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The implementation of integral concepts in physics problem-solving by students with a conceptual blending framework approach

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ABSTRACT

This research employed a qualitative descriptive approach to explore the application of integral concepts in solving physics problems with the conceptual blending framework. The sample of 26 students were categorized into four groups. The research investigated how different groups applied conceptual blending in addressing physics problems involving integrals. The findings revealed diverse understandings and approaches across the groups, with Group 4 exhibiting a more integrated understanding of physics and mathematics concepts. The study highlighted the effectiveness of conceptual blending in fostering a deeper comprehension of complex concepts in physics and mathematics, suggesting a potential pedagogical strategy to enhance students' problem-solving skills and theoretical understanding. This research contributes to the field by demonstrating the nuanced ways students engage with interdisciplinary concepts, offering insights for educators to refine teaching methodologies in integrating mathematics into physics education.

Penerapan konsep integral dalam pemecahan masalah fisika oleh mahasiswa dengan pendekatan kerangka *conceptual blending*

Kata Kunci:

Conceptual blending
Konsep integral
Konsep fisika
Pemecahan masalah

ABSTRAK

Penelitian ini menggunakan pendekatan deskriptif kualitatif untuk mengeksplorasi penerapan konsep integral dalam penyelesaian masalah fisika pada mahasiswa dengan menggunakan kerangka blending konseptual. Dengan sampel 26 siswa yang dibagi menjadi empat kelompok, penelitian ini menyelidiki bagaimana kelompok yang berbeda menerapkan pencampuran konseptual dalam mengatasi masalah fisika yang melibatkan integral. Temuan ini mengungkapkan pemahaman dan pendekatan yang beragam di seluruh kelompok, dengan Kelompok 4 menunjukkan pemahaman konsep fisika dan matematika yang lebih terintegrasi. Studi ini menyoroti efektivitas pencampuran konseptual dalam menumbuhkan pemahaman yang lebih dalam tentang konsep-konsep kompleks dalam fisika dan matematika, menyarankan strategi pedagogi potensial untuk meningkatkan keterampilan pemecahan masalah dan pemahaman teoritis siswa. Penelitian ini berkontribusi di lapangan dengan menunjukkan berbagai cara siswa terlibat dengan konsep interdisipliner, menawarkan wawasan bagi pendidik untuk menyempurnakan metodologi pengajaran dalam mengintegrasikan matematika dalam pendidikan fisika.

1. INTRODUCTION

Improving abilities in mathematical application is necessary for understanding topics in physics courses [1]–[3]. Applying mathematics in physics entails more than just using algorithms and laws that students may have gained in mathematics classrooms. Assessing how students use and comprehend mathematical concepts in physics is an important research topic crucial to physics education research [4]–[10].

In physics, the world is determined by mathematical structures at all levels of physics, with mathematics playing an increasingly significant part as the level rises. As a result, mathematics expertise is necessary for understanding physical processes, and the capacity to incorporate multiple subjects is an absolute prerequisite to improving one's physics abilities [11]–[13]. Understanding a physics equation involves not only connecting symbols to physical variables but also performing calculations and operations [14], [15], as well as connecting the mathematical equation with its physical meaning and integrating the equation with its implications in the physical world [16].

Discussing students' comprehension of mathematics and physics is challenging since incorporating mathematics into physics concepts is more sophisticated than just integrating the two disciplines of knowledge. Some studies have used the conceptual blending approach [17] to describe how students recognize the relationship between mathematics and physics [18], [19]. According to Huynh & Sayre [20], effective use of mathematics in understanding physics processes requires fundamental integration of mathematics and concepts, not restricted to applying mathematics in physics.

Previous research in Physics Education has emphasized the difficulties students have when attempting to utilize their mathematical skills to solve physics problems [16], [21]–[24]. In calculus-based physics education, students must frequently understand and apply higher-order mathematical concepts such as differentials and integrals [25].

To assist students in incorporating mathematical skills into physics concepts, the first step is to analyze how students solve physics integral issues and understand their thought processes [26]–[28]. Integral problems in physics require merging characteristics of the physical world with mathematical symbols and concepts [26], [29]. There are various approaches to interpreting and applying mathematics to physics problems. When faced with a physics problem, students may come up with various combinations. This study employs a conceptual blending framework to assist students in developing mathematical integrals for physics concepts [30].

