'Connor et al., 2021), and others, it is important to provide mathematical reinforcement so that students can solve various physics problems (Juandi 2021; Wancham & Tangdhanakanond, 2022; Wijaya et al., 2021).

Students Understanding of Applying Differential and Integral Concepts to Solve Kinematics Problems

The questions shown in Figure 3 measure students' understanding of applying differential and integral concepts to solve kinematics problems.

2. A particle moves in a straight line. The position of the particle relative to the origin O is described by the function $x(t) = 2t^2 - 12t + 15$, with x in meters and t in seconds. Calculate:
   a. The velocity of the object at t = 3 seconds
   b. The acceleration of the object at t = 2 seconds

(a)

4. A particle moves in a straight line with particle acceleration expressed by the function $a(t) = 2t + 1$, with a in m/s^2 and t in seconds. If at t = 2 seconds, the particle velocity is 3 m/s, Calculate the particle velocity at t = 5 seconds.

(b)

Figure 3 Questions to measure students' understanding in applying the concepts of (a) differential and (b) integral in solving kinematics problems

Based on the research results conducted using the questions shown in Figure 3, a description of the PA, SAP, and MP used by students in solving questions 2a, 2b, and 4 was obtained. Figure 4 shows the description of the number of students at each PA, SAP, and MP score based on the results of working on question 2a.

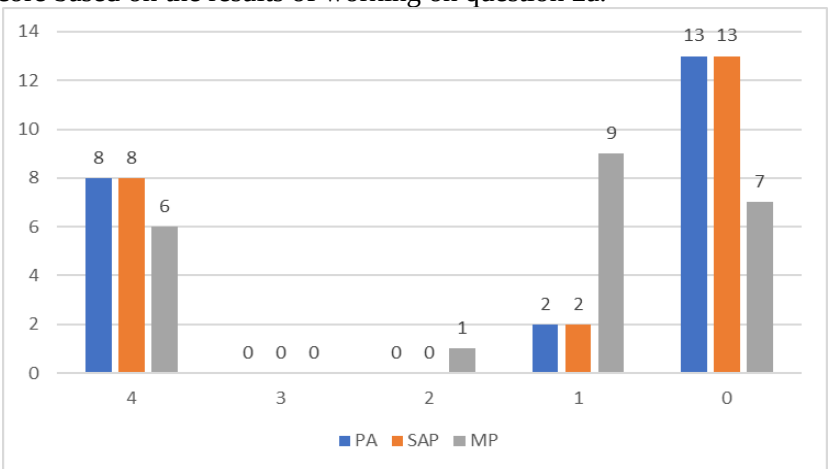

Figure 4 Number of students for each score of PA, SAP, and MP for question number 2a

In Figure 4, only 8 students have a score of 4 for PA and SAP. This shows that the eight students know the relationship between position and velocity, where velocity is the first

derivative of time from the position function. In contrast, only 6 students can properly (score 4) apply mathematical procedures, in this case, the concept of differential, to find a solution to question 2a.

The results in question number 2b are not much different from those in question 2a. This can be seen in Figure 5. In Figure 5 it can be seen that only 7 students got a score of 4 on PA and SAP. This shows that 7 students know the relationship between position and acceleration well, where acceleration is the second derivative concerning the time of the position function. Although 7 students have a good concept of the relationship between acceleration and position, only 5 students apply mathematical procedures, in this case, the concept of differential, to find a solution to question number 2b.

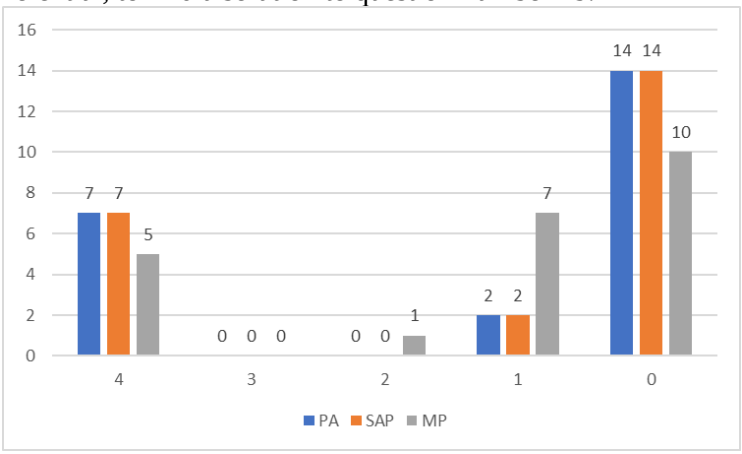

Figure 5 Number of students for each score of PA, SAP, and MP for question number 2b

