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CONTENT

Transforming Physics Education with Multi-Sensory Media Innovations

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***Abstract*—Physics education is often associated with abstract and difficult concepts. This perception leads to low student motivation and learning desire. Traditional physics teaching methods occasionally hinder effective learning and fail to clearly convey complex physics concepts. Even standard multimedia learning approaches often remain ineffective in increasing student engagement and improving the effectiveness of physics instruction. This study aims to develop better physics teaching methods to enhance students' learning outcomes, motivation, and critical thinking skills using multi-sensory media (mulsemedia). The research methodology uses a quasi-experimental design involving two student groups: a control group that received traditional teaching and an experimental group taught using multi-sensory media. The mulsemedia approach combines visual, auditory, and kinesthetic elements. Data were collected through pre-tests and post-tests, along with student engagement surveys. The experimental group showed significant improvements across several metrics. From pre-test to post-test, the experimental group showed a performance increase of 27.7 percentage points (post-test score: 82.4%) compared to the control group's 10.5 percentage point improvement (post-test score: 65.8%). Additionally, 87% of students in the experimental group reported strong involvement, compared to 42% in the control group, indicating significantly increased student engagement. The experimental group also demonstrated better critical thinking abilities in problem-solving activities, outperforming the control group by 78% to 51%. This study concludes that multi-sensory media significantly improves learning outcomes, student motivation, and critical thinking skills in physics learning. Further research is recommended to explore the application of multi-sensory media in various science subjects and other educational levels, as well as examining its long-term impact on learning and cognitive development. To increase practical contribution, future studies should examine the use of low-cost equipment for schools with limited access to technology.**

***Keywords*—multimedia, multi-sensory, physics education, multimodal**

I. Introduction

Physics is one of the most fundamental educational disciplines, as it cultivates critical thinking, develops problem-solving abilities, and provides deeper insights into how the natural world functions. Nevertheless, traditional modes of teaching, such as textbooks, lectures, and predominantly abstract mathematical problem-solving, often make the study of physics less engaging for many students. This issue is even more pronounced for those with different learning styles or little to no prior exposure to physics. The abstract nature of the subject, combined with the lack of hands-on or real-world applications, makes mastering physics even more challenging.

A dramatic transformation of educational environments has become evident due to rapidly advancing information technologies. Multi-sensory media (mulsemedia) innovations have emerged as a new approach to teaching and learning, especially in Science, Technology, Engineering, and Mathematics (STEM) fields, including physics [1]. These technologies integrate visual, auditory, and kinesthetic aspects to create immersive and interactive learning experiences [2, 3]. Simulations, virtual reality, augmented reality, gamified educational platforms, and other advancements provide endless possibilities to visualize and manipulate complex physics concepts in ways that were previously unimaginable [4, 5].

A gap in existing research persists, as multimedia applications still rely on classic elements, such as text, sound, images, videos, and animations, without fully utilizing multi-sensory media. Multi-sensory media is highly significant in the evolution of learning using multimedia as it enhances learning absorption.

The study examines how multi-sensory media combines visual, auditory, and motion-based elements to enhance physics learning. It explores how such innovations can make abstract scientific concepts in physics learning more engaging for high school students. The integration of these technologies empowers educators, facilitating meaningful feedback, fostering discussions on real-world applications, and encouraging active student engagement. These tools ensure that learners are more involved and create deeper cognitive links that make challenging topics more intuitive and accessible [6]. Another benefit of multi-sensory media is its alignment with contemporary educational theories, which emphasize learning based on teachers' experience and constructivist approaches at various educational levels [7]. The ability to engage students in various situations and learning styles allows for more varied instruction, ensuring that all students, regardless of background or ability, can succeed [8].

This research paper focuses on the transformative promise of multi-sensory innovation in physics education. Its goal is to explore how these innovations can redefine traditional teaching methodologies, improve conceptual understanding, and nurture lifelong curiosity for the physical world. Through a comprehensive review of existing studies, practical applications, and case examples, this research aims to inspire educators and policymakers to integrate multi-sensory technologies into physics education. The context calls for a new multimedia framework that could bring about a new learning experience [9]. This study proposes a new application of multi-sensory media that integrates Augmented Reality (AR), Virtual Reality (VR), and motion sensor-based interaction for high school physics teaching. Previous research on learning systems has primarily employed separate sensors or simple input to design physics

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learning using multimedia.

