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Modern Physics Course in Online Learning: To What Extent are Students Successful in Learning?

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Abstract

The shift towards online education platforms has accelerated, highlighting the need for comprehensive evaluations of their effectiveness in delivering complex subjects like modern physics. This study aims to determine the success of students in an online modern physics course at Mataram University, focusing specifically on cognitive skills, conceptual understanding, and overall academic performance. Utilizing an experimental design, the research engaged 26 physics education students, aged 17 to 19, over a six-month academic period. The methods encompassed structured assessments through validated essay tests designed to measure distinct educational outcomes throughout the course duration. Findings reveal a broad variance in performance across measured metrics, with notable distinctions in students' abilities to grasp and apply complex physics concepts effectively. The results indicate that while online platforms can significantly enhance student learning outcomes when combined with interactive tools and effective engagement strategies, challenges such as limited hands-on experiences and variable technology access persist. These findings highlight the necessity for adaptive educational methods that cater to a diverse student body and underscore the potential of online education to extend beyond traditional classroom boundaries, enhancing learning through innovative approaches. This research contributes to the broader educational discourse by demonstrating that proactive adjustments in course design and delivery are essential to maximize the efficacy of online learning environments.

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INTRODUCTION

The integration of online learning platforms in modern education has significantly reshaped the delivery of academic content, particularly in the realm of physics. Despite the growing adoption of online learning, a clear research gap exists in understanding how these platforms specifically influence student success in learning modern physics—a subject characterized by abstract and complex concepts. Therefore, this study aims to address this gap by exploring the extent to which students succeed in modern physics courses conducted online. By identifying the challenges and benefits of online learning in this context, we hope to provide valuable insights into effective pedagogical strategies for physics education.

This shift has been driven by the need to provide flexible, accessible, and effective learning experiences. In Indonesia, particularly at Mataram University, the sudden transition to online learning during the COVID-19 pandemic has revealed unique challenges. Students have faced difficulties such as limited access to reliable internet, inadequate digital literacy, and the absence of physical interaction with instructors and peers. These local challenges underscore the need to examine the effectiveness of online learning in modern physics, which is often perceived as a challenging subject even in traditional settings. Addressing these specific local issues is critical to improving online education outcomes. For example, the transition to online learning environments has become increasingly prevalent due to advancements in technology and the need for remote education solutions (Bilad et al., 2022; Bilad, 2023; Zhao et al., 2020). Thus, this study seeks to evaluate the effectiveness of modern physics courses delivered through online platforms, focusing on how students at Mataram University navigate these environments and succeed despite the inherent challenges.

Online learning in physics has been shown to be highly effective when certain key elements are considered. Research indicates that the effectiveness of online learning depends on well-designed learning materials, active engagement of lecturers in the online environment, and interactions between lecturers and students or among students themselves (Aliyu et al., 2023; Asy'ari & da Rosa, 2022; Aristovnik et al., 2020). Additionally, self-regulatory skills such as time management and the ability to structure the learning environment play a crucial role in enhancing performance and efficiency in e-learning and blended learning settings (Kintu et al., 2017). For students at Mataram University, the need to develop these self-regulatory skills has been particularly pronounced due to the lack of structured physical environments and the varying levels of support available in online settings. Addressing these specific needs is crucial to improving student outcomes in modern physics courses conducted online. Online spaces offer unique opportunities for participation and network building, particularly for students who may lack access to traditional science activities and resources in their daily lives (Danielsson et al., 2023). This highlights the potential of online platforms to facilitate students' engagement in university physics programs.

A study on the integration of virtual simulations in physics courses revealed significant improvements in students' reasoning skills, particularly in abstract concepts of modern physics (Verawati et al., 2022). This suggests that the use of interactive and immersive tools in online platforms can enhance students' understanding and engagement, leading to better academic outcomes. Furthermore, the deployment of remote experiments and interactive online courses has provided students with opportunities to engage with real-life physical scenarios, thereby bridging the gap between theoretical knowledge and practical application. For instance, the OnPReX course at the Technische Universität Berlin, which incorporates remote experiments, has been successful in providing students with hands-on experience that complements their theoretical studies (Khachadorian et al., 2010). Such courses enable students to apply their learning in a controlled yet practical environment, fostering a deeper comprehension of complex physics concepts.

