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Enhancing Learning Outcomes in Applied Physics Through Web-Based Simulation Media

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Abstract: This study aims to develop interactive web-based simulation learning media for applied physics subjects and to evaluate the validity, practicality, and effectiveness of the media in improving student learning outcomes. The research method used is Research and Development (R&D) with the ADDIE development model, which includes five stages: analysis, design, development, implementation, and evaluation. Validation was carried out by media and content experts, followed by field trials involving 69 students from SMKN 1 Bintan Utara. The research instruments used structured Likert-scale questionnaires to assess the validity, practicality, and effectiveness of the media. The validation results indicated that the learning media were valid and aligned with learning needs. The practicality test yielded an average score of 84.94%, categorized as highly practical. Effectiveness testing through gain score analysis showed an improvement in student learning outcomes, with a gain value of 0.32, categorized as moderate. In conclusion, the web-based simulation media is effective, valid, and practical in enhancing students' understanding of concepts and learning outcomes in applied physics.

Keywords: Educational Technology; Learning Media; Physics; Web-Based Simulation

Introduction

Education is the main pillar in human resource development (AlGerafi et al., 2023; Amani et al., 2021; Muskhir et al., 2023). In the era of globalization and technological advances in the industrial revolution 4.0 that is being experienced by society, the need for innovative and affordable education is increasingly becoming a top priority (Kaur et al., 2023; Lampropoulos, 2023). Facing the complexity of the times, one of the growing branches of science is distance education (Gummadi et al., 2023; Li et al., 2023; Paulauskas et al., 2023). PEducation is not only a means to acquire knowledge, but also the main foundation in shaping individuals who have adequate skills, deep understanding, and competitiveness. Education is not only concerned with improving the capacity of individuals, but is also a top priority for the development of society and the progress of the nation. In line with the era of industrial revolution 4.0 and digitalization, the transformation of education is an urgent necessity (Fitria, 2023; Poçan et al., 2023). This is necessary so that the younger generation can understand, adapt and face the dynamics of global change with a deep understanding and relevant skills.

Learning applied physics often faces great challenges, especially in conveying complex and abstract concepts to students (Bouchée et al., 2023; Djudin, 2023). Applied physics integrates physics theories with their application in real contexts, such as mechanics, electromagnetism, and thermodynamics, which are often difficult to understand if only explained through traditional approaches such as lectures and textbooks. Conventional learning methods cannot often depict the dynamics of physics processes visually and interactively, thus limiting student understanding (Abbasian, 2024; Girwidz & Kohnle, 2022; Wibowo et al., 2023). Therefore, an innovative approach is needed that can present these concepts in a more real and understandable form, one of which is through web-based simulation media.

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Web-based simulation media offer great potential in overcoming the obstacles of learning applied physics (Dhang et al., 2023; Maharani, 2023). Simulations allow students to view, manipulate, and understand physics phenomena through interactive visual representations, which cannot be achieved solely by theory learning or conventional laboratory experiments. Web-based simulations not only provide easy access to learning materials but also allow students to experiment with various scenarios without time constraints, costs, or safety risks. This technology provides more flexible learning, where students can learn according to their own pace and learning style, thus improving comprehension and retention of the material.

The development of web-based simulations in applied physics learning is driven by the rapid advancement of information and communication technology (Ormancı et al., 2020; Rehman et al., 2021). With increasingly sophisticated computing capabilities, simulations can be made more realistic and detailed, approaching the experience of real experiments in the laboratory. For example, fluid dynamics simulations or electromagnetic interaction simulations can be created with a high degree of accuracy, allowing students to observe complex phenomena directly. This is particularly beneficial in applied physics, where hands-on experiments may require expensive equipment or special conditions that are difficult to replicate in the classroom.