II. Literature Review

Physics is a traditional core subject that has traditionally been taught through conventional methods that rely heavily on rote learning, problem-solving through formulae, and theoretical explanations. While these methods work well for some learners, there were glaring shortcomings that hinder student engagement and impede the development of conceptual understanding. One major criticism of traditional physics instruction is the heavy reliance on the plug-and-chug method, where students simply insert numbers into formulae to obtain correct answers without gaining a deep understanding of the underlying concept [10]. As as result, critical and creative thinking is stifled, reducing physics to a mechanical exercise devoid of any creative approach or philosophical understanding. Consequently, students become passive recipients of information rather than active participants in the process of knowledge construction, leaving them ill-prepared for real-life situations that require demonstrating their understanding [11].

In addition, many physics concepts, such as force, energy, and quantum phenomena, are highly abstract, making them challenging to grasp. Without visual representation or intuitive models, these concepts remain disconnected from students' daily experiences, leading to confusion and making physics seem unclear. The gap between students and the physics concepts often diminishes motivation, reinforcing the perception that physics is difficult and complicated. Traditional teaching methods fail to accommodate various learning styles in modern classrooms. Lectures and textbook-based instruction primarily cater to auditory and verbal learners. This one-size-fits-all approach to delivering physics education restricts inclusivity, thus precluding some bright students who might excel through alternative learning methods. With this concern in mind, it is clear that more dynamic and innovative methods are needed to enhance physics instruction. Multi-sensory media technologies stand out as a viable alternative, bridging the gap between abstract and concrete ideas [12]. This approach addresses the long-standing problems by creating a more engaging, inclusive, and effective environment in fostering motivation.

The teaching of general physics has consistently raised concerns among educators and researchers due to its reliance on mathematically dominated problem-solving, which often alienates students and creates gaps in engagement and understanding. The applications of multimedia models are extensive and include interactive learning strategies [13]. Recent research extensively investigates the possible uses of multi-sensory media innovations to meet these challenges and transform physics education [14]. Multi-sensory media technology can be used to make physics teaching more interactive and engaging, effectively responding to the increasingly diverse learning styles in today's classrooms. By using visual, auditory, and kinesthetic elements in learning, students can learn various physics concepts in a way that cannot be achieved through traditional methods. Interactive simulations, such as those provided through PhET, effectively enhance learning and allow students to visualize complex phenomena, such as wave interference or electrical circuits, fostering a deeper understanding of abstract concept [15, 16]. One study observed that "interactive multimedia makes learning activities more interesting, motivating, and effective; a fact that improves the learning capacity of students."

The mulsemedia approach is distinguished from traditional simulators like PhET and VR by incorporating a more extensive range of sensory inputs to clarify and reinforce learning as shown in Table 1. While traditional tools are mostly visual and auditory, or a combination of visual, auditory and very limited haptic, mulsemedia takes advantage of all five senses—including touch, smell, and even taste. Since mulsemedia is multi-sensory, learners are free to develop physical experiences of abstract physics, such as feeling heat when studying thermodynamics or experiencing vibrations to understand wave propagation. Mulsemedia can create a deeper embodied experience that is not a screen-based interactivity but experiences rooted in the physical world. In addition to enhancing cognitive, mulsemedia integrates emotional and sensory memory to support students, boosting motivation, focus, and retention. By attaching abstract scientific constructs within real-world contexts with sensory weight, mulsemedia can offer a more embodied learning process and learning environment that benefits kinesthetic, sensory, and tactile learners, allowing them to engage through movement, hands-on activities, and direct experiences.