Despite these advantages, challenges remain in ensuring the effectiveness of online physics courses. Issues such as lack of interaction, limited hands-on experiences, and difficulties in maintaining student engagement are frequently cited. However, innovative approaches, such as the use of blended learning models and the incorporation of synchronous and asynchronous teaching methods, have shown promise in addressing these challenges (Bazelais et al., 2022). These models combine the flexibility of online learning with the benefits of face-to-face interaction, providing a more holistic educational experience.

Moreover, the role of online learning in enhancing student performance has been highlighted in various studies. For example, a study conducted at the University of Mataram demonstrated that integrating virtual simulations into the Learning Management System (LMS) platform significantly improved the reasoning performance of STEM students in modern physics courses (Verawati et al., 2022). Such findings underscore the potential of online learning platforms to not only replicate but also enhance traditional classroom experiences. The success of students in online modern physics courses is influenced by the design and implementation of the courses, the use of interactive and immersive technologies, and the ability to provide practical, hands-on experiences. As educational institutions continue to adapt to the evolving landscape of online education, the focus should remain on leveraging these technologies to create effective and engaging learning environments that support student success.

Despite the potential benefits of online learning in physics education, several research problems need to be addressed to fully realize its effectiveness. One of the primary challenges is the difficulty in teaching abstract and complex concepts through online platforms. Physics, by nature, involves intricate theories and principles that often require hands-on experiments and direct interaction with instructors to fully comprehend. This issue is exacerbated in online environments where physical presence is absent (Zhao et al., 2020).

Another significant problem is the variability in students' access to technology and the internet. In many regions, students face limitations in terms of internet connectivity and access to necessary devices, which can hinder their ability to participate fully in online courses. This digital divide creates disparities in educational opportunities and outcomes, making it crucial to develop inclusive strategies that ensure all students have the resources needed to succeed in online learning environments (Muhametjanova & Akmatbekova, 2019). Furthermore, maintaining student engagement and motivation in online courses poses a significant challenge. The lack of face-to-face interaction and the potential for distractions at home can lead to decreased motivation and lower participation rates.

Innovative pedagogical approaches, such as incorporating interactive elements and continuous assessment methods, are needed to keep students engaged and motivated throughout their online learning journey (Tiili & Manninen, 2015). Additionally, the effectiveness of online learning in improving students' conceptual understanding and critical thinking skills remains a contentious issue. While some studies have shown positive outcomes, others have reported minimal or no significant improvement compared to traditional face-to-face learning (Bazelais et al., 2022). This inconsistency highlights the need for further research to identify the factors that contribute to successful online learning experiences and to develop best practices for course design and delivery.

Addressing these research problems is essential to enhancing the effectiveness of online modern physics courses. By overcoming the challenges related to teaching abstract concepts, ensuring equitable access to technology, maintaining student engagement, and improving learning outcomes, educators can create robust online learning environments that support student success in physics education. The literature on online learning in modern physics courses presents a mixed but insightful picture of its effectiveness and the factors influencing student success. Studies have shown that well-designed online courses can significantly enhance student learning outcomes. For instance, Verawati et al. (2022) found that integrating virtual simulations into modern physics courses improved students' reasoning skills, particularly in understanding abstract concepts. This highlights the potential of using advanced digital tools to enhance cognitive skills in an online learning environment. Additionally, the deployment of remote experiments, as seen in the OnPReX course at the Technische Universität Berlin, has provided valuable insights into the practical application of theoretical knowledge (Khachadorian et al., 2010). These remote experiments allow students to engage with real-life scenarios, thereby fostering a deeper understanding of physics principles. This approach has been particularly effective in bridging the gap between theoretical learning and practical application, which is often a challenge in online education.