The conceptual blending framework sees learning as the selective projection and combining knowledge from many mental areas [21], [30]. An in-depth analysis of students solving physics problems is required to investigate how they connect mathematical symbols and concepts with concepts related to physics so that they can compare the various types of blending used by students and discuss the effectiveness of certain types of blending in facilitating their productive use of integrals. The identification of various sorts of combinations produced by students provides insight into how students think when confronted with physics integral problems [21], [31], [32].

Previous research has frequently focused on the challenges that students experience when using integrals, such as detecting situations that necessitate their usage [33], [34], finding infinitesimal representations for physics quantities [35], [36], and calculating integral limits [33], [35]. According to brief interviews with two female students who were also prospective physics teachers, mathematics-based instruction has traditionally concentrated solely on mathematical knowledge. They argued that there was insufficient clarification of when and how mathematical principles were applied in physics. This makes it difficult to understand physics materials that involve mathematical concepts, particularly those dependent on calculus, such as integral and derivatives.

Based on the interview, the researcher conducted pre-research to determine their level of knowledge when integrating physics and calculus-based mathematics. According to six students' pre-research findings, students struggled to integrate calculus-based mathematical concepts with their application in physics concepts. This fact is consistent with the findings of prior interviews, in which participants indicated that they were merely provided a comprehension of mathematical ideas without any explanation of their application in physics. Although they solved the researcher's physics problem, they could not explain the relationship between the mathematics and physics concepts employed. Instead, they just swapped the initial equation of relativity into the concept of mathematical integral.

This circumstance inspired the researchers to continue their work by including more students in conceptual blending to completely define the approaches employed in applying integrals to physics concepts, particularly in electrical resistance material in wires. This approach can help students better understand the relationship between mathematics and physics concepts.

Conceptual blending has been used in research to determine the interpretation of computational models [17], to model students' reasoning processes [21], [37], and to model computation [17]. In addition, numerous research studies on physics problem-solving have been performed, including physics problem-solving skills in basic physics courses [38] and an overview of problem-solving in physics [39]. However, no research has used the integral concept to solve physics problems using a conceptual blending framework approach.

This study seeks to raise critical issues about physics problem-solving using a conceptual blending framework approach to applying integral concepts. Students frequently struggle to apply what they studied in mathematics to physics. In contrast to many other studies investigating conceptual blending and problem-solving skills, this study is unique because it examines students' ability to solve physics problems using integral concepts.

Contribution to the literature

This research contributes to:

- Enriching the discourse of interdisciplinary learning, particularly at the point of intersection between mathematics and physics education.
- Providing different insights into students' cognitive processes and problem-solving strategies, offering a detailed understanding of how students integrate and apply knowledge from different domains.
- Offering valuable implications for teaching methodologies in physics and mathematics education.

2. METHOD

This research employed a qualitative descriptive research approach to investigate how students used integral concepts in physics problem-solving using a conceptual blending framework. This approach enabled the researchers to thoroughly understand students' cognitive processes, how they integrate mathematics and physics knowledge, and the problem-solving strategies they employed. The subjects were fifth-semester students chosen using a purposive sampling technique. The total number of samples was 26, separated into groups to allow interaction observation and conceptual blending formation. The primary goal of this descriptive qualitative research was to describe how students used the integral concept in physics problem-solving, specifically on the topic of electrical resistance in wire. Furthermore, this study aimed to explain students' application of integral concepts in physics problem-solving utilizing the conceptual blending framework, specifically in the material of electrical resistance on the wire.

The research procedure is a series of actions researchers do while conducting research. The goal is to guarantee that the research steps align with the current difficulties. The research encompassed three primary stages: preparation, implementation, and finalization. Figure 1 illustrates the stages of this research.