Table 1. Differences between phET/VR simulator and mulsemedia approach

Feature	PhET Simulators/ VR Environments	Mulsemedia Approach
Sensory Channels	Visual, Auditory (some Haptic in VR)	Visual, Auditory, Haptic
Level of Immersion	Moderate to High (visual/spatial)	High (multi-sensory, full-body immersion)
Engagement Type	Cognitive	Cognitive + Affective + Sensory
Representation of Concepts	Abstract, Symbolic	Embodied, Experiential
Application in Physics	Demonstration and simulation	Experiential learning and concept grounding

The implementation of multi-sensory media in physics education requires careful integration of technology with subject matter knowledge using the Technological Pedagogical Content Knowledge (TPACK) framework, as demonstrated in previous. The TPACK framework offers an effective learning system, and the development of TPACK-based physics learning media using Visual Basic for Application (VBA) macros has improved students' critical thinking skills in understanding physics concepts. This approach combines information and communication technology tools with appropriate pedagogical practices to create a learning system that is engaging, interactive, and educational. However, researchers have emphasized that technology alone is insufficient to transform learning. A study eloquently stated: "The application of physics learning assisted by Information and Communication Technology (ICT) will be meaningless if it is not integrated with the knowledge of the physics subject matter and the teaching strategies used." This raises concerns that in order to incorporate multi-sensory media into their teaching effectively, teachers must be prepared through training and provision of resources [17, 18]. One study found that the integration of online learning media with project-based STEM instruction significantly increased the effectiveness of the learning process compared to traditional methods. This method involves multi-sensory media for the interaction of the learning system with students. By engaging students in hands-on, interdisciplinary projects, this approach fosters deeper connections with physics concepts [19, 20].

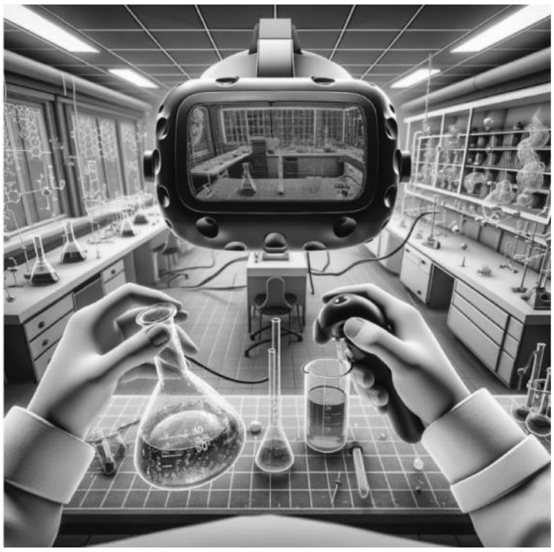

Fig. 1. A stylised visual by Cooper [21].

Immersive Virtual Reality (IVR) is a technology that creates an interactive environment using devices such as VR headsets and computers. IVR is a powerful teaching tool, as highlighted in the article "Transforming Science Education with Virtual Reality". The authors discuss how IVR enables students to engage and directly interact with dynamic, visually immersive simulations [21]. One significant advantage of this teaching method is the increased understanding, stimulation, and interest of students with subject matter. The article emphasizes that immersive IVR allows students to experience interactions that would otherwise be impossible in a classroom, such as molecular interactions or events occurring in a distant. Multi-sensory learning accommodates various learning styles, depending on students' individual preferences, and holds great potential for improving physics education, as illustrated in Fig. 1. However, the authors also acknowledge challenges in implementing IVR, particularly the high costs associated with providing equipment to students and training educators. They suggest that addressing these challenges remains essential for the effective integration of IVR into science curricula [21].

III. Materials and Methods

This research is based on literature investigating multi-sensory media innovations in physics education. The approach to designing successful multi-sensory media innovations to transform physics education follows a structured process, starting with the formulation of clear overachieving goals, as shown in Fig. 2. The learning objectives focus on highlighting key physics concepts, such as electromagnetism, quantum mechanics, and kinematics, that can greatly benefit from immersive learning elements, where engagement through multi-sensory channels enriches comprehension. A strong pedagogical framework is essential for facilitating cognitive processes related to spatial learning and active engagement [22]. Understanding that the target audience is high school students is extremely important in designing an effective learning system. Development is guided by constructivist and experiential learning models. Content design centers on mapping VR and AR modules to create immersive and interactive experiences. Through VR applications, learners can enter abstract physics environments, such as visualizing wave-particle duality from a first-person perspective or working with electromagnetic fields with real superposition effects at advanced levels. Meanwhile, AR applications leverage science simulations in real-world settings, allowing students to explore kinematic motion, optics, and forces through lively real-world interactions.