However, the literature also underscores several challenges associated with online learning. Issues such as limited interaction, lack of hands-on experiences, and difficulties in maintaining student engagement are commonly reported. Studies by Zhao et al. (2020) emphasize the importance of addressing these challenges through innovative pedagogical strategies and the integration of synchronous and asynchronous teaching methods. By combining the flexibility of online learning with interactive and engaging content, educators can create a more effective learning environment. Furthermore, the variability in students' access to technology and the internet presents a significant barrier to online learning. Research by Muhametjanova and Akmatbekova (2019) highlights the disparities in educational opportunities caused by the digital divide. Ensuring that all students have access to the necessary resources is crucial for the success of online education.

In conclusion, while the literature on online modern physics courses presents both opportunities and challenges, it is clear that with the right design and implementation, online learning can be an effective mode of education. By leveraging advanced digital tools, addressing access issues, and maintaining student engagement, educators can enhance the learning experience and outcomes for students in modern physics courses.

Study Objective

The primary objective of this study is to evaluate the extent to which students are successful in learning modern physics through online courses. This involves assessing various factors such as cognitive skills, conceptual understanding, and overall academic performance. By analyzing these aspects, the study aims to provide a comprehensive understanding of the effectiveness of online physics education. The specific objectives of the study are to determine the impact of online learning on students' academic performance in modern physics.

The hypothesis of the study is that students in online modern physics courses, when provided with interactive digital tools, will demonstrate significant improvements in their academic performance. This hypothesis is based on the premise that well-designed online courses can replicate and even enhance the learning experiences typically found in traditional classroom settings.

METHODS

Research Design

The experimental design of this study focused on the evaluation of a modern physics course delivered entirely online, targeting a group of students enrolled at Mataram University. This single-group intervention spanned six months and was structured to enhance specific educational outcomes: Cognitive Skills (CS), Conceptual Understanding (CU), and Overall Academic Performance (OAP). The essay tests used to assess these outcomes were carefully aligned with the course objectives. For Cognitive Skills, tasks were designed to reflect higher-order thinking skills, as outlined in Bloom's taxonomy, with a focus on problem-solving and critical thinking in the context of modern physics. Conceptual Understanding was tested through open-ended questions that required students to explain key physics concepts, ensuring alignment with the course's learning goals, such as understanding wave-particle duality and quantum mechanics. Cognitive skills were assessed by measuring students' ability to handle physics-related cognitive tasks during two different sessions within the course. Conceptual understanding was gauged through a mid-course test conducted three months after the start of the intervention, aimed at determining how well students grasped key physics concepts. Finally, overall academic performance was measured at the course's conclusion, providing a holistic view of student achievement throughout the semester. The comprehensive alignment of these assessments with the course objectives ensured that the tests accurately measured the intended learning outcomes.

Participants

The participant pool consisted of 26 students from the physics education study program at Mataram University, with ages ranging from 17 to 19 years. This specific age range was chosen to maintain homogeneity in the sample, as cognitive and developmental stages during late adolescence are relatively stable, minimizing potential variability that could confound the results. The selected age group also represents the typical university student demographic in Indonesia, making the findings more generalizable to similar educational contexts. Ethical standards were rigorously adhered to throughout the study to ensure the well-being and informed consent of all participants. Students were briefed about the study's aims, the nature of their involvement, and their rights as research subjects, including the confidentiality of their data and their right to withdraw from the study at any time without penalty.

Research Procedures

The methodology was systematically structured beginning with the preparatory phase, which involved setting up the online learning environment, curating content, and ensuring all educational materials were aligned with the study's goals. This phase included close collaboration with subject matter experts to ensure that the course content reflected the core objectives of modern physics education, such as mastery of quantum theory and relativistic mechanics. Additionally, specific steps were taken to align these objectives with the designed assessment tools to ensure coherence throughout the intervention. The intervention then proceeded for six months, during which data on the predefined educational outcomes were collected at strategic points to monitor progress and the effectiveness of the course design. This phase was critical not only for data collection but also for making any necessary adjustments to the course delivery based on interim findings. The final phase involved data analysis and compilation of results into a comprehensive report that detailed the findings and provided insights into the effectiveness of online learning in teaching modern physics.