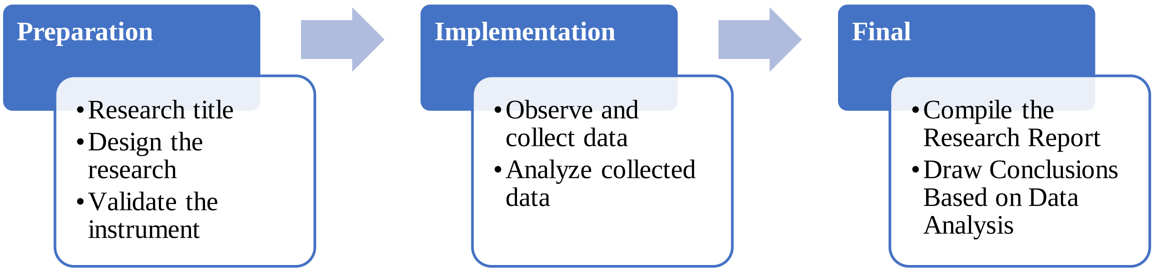


Figure 1. Research Procedure

3. RESULTS AND DISCUSSION

The findings indicated that students first examined the problem before creating a visual narrative using words and actions. After better comprehending the problem, they then used formal mathematics to construct an integral. While generating the integral expression, students uncovered a small portion of the physical phenomenon represented by dR, which is the resistance of each cylinder.

However, combining these resistances to obtain the total resistance was difficult. Some integrations helped students answer the problem correctly, while others restricted their efforts. Thus, this technique highlighted the need for adaptation and dynamic thinking in addressing physics problems using the concept of integrals.

3.1 Blend Group 1

Before starting the discussion, the three students in group 1 had completed their equations and appeared to agree with one another. Figure 2 shows the answer from group 1.

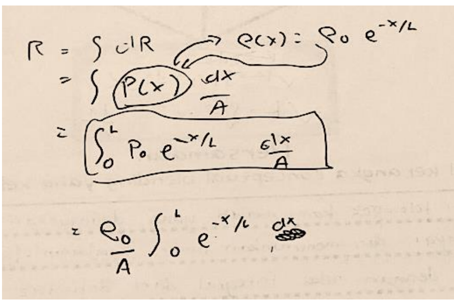


Figure 2. Group 1's Answer

Two Physics Education students (K and S) were interviewed to explain their thoughts. During the interview, students K and S from Group 1 discussed their strategy to solve the given physics problem. They employed basic formulae and the resistivity function, ρ(x), to calculate total resistance in the research area. Student K calculated the total resistance by integrating the resistivity, which varies with distance x from 0 to L. This demonstrated how the change in resistivity with distance affects total resistance, indicating how resistivity grows as point L approaches. When working on this subject, this group of students concentrated mostly on mathematical manipulation and finding ways to connect mathematical symbols to mathematical equations.

3.2 Blend Group 2

When solving this problem, the second group first created a blend. At the beginning of their problem-solving, one student (L) wrote "dR" but did not explain what dR meant, nor did he find an expression for dR. During the interview session, the researcher asked the students to explain what they meant by dR, and they started to look for the expression for dR. Finally, the students made another blend different from the one they had initially made. When asked to explain the differential term of dR, their understanding of the differential template d[] was activated. Therefore, they went from one blend to another.

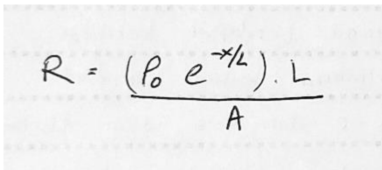


Figure 3. Student L's Answer

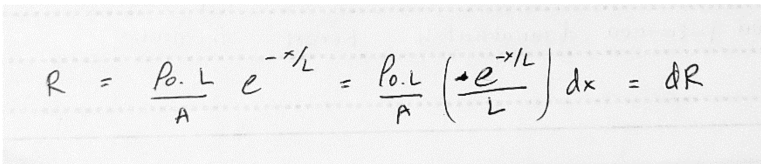


Figure 4. dR Expression

When asked to describe the significance of dR at the start of this interview, student K stated that, like an electric field, the integral of dR must be defined. The researcher observed that student L did not discuss the meaning of dR. Instead, he recalled the electric field problem, in which the entire electric field E equals the integral of dE. Then, he claimed that the total resistance R should be the integral of dR. As a result, his reasoning appeared to be focused on pattern-matching with previous examples rather than a thorough comprehension of what dR is and how it connects to total resistance R.

Student S seemed to have a more tangible knowledge that dR denotes a portion of R or a portion of the resistance. He crossed out the problem's figure to explain the resistance at this stage. When looking for an expression for dR, student P simply included the resistivity function in the basic equation. Student P created the basic resistance equation $R = \rho(x)\frac{L}{A}$ but later recognized it was incorrect since he needed dx.

