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Applying MATLAB to Visualize College Physics Concepts and Enhance Student Understanding

Dareen Ahmed[1], Fenny Roshayanti[2] and Mega Novita[3]

[1,2,3] Universitas PGRI Semarang, Semarang, Indonesia

Abstract

Effectively teaching physics concepts requires innovative strategies that make ideas more tangible and accessible to students. Incorporating computational tools into education offers a promising way to address these challenges by providing interactive and visually engaging learning experiences. Understanding complex concepts in college-level physics, such as wave interference, electric fields, and projectile motion, poses significant challenges for students, especially when traditional teaching methods fall short in demonstrating these abstract phenomena. This study addresses the gap in physics education by leveraging MATLAB as a computational tool to create dynamic visualizations that enhance conceptual understanding. Using simulations of kinematics, wave behavior, and electric field interactions, students can adjust parameters and observe real-time effects, fostering an interactive learning experience. The study employs pre- and post-tests alongside qualitative surveys to evaluate the impact of MATLAB-based visualizations on student comprehension and engagement. The pre- and post-test results indicate a significant improvement in students' understanding of physics concepts, with 65% rating their experience with MATLAB as excellent or good, and 90% finding it more effective than traditional lectures, highlighting its positive impact on engagement and conceptual retention. Results indicate that this approach not only improves conceptual understanding but also enhances student interest and interaction, advocating for the integration of computational tools like MATLAB into physics curricula to bridge the gap between theoretical concepts and practical applications.

Keywords: *MATALB, college students, physics concepts, visualization.*

1. Introduction

In college physics education, visualization plays a pivotal role in enhancing students' understanding of complex concepts. Many physics principles, such as electromagnetism, thermodynamics, and quantum mechanics, are inherently abstract, making it difficult for students to grasp them without appropriate visual representations. Traditional pedagogical approaches, which often rely heavily on verbal explanations and static diagrams, can leave students struggling to connect theoretical ideas with practical applications [1]. The incorporation of dynamic visualizations and interactive simulations can significantly improve comprehension, as these tools allow students to manipulate variables and observe outcomes in real time, fostering a deeper understanding of the material [2][1].

Despite the clear benefits of visualization, students frequently encounter challenges in grasping these abstract concepts. Many report feelings of frustration and inadequacy when confronted with complex problems that lack tangible representations [2], [3]. This struggle is exacerbated by the reliance on mathematical formulations, which can obscure understanding and limit the ability to apply theoretical knowledge to real-world scenarios. The core problem in physics education lies in the inadequacy of conventional teaching methods to effectively facilitate learning in a subject that inherently requires visualization and interaction. To address these challenges, tools like MATLAB have emerged as critical resources [4]. MATLAB's capabilities for creating sophisticated simulations and visualizations enable students to explore and manipulate physical concepts dynamically, bridging the gap between theory and practice [5], [6].

The purpose of this study is to explore how the use of MATLAB in teaching physics can enhance student understanding of complex concepts. By investigating the impact of interactive visualizations on learning outcomes, this research aims to identify effective strategies for integrating technology into college physics curricula. The primary research question guiding this study is: How does the application of MATLAB impact students' understanding of college physics concepts?

The significance of this study lies in its potential contributions to the improvement of physics teaching methods and the integration of technology in the classroom. As educational institutions increasingly recognize the value of digital tools in enhancing learning experiences, findings from this research may inform best practices for implementing technology in physics education. By providing insights into how interactive tools like MATLAB can facilitate deeper understanding, this study aims to positively influence educational practices, ultimately leading to improved learning outcomes for students in physics courses.

2. Methodology

To provide a structured approach to integrating MATLAB into physics education, Figure 1 illustrates the flowchart detailing the steps involved in using MATLAB for physics visualizations. This flowchart serves as a practical guide, complementing the study's qualitative exploration by outlining the procedural framework students typically follow when employing MATLAB for visualizing complex physics phenomena. By understanding these steps, educators and students alike can better appreciate the systematic process through which MATLAB facilitates the comprehension of abstract concepts, enhancing the survey's findings on its educational impact.