In addition, web-based simulations create problem-based learning and discovery learning, both of which are effective approaches in applied physics (Idrus, Fitrawati et al., 2021; Perdana et al., 2020). Students can explore various scenarios, ask questions, and seek answers through virtual experiments conducted in simulations. Thus, simulation is not only a visual aid but also an active learning tool that encourages students to think critically and understand physics concepts deeply. This is important in learning applied physics which requires high analytical skills.

However, despite its great potential, the effectiveness of web-based simulations in applied physics learning depends on proper design and implementation (El Kharki, Berrada, & Burgos, 2021). Simulations should be designed with pedagogical needs in mind, content compatibility with the curriculum, and ease of use by students and teachers. The interactivity and visualization aspects should be developed in such a way that it can motivate students and increase their engagement during the learning process. In addition, simulations need to be equipped with informative feedback so that students can understand their mistakes and improve their understanding.

Previous research shows that the use of interactive simulation media can significantly improve student learning outcomes (Alam, 2023; Kamran et al., 2023; Tsirulnikov et al., 2023). Students who learn using simulations usually show better concept understanding, higher critical thinking ability, and more effective problem-solving skills compared to students who learn through traditional methods. In addition, web-based simulations also increase students' learning motivation as they provide a more enjoyable and engaging learning experience (Moozeh et al., 2023; Zatarain et al., 2023). This is important in the context of applied physics, where student motivation and engagement are highly influential to learning success.

The availability of web-based simulations that can be accessed anytime and anywhere also adds flexibility to the learning process (Guzmán & Joseph, 2021; Praherdhiono & Prihatmoko, 2023). Students are no longer limited to class schedules or laboratory availability to conduct experiments. They can access simulations through digital devices such as laptops, tablets, or smartphones, allowing them to study outside of school hours and reflect on the material that has been learned. This supports more in-depth independent learning, where students can repeat simulations to reinforce their understanding without time pressure.

Overall, the development and implementation of interactive web-based simulation learning media offers a great opportunity to improve learning outcomes in applied physics subjects. By providing an interactive, flexible and immersive learning experience, web-based simulations can bridge the gap between theory and practice, thus helping students to not only understand physics concepts in depth but also apply them in real situations. By continuously developing this technology and integrating it into the educational curriculum, it is expected that the quality of applied physics learning can be significantly improved.

Method

Research Method

The research method used in this study is Research and Development (R&D). Research and Development or R&D is a procedure or series of processes aimed at creating new products or improving existing products (Taherdoost, 2024). This research, using the ADDIE development model. This model helps understand the process of designing a design display system (Dong, 2021; Samsudin et al., 2021). For example, product development can provide a direct picture for users about the steps of designing an interactive web and how the interactive web works in supporting the learning process.

Research Procedures

The media development stages follow the ADDIE method in a circular manner, namely Analysis, Design, Development, Implementation, and Evaluation. This approach can be used to create models, learning techniques, learning methods, and learning media and teaching materials. Figure 1 shows the stages of the ADDIE model used in this study.

Figure 1. Development stages of the ADDIE model

The first stage begins with the analysis stage which aims to identify the fundamental needs in making an interactive web, including the problem of low student understanding and not optimal utilization of technology in learning. This stage also considers the potential of developing technology and the high interest of students in the use of technology, which can be utilized as an opportunity to support the learning process. In the second stage, design, the development of an interactive web design is carried out by determining relevant elements and compiling a storyboard as a guide to creating an effective user interface.

The third stage, development, involves the creation of an interactive web and product validation by media and material experts to ensure the feasibility of its use. The fourth stage, namely Implementation, is carried out by involving students in testing the interactive web that has been validated and followed by evaluating student performance through pre- and post-use tests. The fifth or final stage is the evaluation stage which aims to assess the effectiveness of the interactive web through student feedback and quantitative and qualitative data analysis. The results of this evaluation will determine whether the interactive web is feasible to use as a learning support tool in the independent curriculum. Overall, the ADDIE process ensures that the development of the interactive web is carried out systematically and focuses on improving students' learning experience.