3.3 Blend Group 3

In this group, two students (T and U) employed distinct ways of addressing the problem. In this case, we will look at student T's approach. Student T began with the basic resistance equation and then transformed it to integral form, as illustrated in Figure 5. When group 3 solved the equation, the researchers invited them to describe their reasoning. Group 3 discussed how they transformed the concepts of resistivity and length into an integral form to calculate total resistance. They described how the entire value was calculated by integrating each little section, denoted as "dx". Their argument emphasized the importance of integrals in integrating small physical quantities into a meaningful total.

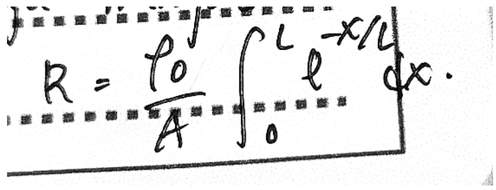


Figure 5. Group 3's Answer

3.4 Blend Group 4

In this group, two students, student C and student M, took a similar approach to the problem's description. They divided the cylindrical resistor into very thin disks and then summed the resistance induced by each thin disk to calculate the total resistance.

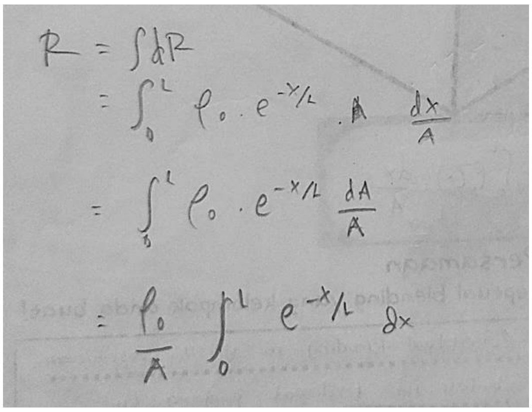


Figure 6. Group 4's Answer

They calculated the differential form dR, the infinitesimal resistance due to the cylinder's thin section of thickness dx. They calculated the overall resistance R by calculating the integral of dR. The researcher then asked the participants to clarify their thoughts. In their discussion, Group 4 discussed how they used the process of cutting the cylinder into thin disks and integrating the resistance caused by each disk to calculate the total value. This method demonstrated their awareness of how resistivity changes along the length of an object and the relevance of summation through integration in determining the object's overall characteristics.

The four blends were then identified based on the interviews and the students' works and summarized into a brief description, as shown in Table 1.

Table 1. The Description of the Four Blends

Blend	Conceptual Blending Framework	Description and Structure	Representation
Group 1	Integral as a sum (from the concept of mathematics)	$\int_0^L \rho(x)\, {}^{L}\!/_{A}\, dx$: The total resistance is the sum of the resistances that vary along the length where the resistivity varies.	Mainly algebraic
Group 2	Differential as taking the derivative of a function (from the mathematical concepts)	$\int DR$: Total resistance is the integral of differential resistance -the derivative of a resistance function.	Mainly algebraic

Group 3	Structure of basic resistance equation and integral as a sum (a combination of symbolic and mathematical concepts)	$\int_0^L \rho(x) \, {}^{L}\!/_{A} \, dx$: $\int_0^L \rho(x)$ represents the resistivity increment, and dx is the small distance added when integrated.	Algebraic and narrative
Group 4	Structure of basic resistance equation, integral as a sum, cutting resistor (a combination of symbolic, mathematical concepts, and physics)	$\int dR$: Dividing the total resistance R and summing the small pieces of resistance dR.	Algebraic, narrative, imagery, and heavy use of gesture.

3.5 Achievement Results of the Five Conceptual Blending Indicators

Five indicators demonstrate FKIP UNTAN physics education students' ability to use integral concepts in addressing physics problems utilizing a conceptual blending framework approach. In this research, there were 26 students observed. The data on the results of student achievement related to the implementation of the conceptual blending framework is as follows.

Table 2. The Number of Students on Each Conceptual Blending Indicator

No	Indicators	Number of Students			
		Point 0	Point 1	Point 2	Point 3
1	One-way mapping from symbolic and physics space to mathematical concept space.	-	-	-	26
2	Ability to construct resistance functions as summed quantities through mathematical substitution.	-	-	20	6
3	Narrative representations that create new structures based on blending structures from all three input spaces.	-	-	-	26
4	When creating blends use multiple representations, including algebraic representations, narrative, pictures, and hand gestures.	15	5	-	6
5	Involves a higher level of blending of mathematics and physics knowledge.	-	5	15	6

3.6 How is the integral concept applied to physics problems by Physics Education students?

3.6.1 Group 1

First, students substituted the resistivity function ρ(x) into the basic resistance equation $R = \rho \frac{L}{A}$. Substitution is one of the most fundamental mathematical processes, and students often perform it unconsciously despite the resulting equation having no concrete meaning in this particular physics context. The students also displayed a fundamental understanding of functions. S shows that the resistivity function provides us ρ at one point, and K describes how it becomes more resistive as it approaches L. In their explanation, S mentions summing over all of its points. Still, K mentions calculating the complete integral and summing along S. As a result, they believe the integral is equivalent to the sum.