Instruments

To accurately measure the variables of interest—cognitive skills, conceptual understanding, and overall academic performance—a series of essay tests was developed. The content of these essay tests was explicitly designed to reflect the learning objectives of the modern physics course. For instance, the essay questions for Cognitive Skills required students to solve problems related to quantum mechanics and wave theory, demanding not just rote memorization but the application of theoretical knowledge to novel situations. Conceptual Understanding was tested through open-ended questions that asked students to articulate their understanding of complex phenomena, such as the implications of the Heisenberg Uncertainty Principle or the behavior of particles at a subatomic level. These instruments were meticulously designed to align with psychometric principles, ensuring that they were both valid and reliable for assessing educational outcomes. The validation process included a two-stage approach: first, expert reviews were conducted to assess the content validity, ensuring that the test items were representative of the course material. Second, a pilot test with a smaller group of students was performed to evaluate the reliability of the instruments, using Cronbach's alpha to confirm internal consistency. The reliability and validity of these tests were confirmed through statistical analyses, establishing that the instruments could reliably reproduce consistent results under similar conditions and genuinely measure what they were intended to.

Data Analysis

Descriptive and inferential statistical methods were used to analyze the data collected from the tests. Descriptive statistics provided a preliminary overview of the students' performance by calculating average scores, which helped in understanding the general effectiveness of the course delivery. In addition to mean and standard deviation, measures such as skewness and kurtosis were calculated to assess the distribution of scores, ensuring that the assumptions for parametric testing were met. The use of ANOVA for inferential statistics was pivotal in this research, as it allowed for a detailed examination of the differences in mean scores between different testing times and across various educational outcomes. The ANOVA results indicated significant differences in student performance across different time points, particularly between mid-course and final assessments. These differences reflect the effectiveness of the online course structure in enhancing students' conceptual understanding and cognitive skills over time. The analysis demonstrated that students showed marked improvement in their ability to apply theoretical knowledge to problem-solving tasks by the end of the course. The choice of ANOVA was based on its ability to handle comparisons across multiple groups and time points, which was essential for assessing the impact of the online intervention on student learning outcomes. The significant differences observed in the ANOVA results highlight the practical implications for online course design in modern physics. Specifically, these findings suggest that iterative assessments and continuous interaction in the online platform significantly enhance student engagement and learning outcomes. This has important implications for the future implementation of online learning strategies in STEM fields, where hands-on experience and conceptual understanding are critical.

Finally, potential limitations of this study include the relatively small sample size and the single-institution focus, which may affect the generalizability of the findings. However, these limitations were mitigated by ensuring a rigorous experimental design and by employing robust statistical methods to control for potential confounding factors. Additionally, the six-month duration of the study provided ample data points to strengthen the reliability of the findings.

RESULTS AND DISCUSSION

This study assesses the success of students in an online modern physics course, focusing on cognitive skills, conceptual understanding, and overall academic performance. Leveraging an experimental design, the research targeted students from Mataram University's physics education program. Results presented herein are based on a systematic collection of scores across semesters, evaluating students' cognitive capabilities, depth of conceptual understanding, and overall academic outcomes within the course framework. The analysis explores variances in performance, aiming to correlate educational delivery methods in an online setting with student success rates, thereby addressing broader questions about the efficacy of online physics education in fostering deep, actionable learning among undergraduates.

The results presented in Table 1 provide detailed insights into the academic performance of 26 students in a modern physics course delivered through online platforms. The table displays scores across three critical metrics: Cognitive Skills (CS), Conceptual Understanding (CU), and Overall Academic Performance (OAP). These scores were derived from structured assessments designed to evaluate distinct aspects of the students' learning and comprehension.