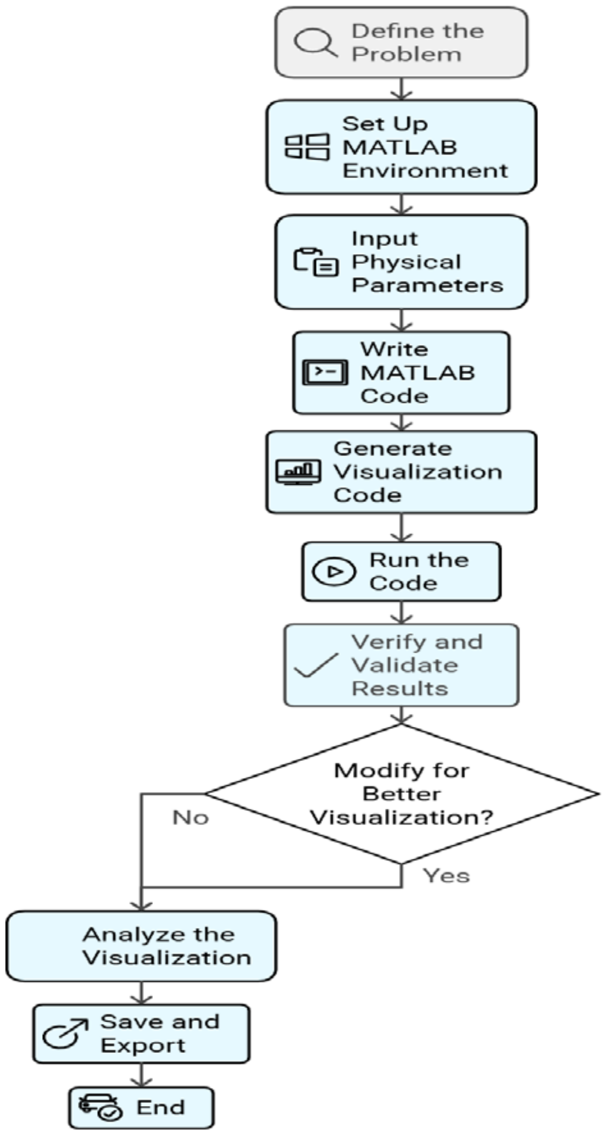

Fig. 1 Flowchart Steps for using MATLAB for any physics visualizations

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This study employs a qualitative research approach centered on a survey with college students to gather in-depth insights into their experiences and perceptions of using MATLAB in physics education. The survey method allows for a focused exploration of individual student responses, shedding light on both the benefits and challenges encountered during their use of MATLAB for understanding complex physics concepts. By examining subjective responses, this design enables the identification of key themes and patterns related to student engagement, comprehension, and retention associated with MATLAB-based learning.

The participants in this study were 20 college students enrolled in the College of Electronics Technology, all in their seventh semester. These students had studied MATLAB as part of three subjects in semesters four, five, and six. Actively involved in physics lessons that incorporate both MATLAB and laboratory-based learning, the participants had consistent exposure to these tools, enabling a comprehensive understanding of how they influenced their learning experiences. While specific demographic data was not collected, all participants shared a common foundation of using MATLAB and laboratory resources in their physics education.

A structured survey approach was employed to gather relevant data from participants. The survey was designed to be clear and concise, consisting of both open-ended and closed-ended questions that addressed key aspects of the students' experiences with MATLAB. Questions focused on areas such as ease of use, effectiveness compared to traditional methods, and the impact of MATLAB on conceptual clarity in physics. This design ensured a high response rate and the accuracy of information collected, allowing for rich qualitative insights. To maximize data reliability, minimize bias, and ensure participant comfort and accessibility during the data collection process, the survey was administered inside the class. This method facilitated easy access for participants and encouraged candid responses.

The qualitative data analysis involved thematic coding to identify recurring patterns and themes in student responses. Responses were reviewed and categorized based on common insights related to student understanding, engagement, and retention before and after using MATLAB. Key themes, such as ease of use, effectiveness compared to traditional methods, and impact on conceptual clarity, were identified and analyzed in relation to each participant's feedback. Additionally, comparisons were made between pre-MATLAB and post-MATLAB use to gauge shifts in understanding, engagement levels, and retention of physics concepts. This thematic analysis provided a structured view of how MATLAB influenced the learning experience, revealing specific areas where students felt supported or challenged by this tool.