When determining the integral, the students used three input spaces: symbolic space, mathematical concept space, and physics space. The symbolic space contains abstract mathematical symbols and notations, including the resistivity function ρ(x) and the resistance equation of $R = \rho \frac{L}{A}$. Mathematical idea space includes students' understanding of mathematical concepts and symbols. In this scenario, the mathematical concept space comprises students' concepts about function as a nonconstant, integral ∫ as a sum, and d[-|] as an integration variable.

3.6.2 Group 2

First, they replace the resistivity function with the fundamental resistance equation to get a new expression for R (Figure 3). Then, they take the derivative of this new expression concerning x to get the differential of R, or dR (Figure 4). Finally, they set a specific integral of dR to determine total resistance. When asked for an answer for dR, student L responded that it would be multiplied by dx... they needed to compute the derivative of anything. The researcher assumes that student L understood dx was required in student P's differential equation, prompting him to take the derivative of anything to obtain dx.

In this problem, student K used the mathematical technique 'taking the derivative' to calculate the differential equation dR. Student P removed his work after seeing student L's approach and appeared to agree with it. The researcher observed that students P and L described dR in distinct ways. However, student P did not provide an alternative strategy for solving this problem based on his understanding.

3.6.3 Group 3

In this group, student T initially explained that each small portion was represented by dx, which was then combined using the integral. Student T appeared to interpret the application of the integral in this physics scenario as adding little quantities. Student T used the phrase "I took this ρL and converted it to this here" to integrate the basic resistance equation and the concept of addition. He viewed the integration variable dx as a small piece and the integral component in the rectangle box (Figure 6) as the sum of all those small resistivities.

The equation in the rectangle box was incomplete and incorrect without dx. He seemed to have understood that the integral signified a sum when he said, "Add all the resistivity." However, he did not appear to understand that resistivity is a feature of this material. Therefore, resistivity in different areas cannot be summed in this physical setting.

3.6.4 Group 4

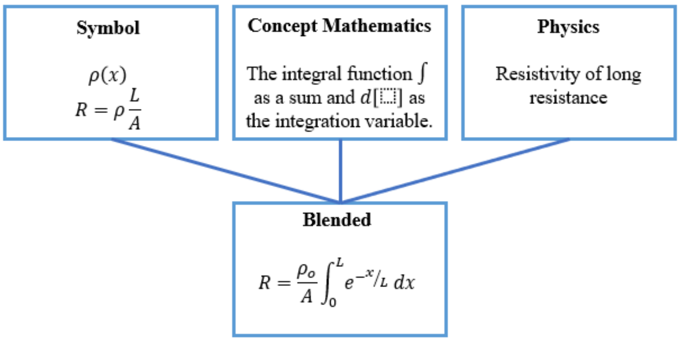
Student C in this group began by separating into small parts and using his hands to simulate breaking an entire cylinder into small pieces. He explained that resistivity fluctuated with length and demonstrated that resistivity varies in different positions by swinging his hand in the indicated motion. The students recognized they needed to make a sum or integral to add all values.

The students first studied the actual issue, then created a narrative about it with words and actions, and lastly, began to use formal mathematics to construct an integral. When creating the integral expression, they first found dR, a little slice of R or the resistance of each cylinder. Then, they added those resistances using the integral to get the entire resistance. They realized that each resistor had a certain amount of resistance that may be added. The study produced a blending diagram (Figure 9) to demonstrate how the students used their mathematical skills in this physics context to develop an integral.