Table 1. Students' academic performance score in modern physics courses

Students	CS score	CU score	OAP score
Students 1	90.00	78.70	66.93
Students 2	76.00	72.10	64.07
Students 3	56.00	68.80	61.21
Students 4	82.00	58.90	66.93
Students 5	83.75	65.50	61.21
Students 6	90.00	82.00	64.07
Students 7	90.00	85.30	81.21
Students 8	88.24	58.90	69.79
Students 9	90.00	65.50	69.79
Students 10	90.00	62.20	55.50
Students 11	66.00	68.80	84.07
Students 12	27.75	72.10	69.79
Students 13	76.38	52.30	58.36
Students 14	83.25	65.50	69.79
Students 15	90.00	65.50	69.79
Students 16	84.00	65.50	61.21
Students 17	20.00	58.90	46.93
Students 18	84.50	75.40	66.93
Students 19	86.50	65.50	66.93
Students 20	78.25	72.10	58.36
Students 21	73.50	55.60	72.64
Students 22	71.75	68.80	72.64
Students 23	64.00	65.50	64.07
Students 24	74.25	88.60	78.36
Students 25	71.75	62.20	66.93
Students 26	72.25	68.80	69.79

The scores for Cognitive Skills range widely, reflecting the varied ability of students to apply theoretical knowledge to solve physics-related problems effectively. The highest score recorded was 90.00, achieved by multiple students, indicating a strong grasp of the cognitive components of the course. The lowest score was a notable outlier at 20.00, suggesting significant challenges in cognitive applications for that student. This broad range indicates the diversity in cognitive capabilities among the students and highlights the need for differentiated teaching strategies to cater to the wide spectrum of learners.

Conceptual Understanding scores were generally more consistent but still showed considerable variability, with a high of 88.60 and a low of 52.30. These scores reflect the students' grasp of physics concepts after the mid-course assessments. The high scores suggest that several students were able to deeply understand and integrate complex physics concepts effectively. In contrast, the lower scores indicate areas where the course content or delivery method may need adjustment to enhance comprehension.

Overall Academic Performance scores, which consider all aspects of the students' engagement and achievement in the course, also varied. The scores ranged from 84.07 to 46.93, with the highest scores suggesting excellent integration and application of the course materials and the lowest indicating potential barriers to successful learning, such as inadequate engagement or external factors affecting performance.

Table 2. Descriptive analysis results of students' academic performance in modern physics courses

Academic performance	N	Mean	SD	SE	Coef. of var.
Cognitive Skills (CS)	26	75.389	17.758	3.483	0.236
Conceptual Understanding (CU)	26	68.038	8.721	1.710	0.128
Overall Academic Performance (OAP)	26	66.819	7.855	1.540	0.118

The data in Table 2 and Figure 1 presents a comprehensive overview of the students' performance in the online modern physics course, focusing on three critical areas: Cognitive Skills (CS), Conceptual Understanding (CU), and Overall Academic Performance (OAP). The average scores for CS, CU, and OAP are 75.389, 68.038, and 66.819, respectively. These means suggest moderate performance across all metrics, with cognitive skills scoring slightly higher on average than the other areas.

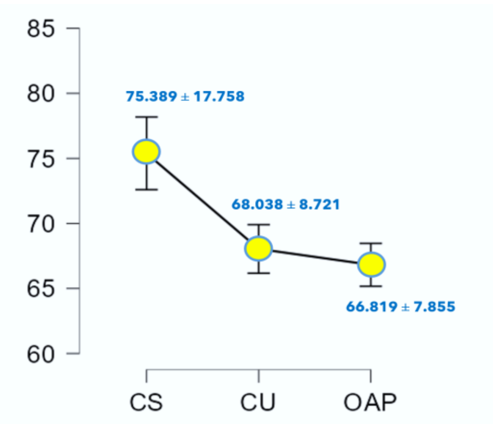

Figure 1. Descriptive plot of students' academic performance in modern physics

The standard deviations (SD) are 17.758 for CS, 8.721 for CU, and 7.855 for OAP, indicating the variability of scores within each metric. The coefficient of variation (Coef. of var.) further illustrates this variability, particularly in CS, where it reaches 0.236 compared to 0.128 for CU and 0.118 for OAP. This suggests that while students generally performed consistently in CU and OAP, their performances in CS were more varied, potentially indicating differing levels of engagement or understanding of the course's cognitive demands.