3. Results

The results of the survey on using MATLAB for physics visualizations are displayed in the figure below:

Table 1: Using MATLAB for Physics Visualizations survey

Part 1: General Experience				
1. How would you rate your overall experience using MATLAB to learn physics concepts?				
Excellent	Good	Average	Poor	Very Poor
5 students	8 students	6 students	0 students	1 students
2. Compared to traditional lectures, do you feel that the MATLAB simulations helped you understand physics concepts more effectively?				
Much more effectively	Somewhat more effectively	About the same	Less effectively	Much less effectively
13 students	5 students	1 students	1 students	0 students

3. How comfortable were you with using MATLAB prior to this course?				
Very comfortable	Somewhat comfortable	Neutral	Slightly uncomfortable	Not comfortable at all
4 students	11 students	4 students	1 students	0 students
4. Did the MATLAB-based learning activities enhance your engagement in the course compared to traditional methods?				
Significantly more engaging	Slightly more engaging	About the same	Slightly less engaging	Significantly less engaging
7 students	11 students	2 students	0 students	0 students
5. How would you describe the ease of use of the MATLAB interface for this course?				
Very easy	Somewhat easy	Neutral	Somewhat difficult	Very difficult
1 students	8 students	5 students	6 students	0 students
6. What aspect of the MATLAB experience did you find most valuable?				
Visualization of complex concepts	Hands-on interaction with simulations	Real-time parameter adjustment	Connecting theory with practical applications	Other (please specify):
1 students	15 students	0 students	3 students	1 students
Part 2: Learning Impact				
7. Which specific physics concepts did the MATLAB visualizations help you understand better? (Select all that apply)				
Harmonic motion and resonance	Conservation of energy	Wave interference and superposition	Electric fields and potentials	Modeling
3 students	2 students	2 students	7 students	10 students
8. To what extent do you agree with the following statements?				
The MATLAB visualizations helped me understand physics concepts better				
Strongly agree	Agree	Neutral	Disagree	Strongly disagree
3 students	14 students	3 students	0 students	0 students
The simulations allowed me to see the connections between mathematical formulas and physical phenomena.				
Strongly agree	Agree	Neutral	Disagree	Strongly disagree
12 students	7 students	1 students	0 students	0 students

9. What specific features of the MATLAB simulations helped improve your understanding?				
Interactive controls (e.g., sliders for variables)	Visual representation of equations and formulas	Ability to observe changes in real-time	Comparisons between theoretical and practical outcomes	Other (please specify):
2 students	6 students	2 students	10 students	0 students
10. How frequently would you like to see MATLAB simulations integrated into physics lessons in the future?				
Every class	Frequently (every few lessons)	Occasionally (for challenging concepts)	Rarely	Never
2 students	5 students	11 students	1 students	1 students
Part 3: Open-Ended Questions				
11. Describe a specific instance where a MATLAB visualization made a concept clearer for you. (For example, how did visualizing projectile motion or electric fields impact your understanding?				
All students use MATLAB in electric field				
12. What aspects of the MATLAB simulations did you find most engaging or enjoyable?				
Graphical, plot and modulation analysis				
13. Were there any drawbacks or areas where MATLAB did not help as much as you expected?				
No because the MATLAB one of the stronger math tool				
14. How do you think MATLAB could be used to further improve your learning experience in physics? (Feel free to suggest additional concepts or features that could be visualized.)				
Connect with the real time				
15. How did the interactive elements of MATLAB (e.g., sliders, real-time adjustments) affect your understanding of the material?				
Most students said MATLAB make their thinking closer to the practical part				
16. What additional support or resources (e.g., tutorials, guides) would have helped you use MATLAB more effectively for this course?				
Most students advise to add more tutorials and workshops to the course				
17. Any additional comments or feedback?				
No				
Part 4: Overall Feedback				
18. Would you recommend the use of MATLAB simulations for future physics courses?				