3.7 The Application of Integral Concepts in Physics Problem-Solving by Physics Education Students with Conceptual Blending Framework Approach

3.7.1 Group 1

Figure 7 depicts how group 1 constructed the solution. Group 1 demonstrated initial understanding by substituting the resistivity function ρ(x) into the basic resistance equation R= ρL/A. This mirrored their approach of mixing physical parameters with mathematical symbols to compute the total resistance. However, the application demonstrates a primitive conceptual blend level, with the equation's physics significance remaining superficial. The students' narratives revealed that they saw integration as a mechanical summation of resistance over time, overlooking the deeper connection between the mathematical operation and its physical consequences. Thus, the results from group 1 met the high criteria for learning physics and mathematics concepts. Although there has been exceptional progress in some areas, more effort is required to enhance knowledge and integration across both fields.



Gambar 7. Group 1's Blend

3.7.2 Group 2

Figure 8 below is based on student L's work. Group 2's analysis revealed that they understood certain essential concepts in physics and mathematics. They could blend components from symbolic space and physics into mathematical notions by employing algebraic representations like differentials, integrals, and narratives to create new structures that integrated the three spaces. Despite successfully developing a novel expression for resistance, the group relied too heavily on mathematical manipulation and paid insufficient attention to the physics implications of their calculations. This shows they had not fully integrated their mathematical knowledge with their physical surroundings. Despite these inadequacies, group 2 met most conceptual blending indicators, particularly in combining symbolic space and physics into mathematics and creating new structures through narrative. However, they must continue to increase their understanding of the physical applications of the mathematical models they created. Thus, group 2's findings can be classified as "high" regarding comprehension of physics and mathematical concepts. However, there is room for growth, and the development demonstrated the group's potential to gain a deeper understanding in this context.

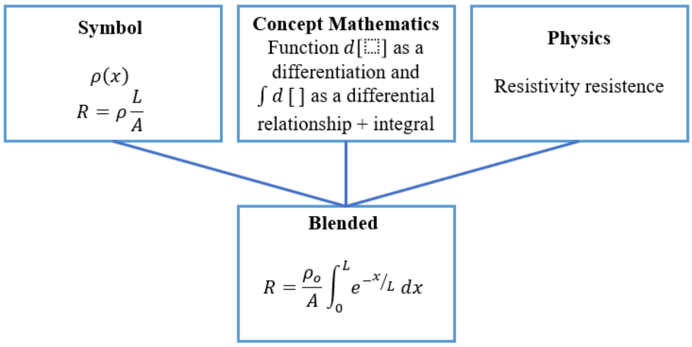


Figure 8. Group 2's Blend

3.7.3 Group 3

Figure 9 below illustrates how Group 3 constructed their solution. The study revealed that students in group 3 had met several key indications of mastering physics and mathematics concepts. They effectively transformed items from symbolic spaces, such as the ρ(x), and physical spaces, such as the length of a cylinder, to mathematical concept spaces by employing algebraic representations, such as integrals, as the first indicator. Furthermore, they performed well in the third and fourth indicators, where they employed narrative representations to develop new structures by blending aspects from symbolic space, physics, and mathematical concepts.

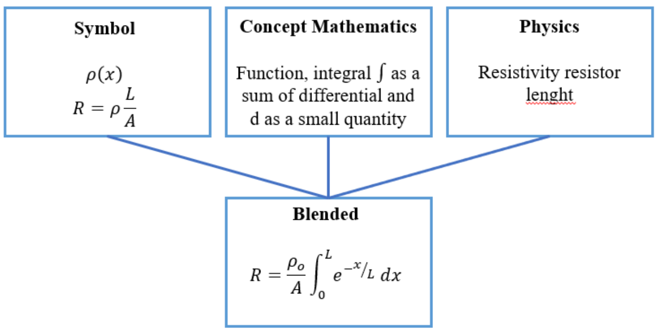


Figure 9. Group 3's Blend

However, several flaws should be noted. One is in the second indicator, where mathematical substitution constructs the resistance function as a summed quantity. Although students attempted to develop an integral expression for total resistance, they failed to consider the physics aspect, which required that the resistivity of different parts of an object should not be summed. Furthermore, the relationship between the mathematical manipulations applied and the fundamental physics principles was unclear.

Thus, group 2's findings can be classified as "high" in terms of understanding physics and mathematical concepts. Although some flaws remained, their capacity to transform pieces from symbolic and physical space into mathematical concept space, as well as their use of narrative representations to form new structures, demonstrated significant advancement in their comprehension.