Table 3. ANOVA test results of differences in students' academic performance scores

Cases	SS	df	MS	F	p	η^2
Within Subjects Effects	1117.699	2	558.849	4.602	0.015	0.155
Residuals	6072.142	50	121.443	-	-	-
Total	7189.841	52	-	-	-	-

Table 3 details the results of the ANOVA performed to examine the differences between the students' scores across the three measured areas. The within-subjects effects, representing the variability attributable to differences in performance across CS, CU, and OAP, show a sum of squares (SS) of 1117.699 with a mean square (MS) of 558.849. The F-statistic is 4.602 with a significant p-value of 0.015, indicating that there are statistically significant differences in the performance scores across the three domains of academic performance. The effect size, represented by η^2 (eta squared), is 0.155. This value indicates a moderate effect size, suggesting that about 15.5% of the variance in the academic performance scores can be attributed to the differences between the three types of performance metrics. This finding supports the notion that different aspects of the learning experience in the modern physics course affect student outcomes in distinct ways.

The success of students in an online modern physics course, with a focus on cognitive skills, conceptual understanding, and overall academic performance, is a multifaceted area that can be influenced by various factors. This study's findings align with those of previous research, particularly the study by Barnes and Vance (2022), which demonstrated that students perform equally well in online examinations compared to face-to-face settings, suggesting the potential effectiveness of online modalities in maintaining educational standards in complex subjects like modern physics. However, the observed variability in students' performance, especially in cognitive skills, contrasts with the more uniform outcomes reported in studies like Yoel et al. (2022), where a more structured online environment led to less variability in student performance. This discrepancy might be due to the nature of the tasks assigned in this study, which required not only theoretical understanding but also higher-order thinking and problem-solving, areas that are more challenging to foster in an online setting without direct supervision.

One potential confounding variable that could have influenced the results is the varying levels of technological proficiency among the students. As seen in research by Subotic and Poščić (2014), students' comfort with online learning tools directly impacts their engagement and performance. In this study, some students may have struggled with navigating the online platform or using the digital tools, which could explain the lower scores in cognitive skills for certain individuals. Additionally, external factors such as internet stability and access to resources—commonly referred to as the digital divide—might have contributed to the discrepancies in student performance, especially in a region like Mataram, where technological infrastructure is still developing.

Another factor worth considering is the cognitive load imposed by the online learning environment. Research by Cheng (2024) on cognitive load theory in online STEM courses suggests that asynchronous learning environments, while flexible, can impose higher cognitive demands on students, particularly when complex topics like quantum mechanics or wave-particle duality are involved. The students in this study may have experienced cognitive overload during certain sessions, which could have contributed to the observed variability in both conceptual understanding and overall academic performance.

The findings from this study also offer several practical implications for educators and policymakers. For educators, the significant differences in performance across cognitive skills, conceptual understanding, and overall academic performance highlight the need for differentiated instructional strategies. Online courses should not rely solely on passive content delivery, but rather incorporate interactive elements like virtual simulations and real-time problem-solving sessions. As demonstrated by Verawati et al. (2022), the integration of virtual simulations in modern physics courses significantly enhances conceptual understanding, especially for abstract concepts such as quantum mechanics. This aligns with the success observed in higher-performing students in this study, where better grasp of abstract concepts correlated with improved overall performance.

From a policy perspective, this study underscores the importance of ensuring equitable access to technology and resources in online education. The digital divide, as discussed by Muhametjanova and Akmatbekova (2019), remains a significant barrier to achieving consistent educational outcomes. Policymakers must focus on providing infrastructure support, such as improving internet access and distributing necessary devices, to ensure that all students can engage fully in online learning environments. Moreover, targeted training programs that enhance both students' and teachers' proficiency with online learning tools could help mitigate the variability in performance attributed to technological challenges.

Additionally, the significant differences observed across the three measured metrics (Cognitive Skills, Conceptual Understanding, and Overall Academic Performance) suggest that online learning affects each dimension of student performance differently. This finding is consistent with research by Faulconer et al. (2022), which emphasizes the importance of aligning course design with specific learning outcomes to optimize educational results. For example, while cognitive skills may benefit from structured, problem-based learning activities, conceptual understanding requires a more immersive, exploratory approach, such as the use of simulations and visualizations, which can make abstract physics concepts more tangible for students. The practical implication here is that educators should tailor their online course design to address the distinct needs of each learning domain.