In contrast to question number 2, which applies the differential concept in solving kinematics problems, the results shown from the answer to question number 4, which applies the integral concept in solving kinematics problems, are very different. This can be seen in Figure 6. The results show that only 3 students scored 4 for PA and SAP. This means that only 3 students know the relationship between acceleration and velocity well, where acceleration is the first derivative of time from the velocity function. This means that to determine the speed of the acceleration function, the application of the differential concept is required. Based on the mathematics procedure (PM), only 1 student scored 4. This shows that only 1 student produced the correct answer for question number 4.

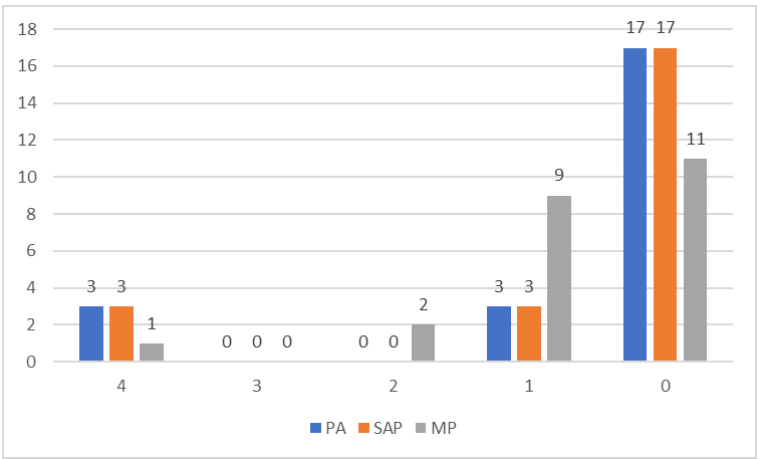

Figure 6 Number of students for each score of PA, SAP, and MP for question number 4

These results show that understanding the concept of physics is no less important than reinforcing mathematical abilities. Both the results demonstrated by applying differential and integral concepts in solving physics problems show that students who can solve problems about differentials or integrals cannot necessarily apply them in solving physics problems. This indicates a lack of understanding of the concept of physics. Students with a good understanding of the concept should be able to solve problems well, including choosing the right strategy to solve problems (Simanjuntak et al., 2021a; Uden et al., 2023). The strategy referred to here is the mistake of choosing the right mathematical procedure to solve the problem (Banda & Nzabahimana, 2021; Herayanti et al., 2022; Redish 2021). This indicates the importance of training students in the interconnection of mathematics and physics so that students can see both as inseparable parts (Diego-Mantecon et al., 2021; Prochazka et al., 2021; Wittmann, 2021) so that students realize that to solve physics problems, good mathematical skills must also support a good understanding of physics concepts. In addition, students must also know how to use mathematics to solve physics problems.

Based on the results of working on questions 1 to 4, students can be grouped into three categories to understand the concepts of differential and integral. Table 3 shows the grouping of students based on working on questions related to differential.

Table 3 Grouping of students based on their understanding of differential concepts and their ability to apply them in solving kinematics problems

No.	Categories	Number of Students
1	Not understanding the concept of differential at all, so unable to apply it in solving kinematics problems.	9
2	Understanding the concept of differential but not knowing how to apply it in solving kinematics problems.	6
3	Understanding the concept of differential and applying it in solving kinematics problems.	8

Table 3 shows that only about 1/3 (8 students) of the total number of research subjects understand the concept of differential and can apply it in solving kinematics problems. In addition, 6 students understand the concept of differential but do not know how to apply it in solving kinematics problems. This shows a lack of understanding of physics concepts that students have, so students do not know how to apply mathematics in solving problems. In addition, 9 students cannot determine the differential of a function at all. This will certainly be an obstacle in solving physics problems that use many differential concepts, such as kinematics.

Not much different from the results showing students' ability to use differential concepts to solve physics problems, grouping students based on their understanding of integral concepts and their ability to apply them to solve kinematics problems is shown in Table 4. The results show that out of 23 students who were the study subjects, only 1 student understood the integral concept and was able to apply it to solve kinematics problems. A total of 7 students mastered the integral concept but did not know how to apply it to solve kinematics problems. This raises concerns about the importance of strengthening physics concepts so students can correctly use mathematical concepts to solve problems. In addition, 15 students did not understand the integral concept at all. This shows that the number of students who do not understand the integral concept is greater than those who do not understand the differential concept. This must be overcome by reinforcing mathematical concepts because physics cannot be separated from mathematics. In solving physics problems, good mathematical skills are needed, one of which is in applying differentials and integrals.