Research Subject

This study involved four experts, consisting of two material experts and two media experts, to assess the validity of web-based interactive learning media on applied physics subjects. The material experts assessed the suitability of the content with the curriculum, while the media experts evaluated the design, interactivity, and ease of use. User trials were conducted on 69 students of SMKN 1 Bintan Utara from two different majors, to obtain feedback on the effectiveness of the media in real learning. Students participated in evaluating aspects of usage, concept understanding, and interactivity, which served as the basis for improving the media. Through a combination of expert evaluation and user trials, this research aims to develop a valid, practical and effective learning media to improve applied physics learning outcomes.

Research Instruments Data

The instrument data in this study used a non-test device in the form of a structured questionnaire to collect data from media experts, material experts, and students. The instrument used was a Likert scale-based questionnaire that measured respondents' opinions on the feasibility of the media in material and technical aspects. This questionnaire was used to evaluate the success of the development research, with different categories of questions according to the background and specialization of the respondents, such as material experts and media experts. Each respondent provides an assessment based on a scale from Strongly Disagree to Strongly Agree.

The questionnaire also assessed several indicators, such as quality, effectiveness, relevance, and ease of use of the media. In the instrument validation, media and material experts responded to aspects such as display quality, learning effectiveness, and ease of navigation. Meanwhile, users (learners) are evaluated through indicators such as information presentation, ease of navigation, and design suitability. Through this assessment, the instrument measures the extent to which the web-based learning media meets user needs and the established eligibility standards.

Data Analysis Technique

The instruments used in this study include validity instruments, practicality instruments, and effectiveness instruments. This study used a one-group pretest-posttest design, which is an experiment involving one group without a comparison group (Sabur et al., 2023). The effectiveness test was carried out through objective questions twice with the same questions, namely before the experiment (pretest) and after the experiment (posttest) on the same group of subjects. The product trial design is presented in Figure 2.

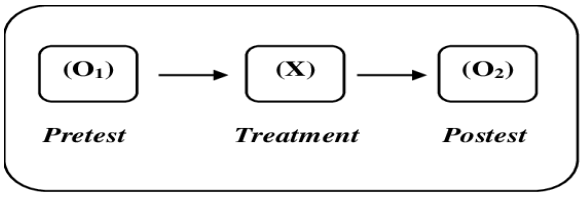

Figure 2. Product Trial Design

Description:
X : Treatment (Web-Based Simulation Media)
O1 : Pretest (before treatment)
O2 : Posttest (after treatment)

The analysis technique used in learning media validation aims to assess and evaluate experts in determining the feasibility of learning materials and media before proceeding to the testing stage and being used in the learning process. Media validity assessment was conducted using a Likert scale. The results of the product validity analysis, which were calculated using Aiken's V statistics, are presented in Equation 1.

$$V = \sum s/[n(c-1)] \quad (1)$$

Description:
V : Index validated
S : r – Io
n : Number of validators
Io : The lowest validity score (in this case = 1)
c : The highest validity score (in this case = 5)
r : The number given by a validator

The reference for assessing the validity of this learning media is presented with two categories of validity levels found in Table 1 as follows:

Table 1. Category of Media Validity

Level of Achievement	Category
0.60 – 1,00	Valid
< 0.60	Not Valid

In the practicality analysis of the product, trial data were collected through questionnaires filled out by students participating in the trials. These questionnaires were designed to gather feedback on how well the developed media met learning needs and ease of use. The evaluation of media practicality was conducted using a Likert scale, which allows for measuring the degree of agreement or disagreement among respondents on various assessed aspects. The raw scores obtained from the questionnaires were collected from all respondents, summed up, and analyzed using specific calculation methods to determine the product's level of practicality. This analysis aims to provide a clear picture of the practicality of the developed media and identify areas that may need improvement or adjustment based on student evaluations. The results of the practicality analysis, calculated using Aiken's V statistics, presented in Equation 2.

$$Practicality\ Score = \frac{\sum The\ score\ obtained}{\sum The\ \text{expected}\ score}\ X\ 100\% \quad (2)$$

Description:
The score obtained: Total score of respondents
The expected score: Total number of maximum scores

Once the results of the practicality assessment from students were obtained, the assessment data were classified into several categories: not practical, less practical, practical, and very practical, based on the levels of practicality indicated in Table 2.