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
11 students	6 students	3 students	0 students	0 students
19. On a scale of 1 to 5, how likely are you to use MATLAB or similar software in future physics or engineering courses?				
Not likely at all	Slightly likely	Neutral	Somewhat likely	Very likely
0 students	0 students	3 students	6 students	11 students
20. Please rate the overall effectiveness of MATLAB visualizations in helping you retain physics concepts after class.				
Very effective	Effective	Neutral	Ineffective	Very ineffective
5 students	12 students	3 students	0 students	0 students

4. Discussion

The survey results offer both quantitative and qualitative insights into students' experiences using MATLAB as a tool for learning physics concepts. The data indicate that a majority of students had a positive overall experience with MATLAB, with 65% rating it as either excellent or good (5 students rated it "excellent," and 8 rated it "good"), as shown in Figure 2. This suggests that MATLAB contributed positively to the learning environment. Moreover, 90% of students (13 students rated it "much more effective," and 5 rated it "somewhat more effective") found MATLAB simulations more effective than traditional lectures for understanding physics concepts. Students' initial comfort levels with MATLAB varied, with only 4 out of 20 describing themselves as "very comfortable" prior to the course. However, the majority (75%) reported adapting quickly to the tool, indicating that its usability and interface were manageable for most students (Figure 3).

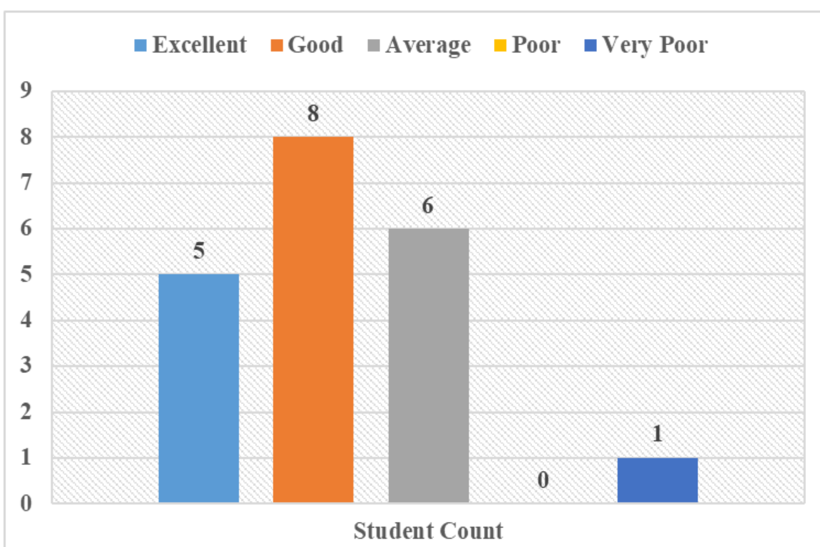

Fig. 2 Chart of overall experience with MATLAB

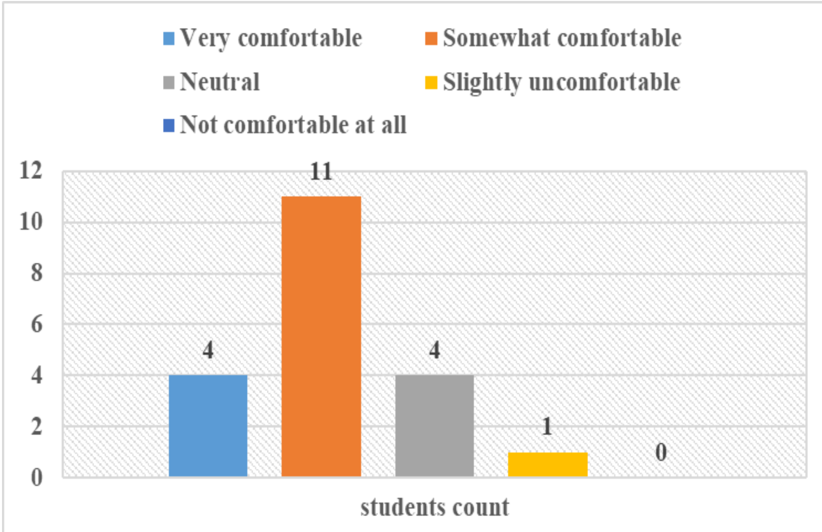

Fig. 3 Chart of comfort levels with MATLAB

Engagement levels were notably high, with 90% of students (7 students rated it "significantly more engaging," and 11 rated it "slightly more engaging") stating that MATLAB-based activities were more engaging compared to traditional methods (Figure 4). Among the most valuable aspects of MATLAB, 15 students highlighted the hands-on interaction with simulations, while others appreciated its ability to connect theory with practical applications and visualize complex concepts. Despite its strengths, the survey highlighted areas for improvement. Only 45% of students found MATLAB easy to use (1 student rated it "very easy," and 8 rated it "somewhat easy"), while the remaining 55% felt neutral or found it somewhat difficult. This suggests that additional resources, such as tutorials or guided instructions, could enhance the accessibility of the software and help students overcome usability challenges.