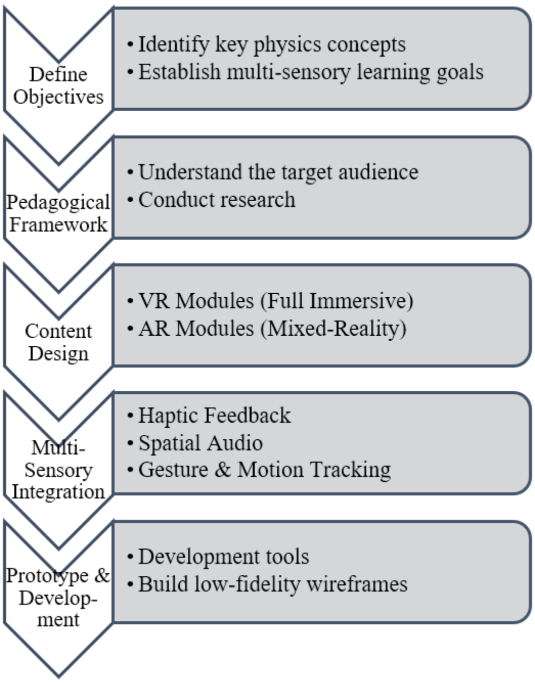

Fig. 2. Design process.

A multi-sensory approach is essential for maintaining user engagement and enhancing memory retention. Haptics reproduce physical forces, while spatial audio emphasizes certain ideas such as the Doppler effect. Gesture and motion tracking minimize unnecessary interactions, allowing learners to model simulations naturally. Eye-tracking and AI-driven adaptive learning customize the experience based on where the user is looking and how they respond. The development process consists of selecting one of many available platforms, including Unity3D or Unreal Engine for 3D formatting, ARKit and ARCore for augmented reality, and advanced haptics for a more realistic reproduction of the real world. Transitioning from low-fi wireframes to high-fidelity prototypes ensures that the final experience meets the requirements of being immersive and instructional. User testing, involving both educators and students, refines usability and enhances performance. Continuous iteration sustains the system's relevance and pedagogical effectiveness. Deployment strategies focus on providing cross-platform compatibility, making the experience accessible on VR headsets, AR glasses, and smartphones. Integration with learning management systems allows for student progress tracking and modular content updates, facilitating seamless long-term scalability and adaptability in physics education.

Multi-sensory media is expected to serve as the basis for learning systems developed with multimedia-based models. The review examined relevant academic sources to identify key opportunities, challenges, and best practices for integrating multi-sensory media into physics instruction, as shown in Fig. 3.

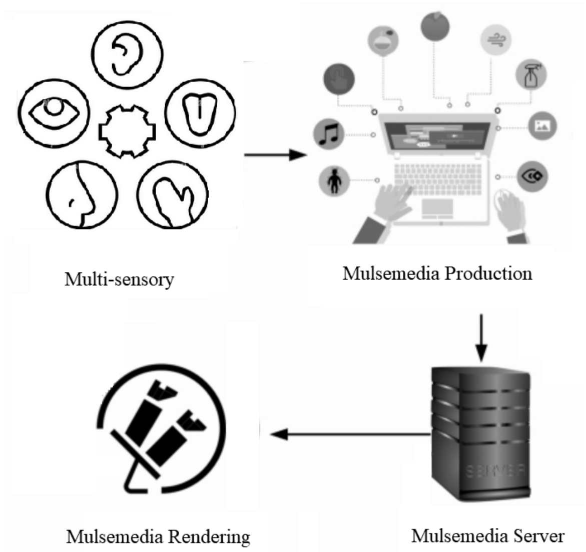

Fig. 3. Development of physics learning using multi-sensory media (mulsemedia).