Table 2. Category of Media Practicality

Level of Achievement (%)	Category
0 – 25	Not Practical
26 – 50	Less Practical
51 – 75	Practical
76 – 100	Very Practical

The effectiveness analysis was conducted by comparing student learning outcomes before (pretest) and after (posttest) using web-based simulation media in Applied Physics learning. Effectiveness testing uses the one-group design method, with only one sample group without a comparison group. Web-based simulation media is considered effective if the value of student learning outcomes after using the media (posttest) is higher than before using the media (pretest). Testing the effectiveness of the media is done using the classical completeness rate and gain score. To determine the percentage of students' classical completeness is calculated using the formula in Equation 3.

$$PK = \frac{JT}{JS}\ x\ 100\% \quad (3)$$

Description:
PK : The percentage of completeness
JT : Number of completed students
JS : The total number of students

Table 3. Interval of completeness

Level of Achievement (%)	Category
0 – 39	Very Less
40 – 55	Less
56 – 65	Simply
66 – 79	Good
81 – 100	Very Good

The percentage determination based on the interval of learning provisions proposed by (Arikunto, 2012) is

presented in table 3. The effectiveness of this study was also evaluated through the gain score aspect, which is used to determine the improvement of student learning outcomes based on the difference between pretest and posttest scores. First, the test subjects were given a pretest, and after the learning was completed, a posttest was given. After the individual student completeness data was obtained, the number of students who achieved completeness was calculated. Next, the pretest and posttest scores were compared. The increase in learning outcomes from pretest to posttest was analyzed using the N-Gain score formula found in equation 4 and for the gain score category in table 4.

$$N - Gain = \frac{Spost - Spare}{Smaks - Spare}\ x\ 100\% \quad (4)$$

Description:
Spost : The average posttest score
Spare : The average pretest score
Smaks : The ideal maximum score

Table 4. Gain Score Categories

Gain Score	Category
N – gain > 70	High
30 ≤ N – gain ≤ 70	Medium
N – gain < 30	Low

Result and Discussion

Result

Developed Learning Media

The development of interactive web-based learning media in applied physics subjects is based on the development method carried out, namely using the ADDIE model. This research aims to produce interactive web-based simulation learning media in applied physics subjects that are valid, practical, and effective. Analysis of validity and practicality was carried out using Aken's V formula. Meanwhile, the effectiveness of learning media is seen from student learning outcomes at the time of implementation.

Validation

In the development of web-based simulation media for enhancing learning outcomes in applied physics, the author employed data collection techniques by distributing questionnaires to media experts and material experts. These questionnaires were designed to gather relevant feedback and insights regarding the effectiveness and usability of the web-based simulation. The results of this study are expected to provide a measure of the validity and practicality of the developed simulation media, as well as its potential to improve learning outcomes in applied physics. Tables 5 and 6 are the result of the assessment of material and media validation.

Table 5. Material Validation Results

Assesment Aspects	Validators		Aiken's Value	Category
	V1	V2		
relevance aspect	0.83	0.83	0.81	Valid
accuracy aspect	0.91	0.83	0.87	Valid
suitability aspect	0.83	0.83	0.83	Valid
completeness aspect	0.75	0.75	0.75	Valid

The material validation results, as shown in table 5, provide an important evaluation of various aspects of the web-based simulation media used to enhance learning outcomes in applied physics. The assessment was conducted by two validators (V1 and V2) across four key aspects: relevance, accuracy, suitability, and completeness. The Aiken's values, which range from 0.60 to 1.00, indicate that the media is highly valid in all these aspects. Specifically, the relevance aspect scored 0.81, demonstrating that the simulation media aligns well with the learning objectives of applied physics. The accuracy aspect received the highest score of 0.87, confirming that the content accurately represents the key concepts and principles of the subject, which is essential for ensuring students learn correct information. The suitability aspect scored 0.83, indicating that the media is appropriate for the target audience and meets the learners' needs effectively. Lastly, the completeness aspect, with a score of 0.75, suggests that the media sufficiently covers all necessary content areas to provide a comprehensive learning experience. Overall, the validation results suggest that the web-based simulation media is a reliable and effective tool for improving student learning outcomes in applied physics.