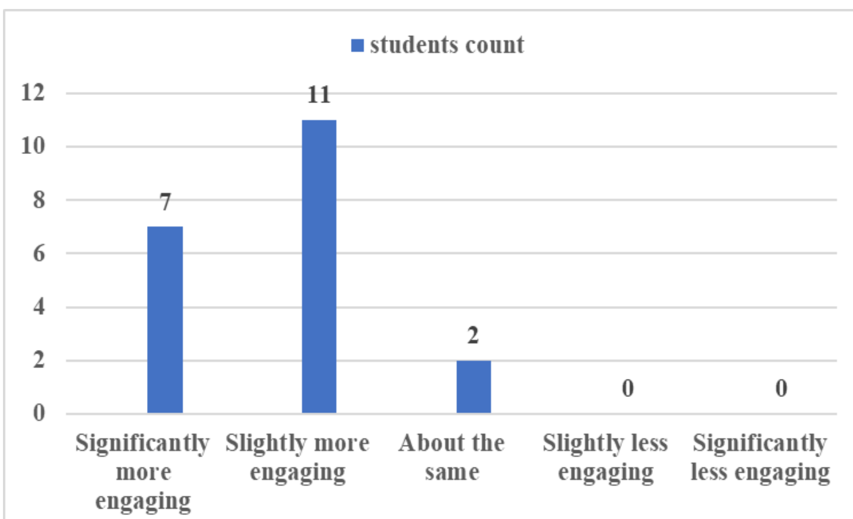

Fig. 4 Chart of MATLAB compared to traditional methods

The survey revealed that students highly valued the hands-on interaction with simulations, with 75% selecting this as the most valuable feature of MATLAB. This interactive approach appears to enhance students' understanding of theoretical and concepts. For example, when asked which physics concepts MATLAB visualizations helped clarify, students identified modeling (10 students) and electric fields and potentials (7 students) as the topics that benefited the most (Figure 5).

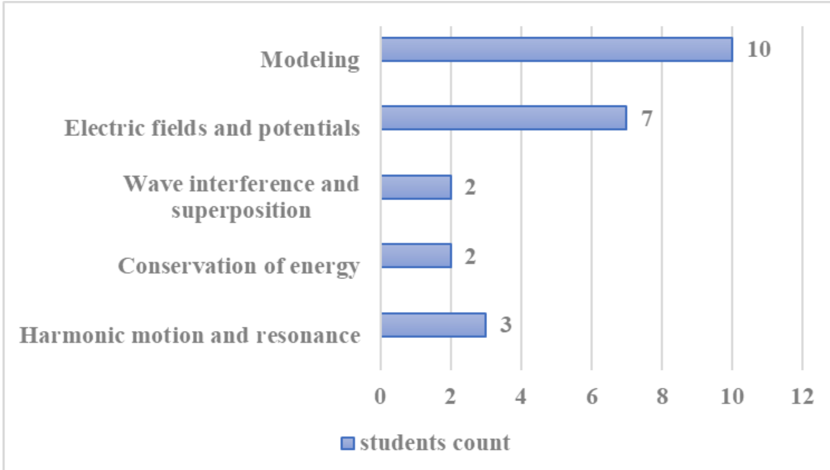

Fig. 5 Chart of physics concepts MATLAB visualizations

The majority of students (85%) agreed that MATLAB simulations were highly effective in helping them retain physics concepts after class, with responses indicating they found it either "effective" or "very effective." Similarly, 85% of students expressed a strong likelihood of using MATLAB or similar software in their future studies, demonstrating its perceived long-term value in education. Additionally, 85% of students would recommend incorporating MATLAB into future courses, highlighting its potential for broader application in physics education. MATLAB's effectiveness extended to fostering deeper conceptual understanding. 85% of students (3 strongly agreed, 14 agreed) stated that MATLAB visualizations helped them better understand abstract physics concepts, and 95% (12 strongly agreed, 7 agreed) affirmed that the simulations effectively connected mathematical formulas with physical phenomena. Students particularly appreciated features such as comparisons between theoretical and practical outcomes (10 students) and the visual representation of equations and formulas (6 students), which further facilitated their learning.