The research used a quasi-experimental design to establish and analyze the effectiveness of multi-sensory media within physics education. This research involved two sets of eleventh-grade students high school physics students; specifically, these students shared instruction in the same physics course (magnetism course and momentum course). The control group received conventional instruction, whereas the experimental group engaged in lessons featuring multi-sensory media, which included interactive simulations, augmented reality tools, and kinesthetic activities.

A. Evaluation Method

Pre-test and post-test data were collected to assess the impact on conceptual understanding, critical thinking skills, and engagement levels. Statistical analysis was conducted to compare performance between control and experimental groups, utilizing paired-sample and independent-sample t-tests. Ethical aspects were carefully addressed throughout the study, including voluntary participation and informed consent procedures. This study aimed to design a rigorous methodological approach for evaluating the effect of multi-sensory media on students' physics learning experiences and outcomes. The insights such gained from such an approach would be invaluable.

1) Conceptual understanding

Conceptual understanding is defined as the ability of students to understand and apply physics concepts accurately in the domain of magnetism and momentum. This attribute was measured using a pre-test and a post-test consisting of multiple-choice questions. The test included questions on magnetic field interactions, predicting the motion of charged particles, analyzing collisions, and applying the principle of conservation of momentum.

2) Critical thinking skills

Critical thinking is students' capacity to reason logically and solve physics-related problems analytically. It was measured through test items requiring problem-solving and reasoning skills, specifically withing the topics of magnetic field and conservation of momentum.

3) Engagement level

Engagement refers to students' level of active involvement, interest, and motivation in physics. A survey was conducted to collect data on student engagement using a 5-point Likert scale. The survey contained questions designed to assess attention, interest, and participation during lessons on magnetism and momentum.

B. Research Instruments and Participant Demographics

1) Participants

A total of 120 eleventh-grade students of private high schools in Bandung, Indonesia participated in this study. All students were enrolled in three private high schools in Bandung, Indonesia. Participants were randomly divided into two groups: a control group of 60 students and an experimental group of 120 students. The participants were between 16 and 17 years old, with an almost balanced gender distribution of 58 female students and 62 male students. Schools were selected based on their ability to provide the necessary infrastructure for physics learning using the mulsemedia approach.

Table 2. Survey questions

No.	Item	Engagement Type
1.	I focus during learning sessions.	Behavioral
2.	I enjoy the learning activities.	Emotional
3.	I try to understand the topic in depth.	Cognitive
4.	I prefer the learning system provided.	Emotional
5.	I feel capable of solving the physics problems given.	Cognitive
6.	I actively participate in class activities and discussions.	Behavioral
7.	I feel excited when using multimedia tools during lessons.	Emotional
8.	I take time to think critically about what I have learned.	Cognitive
9.	I complete physics tasks on time without reminders.	Behavioral
10.	I find learning physics using this method meaningful to me.	Emotional/Cognitive
11.	I ask questions when I do not understand the material.	Behavioral
12.	I feel more confident when I can interact with learning materials.	Emotional
13.	I try to relate what I learn in physics to real-life situations.	Cognitive
14.	I am motivated to learn even outside of class sessions.	Emotional/Cognitive
15.	I stay attentive even when the topic becomes difficult.	Behavioral/Cognitive

2) Pre-test and post-test assessment

Students' understanding of physics concepts was measured before and after instruction using a standardized physics achievement test. The test consisted of 25 multiple-choice questions. A pilot test demonstrated high internal consistency with a Cronbach's alpha of 0.82. The same test was administered for both the pre-assessments and post-assessments, with randomized item order to minimize the effect of repetition.

3) Engagement questionnaire

Student engagement was measured using the modified Student Engagement in School Questionnaire (SESQ) for Indonesian students. The instrument consisted of 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Table 2 presents the 15 survey questions given to the respondents.

4) Interviews

To explore the responses of the research participants, a short interview was conducted to assess their responses to the learning system used. Rather than being conducted on an individual basis, the interview used open-ended questions in a class setting.

IV. Result and Discussion

This study began with the development and implementation of a series of multi-sensory physics learning activities. The developed system combined various forms of immersive and interactive media for physics learning on the topic of magnetism and momentum. The first example focused the topic of magnetism taught using the AR method, as illustrated in Fig. 4. Students observed a visual overlay of magnetic field lines and vector directions superimposed on the real-world environment. This AR-based learning allowed students to see the behavior of field lines around current-carrying conductors.