The media validation results, as displayed in table 6, evaluate three critical aspects of the web-based simulation media designed to enhance learning outcomes in applied physics: quality, effectiveness, and programming. Based on the assessments from two validators, Aiken's values for these aspects range from 0.60 to 1.00, indicating strong validity across all dimensions. The quality aspect achieved the highest Aiken's value of 0.87, confirming that the media offers high-quality content and presentation, essential for effectively communicating complex concepts in applied physics. The effectiveness aspect, with a value of 0.79, suggests that the simulation media successfully supports the improvement of student learning outcomes by engaging students and enhancing their understanding of the subject. Additionally, the programming aspect scored 0.78, indicating that the technical functionality and user interface are well-designed, ensuring that the media is both interactive and

easy to use. In conclusion, these validation results demonstrate that the web-based simulation media is a reliable and effective tool for improving learning outcomes in applied physics.

Table 6. Media Validation Results

Assesment Aspects	Validators		Aiken's Value	Category
	V1	V2		
quality aspects	0.83	0.91	0.87	Valid
effectiveness aspect	0.75	0.83	0.79	Valid
programming aspects	0.81	0.75	0.78	Valid

Practicality

Web-based simulation media designed to improve learning outcomes in Applied Physics subjects, after going through the validation stage by media experts and material experts, then continued with testing in the field trial stage. This field trial involved grade X students in a secondary school, with a total of 69 students from 2 classes. The assessment of student responses in this trial phase was carried out based on 4 main indicators, namely aspects of information presentation delivered through simulation media, ease of navigation that allows students to use the media intuitively, design aspects that include aesthetics and readability of the display, and completeness aspects that assess the extent to which this media provides the necessary material to support the understanding of applied physics concepts. Data regarding the results of student responses to this learning media can be seen in Table 7.

Table 7 shows students' responses regarding the practicality of the web-based simulation media aimed at improving learning outcomes in applied physics. Four key areas were evaluated: information presentation, ease of navigation, design aspects, and completeness. The scores for these aspects ranged from 83.33% to 85.99%, with each category being rated as "Very Practical." The information presentation aspect scored 83.33%, indicating that students found the way the material was delivered to be effective for understanding applied physics concepts. The ease of navigation received the highest score of 85.99%, reflecting that students found the media intuitive and easy to use, an important feature for maintaining engagement. The design aspects scored 84.87%, suggesting that the layout and structure of the media were well-designed to facilitate learning. Lastly, the completeness aspect, with a score of 85.87%, shows that students believe the media comprehensively covers the necessary content. Overall, the average practicality score of 84.94% reinforces that the web-based simulation media is highly practical and effective for enhancing students' learning outcomes in applied physics.

Table 7. Media practicality results

Assesment Aspects	students' response		Score	Category
	$\sum x$	$\sum xi$	%	
Aspects of information presentation	920	1104	83.33	Very Practical
Ease of Navigation Aspect	712	828	85.99	Very Practical
Aspects of Design	1167	1380	84.87	Very Practical
Completeness Aspect	711	828	85.87	Very Practical
Average	877.5	1035	84.94	Very Practical

Effectiveness Test Results of Learning Media

Pretest and posttest data were utilized to evaluate the effectiveness of the web-based simulation media in enhancing learning outcomes in applied physics. To analyze the effectiveness of the simulation media, the researcher applied three methods: an effectiveness test based on classical completeness, gain score analysis, and a t-test. The results of the effectiveness analysis, based on classical completeness, from 69 students who participated in both the pretest and posttest, are displayed in Table 8, which outlines the classical completeness analysis.