Furthermore, this study’s ANOVA results, which indicate significant differences in student performance over time, reflect the dynamic nature of learning in online environments. As students progress through an online course, their ability to adapt to the format and develop self-regulatory learning habits—such as time management and independent problem-solving—becomes crucial. This echoes the findings of Kintu et al. (2017), who argue that self-regulation is a critical factor in the success of online learners. In the context of this study, the students who developed these skills over the six-month course period tended to perform better in both cognitive tasks and overall academic assessments.

Despite the promising results, several challenges remain in optimizing the online learning experience for modern physics education. One of the primary limitations identified in this study is the lack of hands-on experience, a critical component of physics education. While online simulations and remote experiments, like those employed in the OnPReX course at Technische Universität Berlin (Khachadorian et al., 2010), have shown to be effective substitutes for physical laboratories, they cannot fully replicate the tactile and kinesthetic experiences of traditional lab work. This limitation may explain the lower performance of some students in this study, particularly in tasks requiring direct application of theoretical knowledge to physical experiments. Addressing this challenge requires further innovation in the development of virtual labs and augmented reality tools that can better simulate the physical experimentation process in an online setting.

In conclusion, the results of this study offer important insights into the effectiveness of online learning for modern physics courses. While the online format provides flexibility and accessibility, it also presents challenges that must be addressed through strategic course design and policy interventions. Educators must focus on creating interactive, simulation-based learning environments that foster deep conceptual understanding, while also supporting students in developing the self-regulatory skills necessary for success in an online format. Policymakers, on the other hand, must ensure that students have equitable access to the technological resources required to fully participate in online learning, as well as provide training and support to both students and educators in using digital tools effectively.

Future research should explore the long-term impact of online learning on student performance in STEM fields, particularly in courses that involve complex and abstract content like modern physics. Additionally, further studies could investigate the development of more advanced virtual and augmented reality tools to enhance the hands-on experience in online courses. By continuing to innovate and address the challenges of online learning, educators and policymakers can ensure that students are fully equipped to succeed in a digital learning environment.

CONCLUSION

The findings of this study underscore the nuanced effectiveness of online learning platforms in delivering modern physics courses, as evidenced by the varied performance in cognitive skills, conceptual understanding, and overall academic performance among students at Mataram University. The results reveal that while online courses can facilitate substantial educational achievements, they also highlight significant challenges that need addressing, such as the variability in student access to technology, the need for enhanced interaction, and the importance of hands-on experiences in learning abstract physics concepts.

The success of online physics education, as shown through this research, depends heavily on the thoughtful integration of interactive digital tools, well-structured and engaging content, and comprehensive support systems tailored to student needs. Moving forward, the insights gained from this study should inspire continuous improvement in online course delivery, aiming to maximize the pedagogical potential of digital platforms and ensure equitable educational opportunities for all students. This study not only contributes to the ongoing dialogue on the efficacy of online learning but also serves as a foundation for future research aimed at optimizing educational strategies in the sciences within the digital learning landscape.

LIMITATIONS AND RECOMMENDATIONS

One notable limitation of this study is its focus on a single group of students from Mataram University's physics education program, which may not provide a broad enough sample to generalize the findings across different demographics or educational contexts. The inherent variability in technological access and digital literacy among students could also skew the results, as these factors significantly influence the effectiveness of online learning. Furthermore, the study was conducted over a relatively short period (six months), which may not fully capture long-term learning outcomes and adaptations in student behavior and performance in an online learning environment.

In light of these limitations, future research should consider a more extended study period and include a more diverse participant pool across multiple institutions to enhance the generalizability of the findings. It is also recommended that future studies incorporate a control group or multiple experimental groups to compare different online teaching strategies and their impacts on student learning outcomes. Additionally, integrating qualitative data through student feedback and interviews could provide deeper insights into the student experience, which would help in fine-tuning online courses to better meet learner needs. Addressing these recommendations will contribute to a more robust understanding of online physics education's efficacy and pave the way for innovative educational practices that can adapt to the evolving demands of the digital era.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Conflict of interests

The authors declare no conflict of interest.

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