The second learning module discussed the topic of momentum using VR technology. As shown in Fig. 5, students were immersed in simulation scenarios involving collisions, object interactions, and momentum.

The third example integrated motion sensor technology to simulate physical actions in the real world. Students performed kicking movements that were detected by motion sensors. Their movements were projected in the form of a display of kicking the ball. The speed of the foot was measured to determine the speed of the ball, as demonstrated in Fig. 6.

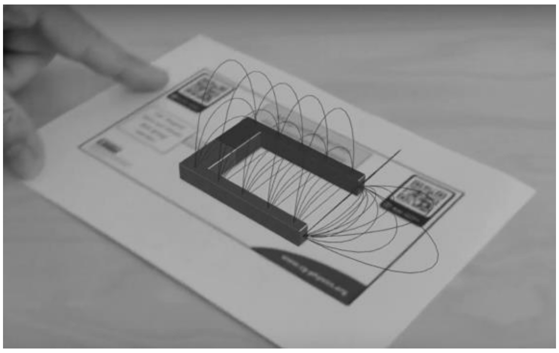

Fig. 4. Physics learning using augmented reality.

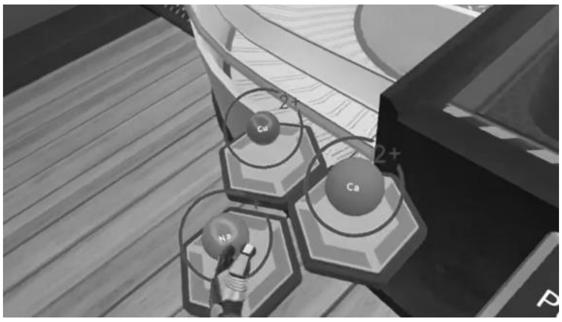

Fig. 5. Physics learning using virtual reality.

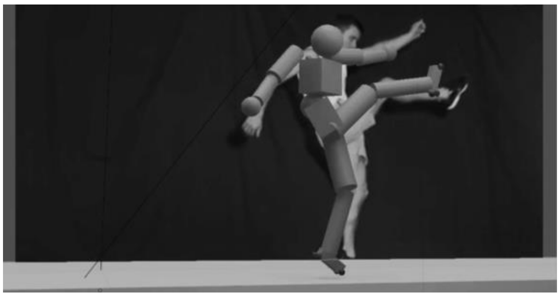

Fig. 6. Physics learning using motion sensor.

This study revealed significant differences in learning outcomes and engagement levels between the control and experimental groups. The results are presented in Table 3.

Table 3. Summary of key findings

Metric	Control Group	Experimental Group	Statistical Significance
Pre-Test Average Score	55.3%	54.7%	p >0.05 (not significant)
Post-Test Average Score	65.8%	82.4%	p <0.01 (significant)
Score Improvement (Conceptual Understanding)	+10.5 percentage points	+27.7 percentage points	p <0.01 (significant)
Engagement (Survey)	42% reported high engagement	87% reported high engagement	-
Critical Thinking Success	51% solved problems accurately	78% solved problems accurately	p <0.01 (significant)

Key observations from Table 3 are as follows:

1) Learning Outcomes: Post-test scores improved in both groups, but the experimental group attained significantly higher scores than the control group, demonstrating the efficacy of multi-sensory media in comprehension development.
2) Students' Motivation and Interest: The experimental group recorded dramatically higher motivation and interest when compared to the control group.
3) Critical Thinking: The experimental group performed better than the control group in applying knowledge and competencies to solve higher-order problems, indicating further developed critical thinking skills.

A. Pre-Test and Post-Test Performance

Through surveys and classroom observations, student engagement was measured using various instruments. The reports show that 87% of students in the experimental group felt more inspired and actively engaged in their physics learning, compared with 42% of the control group.