Table 4 Grouping of students based on their understanding of differential concepts and their ability to apply them in solving kinematics problems

No.	Categories	Numbers of Students
1	Not understanding the concept of integral at all so unable to apply it in solving kinematics problems.	15
2	Understanding the integral concept but not knowing how to apply it in solving kinematics problems.	7
3	Understanding the concept of differential and applying it in solving kinematics problems.	1

Based on the grouping that was done, it can be seen that the dominant number is shown in the category of students who do not understand the concept of mathematics at all, so the students will not be able to apply it in solving physics problems. Several factors may cause students' difficulties in mathematics. Several factors that cause these difficulties are attitude toward mathematics, prior knowledge, and teaching materials (Agustyaningrum et al., 2020). In addition, ineffective mathematics curricula and incompetent teachers or lecturers contribute to the student's difficulties in mathematics (Chand et al., 2021).

A fairly large number is also shown in students who understand the concept of mathematics but are unable to apply it appropriately to solve physics problems.

This could be due to a lack of understanding of physics concepts. Studies found that students who understand the physics concept could solve the physics problem better (Diani et al., 2023; Resbiantoro et al., 2022; Sari et al., 2022). Some factors may cause students difficulties in understanding the concept of physics. Those factors are ineffective learning strategy, lack of learning media, misconception, and others (Bouchée et al., 2022; Kanyesigye et al., 2022; Resbiantoro et al., 2022; Sari et al., 2022).

The description of students' initial conceptual understanding is an important note for physics teachers regarding what should be emphasized in physics learning. In addition to strengthening the concept of physics itself, physics lecturers have an extra task to strengthen mathematical concepts, especially those used in physics (Bahtaji, 2021; Burkholder et al., 2021; Vlasenko et al., 2021).

One of the learning strategies that can be applied to overcome this problem is problem-based learning (PBL). PBL could help students solve real-physics problems (Samadun & Dwikoranto, 2022; Sujanem & Putu, 2023). Studies found that students' problem-solving abilities could be improved by implementing PBL (Anggraeni et al., 2023; Simanjuntak et al., 2021b, 2021a). Students who can solve physics problems well can apply mathematics to find solutions to physics problems. Through PBL, the lecturer can also teach students the interconnection between mathematics and physics.

The disadvantage of this study is that the analysis was only carried out using the test method. The interpretation of students' abilities in understanding the concepts of differential and integral and how students apply them in solving problems is only seen from students' answers when taking the test. The results of this study would be better if the way students solve problems to group student types in solving problems was carried out using in-depth interviews. Through in-depth interviews, the patterns shown by students in solving problems can be seen, including in applying mathematical procedures, so that the problems shown by students in solving problems can be identified. In addition, in-depth interviews can also help group students based on their problem-solving types (Amin et al., 2021; Chen & Chuang, 2021; Setiana & Purwoko, 2021; Vlasenko et al., 2021).

CONCLUSION

Based on the research conducted, it can be concluded that the number of students who understand the concept of differential (60.87%) is twice as many as students who understand the concept of integral (30.44%), which shows that students find it more difficult to understand the concept of integral than the concept of differential. Attitude toward mathematics, prior knowledge, and teaching materials could cause students difficulties in mathematics. In applying the concept of differential and integral in solving kinematics problems, only 8 students understand the concept of differential and its application in solving kinematics problems, and only 1 student understands the concept of integral and its application in solving kinematics problems. A lack of conceptual understanding could cause students difficulty applying mathematics to solving physics problems. This result shows why students have difficulty connecting between mathematics and physics problem-solving. This indicates the importance of strengthening the concepts of mathematics and physics so that students can solve physics problems based on the correct understanding of the concept and can use mathematical concepts correctly in solving physics problems. One of the strategies to improve student problem-solving skills and make interconnections between mathematics and physics problem-solving better is problem-based learning. Students can experience solving the real-physics problem with appropriate strategies.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, DS; methodology, DS & RF; formal analysis, RF and BRK; writing preparation of the original draft, DS.

ACKNOWLEDGEMENT

The authors would like to thank LPPM UMRAH for guiding this independent research process and FKIP UMRAH for assisting with the administrative requirements for completing this research.

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