Interactive web development products can be said to be effective if ≥ 80% of students who have taken part in the learning process are able to achieve the reference value for the success of the basic competency achievement indicators set. Thus, the criteria for stating completeness are that at least 80% of all students who are the subjects of the trial meet learning completeness, namely being able to reach the threshold value of 75 (maximum value of 100). In this study, pretest and posttest questions were given to class X students of SMK Negeri 1 North Bintan.

The data in the table 8 shows that of the 69 students who took the pretest, only 17 students were at the completion criteria with an average score of 62.90 and the percentage of learning completeness reached 24.64%. Meanwhile, of the 69 students who took the first posttest, 44 students were at the completion criteria with an average score of 74.27 and the percentage of learning completeness reached 63.77%. For the second postest activity, of the 69 students who participated, 63 students were in the complete criteria with an average score of 79.46 and the percentage of learning completeness reached a percentage of completeness of 91.30%. Based on the acquisition of the percentage of student learning completeness after the product is implemented in

learning (posttest) of 91.30% ≥ 80%, the quality of interactive web-based teaching materials developed in terms of the results of the analysis of student learning outcomes is in the effective criteria used to improve student learning outcomes.

Table 8. Interval of completeness

Description	Pre-test	Post-test 1	Post-test 2
Examinees	69	69	69
Completed Participants	17	44	63
Incomplete Participants	52	25	6
The Percentage of Completeness (%)	24,64	63,77	91,30
Category	Not Effective	Not Effective	Effective

Table 9. Media effectiveness results of gain score values

N	Posttest - Pretest	Average S_Ideal - Pretest	N-Gain Score	% N-Gain Score
69	13.97	37.10	0.32	32
Category				Medium

Meanwhile, the results of the effectiveness analysis based on the gain score of 69 students who have taken the pretest and posttest related to the use of web-based simulation media in improving learning outcomes in applied physics can be seen in Table 9.

Based on the results of the effectiveness analysis conducted using the gain score of the pretest and posttest scores on 69 students, the average N-Gain Score of 32 was obtained which is included in the moderate category. This shows that there is a significant increase in learning outcomes after the use of learning media. Therefore, it can be concluded that the application of web-based simulation media for applied physics learning is effective in improving student understanding and learning outcomes. This media not only helps visualize complex physics concepts, but also facilitates a more interactive learning process, so that it can support the improvement of more optimal learning outcomes in the field of applied physics.

Discussion

The implementation of web-based simulation media in applied physics has shown significant potential in addressing the challenges faced by traditional teaching methods. The research conducted in this study, which followed the ADDIE model of instructional design, highlights the practicality, validity, and effectiveness of such media in enhancing students' learning outcomes. This finding aligns with a growing body of research that emphasizes the importance of interactive, technology-driven learning tools in STEM education. The following analysis discusses the key results of the study and relates them to similar studies that serve as both relevant comparisons and validations of the outcomes presented.

The validation results from material and media experts, as shown in Tables 5 and 6, confirm that the developed web-based simulation media is highly valid across multiple dimensions, such as accuracy, relevance, and completeness. These results echo findings from (Haryadi & Pujiastuti, 2020), who similarly reported high validity scores for web-based simulations used in engineering physics education. This study demonstrated that accurate content representation in simulations plays a crucial role in supporting students' comprehension of theoretical concepts. The high Aiken's V scores, particularly in the accuracy and relevance aspects, confirm the effectiveness of web-based simulations in delivering precise and contextually appropriate content for applied physics education.