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3.7.4 Group 4

Group 4 met all five conceptual blending indicators, thoroughly comprehending physics and mathematics concepts through blending approaches. They demonstrated complex concepts using a range of representations such as mathematics, narrative, visual, and hand gestures. The synergistic combination of mathematics and physics knowledge allowed them to develop unique solutions that were both theoretical and practical. This degree of comprehension demonstrated a high level of knowledge blending as they merged structures from the existing input while creating new structures more effectively solving the provided physics-mathematics problem.

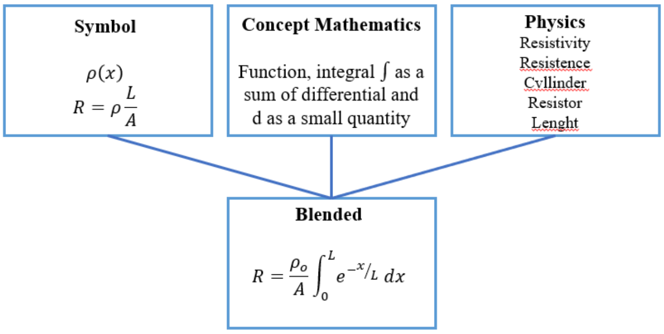

Figure 10. Group 4's Blend

Group 4 can be regarded as the most productive of the groups. They have successfully satisfied all of the conceptual blending indicators and showed an exceptional ability to efficiently integrate physics and mathematics knowledge. Therefore, group 4 met the "Excellent" criteria. This conclusion emphasizes the significance of integrating approaches to assist an extensive understanding of complex topics. Table 3 summarizes the results for each group based on the analysis:

Table 3. Category of Achievement of Five Indicators

No	Indicators	Point			
		Group 1	Group 2	Group 3	Group 4
1	One-way mapping from symbolic and physics space to mathematical concept space.	3	3	3	3
2	Ability to construct resistance functions as summed quantities through mathematical substitution.	2	2	2	3
3	Narrative representations that create new structures based on blending structures from all three input spaces.	3	3	3	3
4	When creating blends, use multiple representations, including algebraic representations, narrative, picture presentations, and hand gestures.	0	0	1	3
5	Involves a higher level of blending of mathematics and physics knowledge.	1	2	2	2
	Total Point	9	10	11	14
	Score	60	66,67	73,33	93,33
	Category	High	High	High	Excellent

Another study, which indicated that many students were unable to use their mathematics and physical knowledge simultaneously, supports the findings of this research [40]. The study revealed that there were both productive and unproductive groups, which is consistent with the findings of this research, which showed that group 4 was the most productive since it met the five indicators of conceptual blending.

However, this research has drawbacks. One key limitation is that the interview questions may have been incomplete, resulting in the omission of certain important components of conceptual blending theory. Furthermore, even with pledges of confidentiality, the integrity of participants' responses may be jeopardized, possibly due to social desirability bias. Another restriction is the diversity of participants' academic backgrounds and personal experiences, which can influence their responses and results from the research.

To elaborate on the findings and overcome its shortcomings, future research should consider employing larger and more diverse interview questions to cover a broader range of conceptual blending theories. Including a larger and more diverse sample of participants is also recommended to reduce the impact of individual variations and improve the findings' generalizability. Further research could use more solid mechanisms to confirm the validity of responses, such as anonymous digital submissions or indirect questioning approaches. These measures will help to better understand how conceptual blending can be used effectively in educational contexts to improve learning outcomes.

4 CONCLUSION

This study demonstrates how students employ integral concepts in physics problem-solving through a conceptual blending approach. The findings revealed that the student groups differed in understanding and implementing the concept. Group 4 stood out for its comprehensive understanding of physics and mathematical concepts. This study emphasizes the relevance of an interdisciplinary approach to teaching, arguing that using instructional strategies that allow conceptual blending can lead to a greater comprehension of physics and mathematical topics. It provides teachers with significant insights into developing instructional approaches that promote integrating mathematics and physics knowledge, thereby improving students' problem-solving skills and theoretical understanding.

AUTHOR CONTRIBUTION STATEMENT

FF contributed to conceptualizing the research framework, drafting the initial manuscript, leading the coordination of the study, formulating research questions and hypotheses, and analyzing and interpreting the data. SS contributed to the research design and methodology, developed qualitative analysis protocols, provided critical revisions to the manuscript, and supported the data collection process. EN contributed to overseeing the data collection, ensuring data accuracy, preparing and implementing research instruments, and participating in the manuscript drafting and review stages.

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