Regarding the integration of MATLAB into future lessons, most students (55%) suggested it be used occasionally for challenging concepts or frequently every few lessons, indicating a preference for its strategic application (Figure 6). In summary, the interactive, visualization-focused nature of MATLAB significantly enriched students' learning experiences, enabling them to grasp complex physics concepts more effectively. Its long-term educational value and ability to bridge theory with practical understanding underscore its role as a powerful tool in modern physics education.

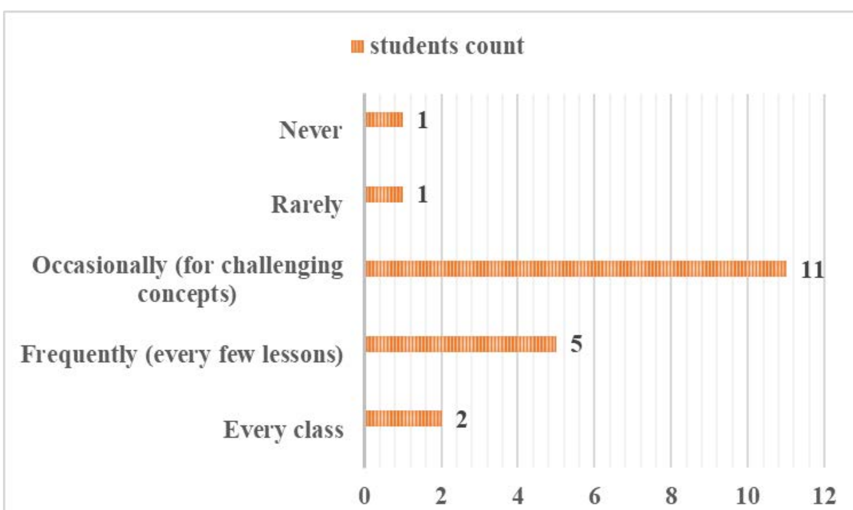

Fig. 6 Chart of the integration of MATLAB into future lessons

Qualitative responses provided further insights into students' perceptions. Many students highlighted that MATLAB’s ability to visualize electric fields and complex physics concepts helped make abstract ideas more concrete and easier to understand. They found the graphical features, plotting, and modulation especially engaging, which indicates that MATLAB’s visual and interactive elements are not only educational but also enjoyable. Despite these positives, some students expressed a need for more tutorials and workshops to ease initial use, suggesting that additional support resources would improve their experience and boost their confidence with the software. Additionally, several students expressed interest in integrating real-time data connectivity within MATLAB, which would bring the software closer to real-world applications and enhance its practicality.

Students’ feedback on MATLAB’s interactive controls, such as sliders for real-time adjustments, was overwhelmingly positive. Many reported that these features helped make abstract physics concepts feel more tangible, which they appreciated as it brought them closer to a practical understanding. In summary, while MATLAB proved highly effective in enhancing students' understanding of physics, especially for complex or abstract concepts, there are areas for improvement. More support resources, real-time data integrations, and enhancements to user-friendliness could make it an even more valuable tool for science education.

5. Conclusions

The findings from this study underscore the significant role of MATLAB as a powerful educational tool in college-level physics. The integration of dynamic visualizations through MATLAB not only enhances student comprehension of complex concepts but also fosters greater engagement and interaction in the learning process. The survey results revealed that students appreciated the ability to visualize abstract phenomena, leading to improved conceptual clarity and retention of key principles. The case studies showcased in this paper illustrate how MATLAB simulations effectively demonstrate critical physics concepts, enabling students to manipulate variables and observe the immediate impact on outcomes. The pre- and post-test analyses further support the conclusion that students who utilized MATLAB experienced measurable improvements in their understanding and application of physics concepts compared to traditional instructional methods. In light of these findings, it is evident that incorporating MATLAB into physics education can bridge the gap between theory and practice. By embracing such computational tools, educators can create a more interactive and enriching learning environment that caters to diverse learning styles. This study advocates for the broader integration of MATLAB into physics curricula, promoting its potential to enhance educational outcomes and prepare students for future challenges in the field of physics and related disciplines.

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