Practicality, as measured through student feedback, also yielded highly positive results, with an average score of 84.94%. This is consistent with the findings of Maraza-Quispe et al. (2023), whose research on simulation-based learning in physics found that ease of use and engaging design are critical to student satisfaction and engagement. In their study, ease of navigation and visual design were highlighted as essential factors that make simulation media an effective supplement to traditional teaching methods. The practicality scores in this study reinforce these findings, suggesting that students are more motivated and engaged when the learning tools are intuitive and visually appealing. The strong practical usability also supports the argument that well-designed simulations can foster independent, self-paced learning, which is crucial for mastering applied physics concepts.

The effectiveness of the web-based simulation was analyzed through pretest-posttest comparisons, revealing a significant improvement in student performance, with the percentage of students achieving passing grades increasing from 24.64% (pretest) to 91.30% (second posttest). This finding aligns closely with research by Khoiri, Ristanto, & Kurniawan (2023), which demonstrated that students using web-based simulations in physics exhibited higher posttest scores compared to those using traditional methods. This study found that simulation-based learning not only improved students' conceptual understanding but also enhanced their critical thinking and problem-solving abilities. The increase in posttest scores in both studies highlights the effectiveness of simulations in facilitating deeper learning, particularly in subjects like applied physics,

where abstract concepts are difficult to grasp through conventional methods alone.

The gain score analysis conducted in this study further confirms the medium effectiveness of the simulation media, with an N-gain score of 32, falling within the moderate improvement category. This is consistent with findings from Antonio & Castro (2023), who reported a medium N-gain score in their study on interactive physics simulations. This research suggested that while simulations significantly enhance learning outcomes, their effectiveness can be further improved when combined with additional instructional strategies, such as teacher-led discussions or collaborative group work. The medium N-gain score in this study similarly suggests that while the simulation alone is effective, it could be even more impactful when integrated into a broader, blended learning environment.

Moreover, the findings of this study align with research conducted by Banda & Nzabahimana (2023), who demonstrated that web-based simulations improve not only the cognitive understanding of students but also their motivation and interest in learning physics. This research emphasized that students using interactive simulations reported higher levels of engagement and enjoyment during the learning process, which directly correlated with improved academic performance. The positive feedback from students in this study regarding the practical usability of the web-based simulations supports this idea. It highlights the importance of using engaging, interactive media to keep students motivated and actively involved in the learning process.

Despite the positive outcomes, it is important to consider the limitations of web-based simulations, which have also been noted in other studies. For instance, Önder et al. (2023) highlighted the need for careful design and alignment with curriculum goals to ensure that simulations are not just visually appealing but also pedagogically effective. The findings of this study also underscore the importance of proper implementation. Simulations must provide feedback and clear instructional guidance to help students correct their misunderstandings and enhance their learning experience.

In conclusion, this study's results on the validity, practicality, and effectiveness of web-based simulations in applied physics are supported by similar research in the field. Comparative studies by Haryadi & Pujiastuti, (2020), Khoiri et al., (2023), Maraza-Quispe et al., (2023), and others reinforce the idea that simulations offer a highly valuable tool for enhancing learning outcomes in science education. While this study demonstrates the clear benefits of web-based simulations, it also suggests the potential for further improvement, particularly when simulations are integrated with other pedagogical techniques. Overall, the research confirms that well-designed, interactive simulations can significantly enhance students' understanding of complex physical concepts, making them a vital component of modern applied physics education.

Conclusion

The study concludes that in the context of the 4.0 industrial revolution, education must transform to address the challenges of globalization and technological advancements. One innovative solution is the use of web-based simulation media in applied physics learning, which enables interactive visualization of complex concepts that are difficult to grasp through traditional methods. Developed using the ADDIE model, this media ensures a systematic approach to design, implementation, and evaluation, proving to be valid, practical, and effective in improving students' learning outcomes. Validation from experts and field trials shows that it enhances understanding and engagement, making it a flexible and effective tool for delivering more interactive and immersive physics education.

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Author Contributions

Writing—original draft preparation, methodology, Analysis, Z; Conceptualization, review, MM; Editing, formal analysis, AL.

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Conflicts of Interest

The authors declare no conflict of interest.

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