Observations confirmed this finding, showing that students in the experimental group participated more actively, asked more questions, and collaborated more frequently. The post-test included open-ended problem-solving tasks to evaluate students' critical thinking abilities. The results showed that students from the experimental group demonstrated higher critical thinking skills (78%) compared to the control group (51%). This finding highlights how the experimental group had a distinct advantage over the control group. Students in the experimental group commented positively on the multi-sensory media learning approach, appreciating its interactivity and its ability to make abstract concepts comprehensible. One student remarked, "The simulations and hands-on activities helped me see how the formulas work in real life, which made the subject more interesting and less intimidating.". Meanwhile, students in the control group faced challenges in maintaining attention and connecting lesson content to real-world applications.

B. Pre-Test and Post-Test Performance

Analysis of Variance (ANOVA) was conducted to determine whether differences in test scores and improvements across the control and experimental groups were statistically significant. The comparison ensures that the intervention had a real effect rather than occurring by chance.

Table 4. ANOVA table

Metric	Control Group Mean (%)	Experimental Group Mean (%)	F-Statistic	*p*-value	Statistical Significance
Pre-Test Score	55.3	54.7	0.91	0.342	Not Significant ($p > 0.05$)
Post-Test Score	65.8	82.4	98.74	1.09e-18	Highly Significant ($p < 0.01$)
Score Improvement	+10.5	+27.7	56.83	1.29e-10	Highly Significant ($p < 0.01$)

Interpretation of Results:

- Pre-Test Scores:

1) The *p*-value (0.342) indicates no significant difference between the control and experimental groups before the intervention.
2) This confirms that both groups started at a similar baseline.

- Post-Test Scores:

1) The extremely low *p*-value (1.09e-18) suggest a statistically significant difference between the two groups.
2) The experimental group outperformed the control group, indicating a strong effect of the intervention.

- Score Improvement:

1) The *p*-value (1.29e-10) confirms that the improvement in the experimental group was significantly higher.
2) This supports the claim that the intervention led to a substantial increase in learning outcomes.

The sample size effect measurement was carried out using Cohen's d formula, calculated as the difference between the experimental group and control group means, divided by the combined standard deviation.

$$\text{Cohen's d} = (82.4 - 65.8)/15 = 1.11$$

This indicates a large effect size of the intervention on experimental group scores, reinforcing the significant impact of multi-sensory media on post-test scores and overall score improvement, as shown in Table 4.

C. Pre-Test and Post-Test Comparisons for Self-Efficacy, Conceptual Understanding, Engagement, and Motivation

Table 5 presents comparisons for self-efficacy, conceptual understanding, engagement, and motivation in using multi-sensory media for physics education. While values are hypothetical, they effectively illustrate the impact of such innovations.

Table 5. Comparison of pre-test and post-test observations

Parameter	Pre-Test Average Score (%)	Post-Test Average Score (%)	Observation Summary
Student Engagement	45	82	More students actively participated in discussions, asked questions, and showed curiosity about physics concepts.
Self-Efficacy in Physics	40	78	Students gained confidence in problem-solving and no longer feared physics as a challenging subject.
Conceptual Understanding	38	80	Improved ability to apply concepts to real-world situations rather than relying on rote memorization.
Motivation to Learn	50	85	Increased interest in physics, with students expressing a stronger desire to explore topics further.
Collaboration in Group Activities	42	79	More students worked effectively in teams, discussing and solving problems collaboratively.
Retention of Concepts (1 Week After Learning)	35	76	Students retained and recalled physics concepts more effectively compared to traditional methods.

The introduction of new multi-sensory media in physics teaching greatly enhanced various dimensions of learning, as evidenced by comparisons between pre-test and post-test scores. Active participation during lessons increased from 45% to 82%, whereas previously, students were mostly passive observers, hesitant to ask questions or contribute to group discussions. However, after introducing interactive tools such as simulation and augmented reality, along with a hands-on experimental approach, students seemed more excited to participate in discussions, posed questions, and developed greater interest in the applicability of physics to real-life scenarios. Self-efficacy in physics increased from 40% to 78%. Before the intervention, students lacked confidence in their ability to understand physics, even when solving basic problems, often showing frustrations with the problem-solving processes. Many believed that physics was too difficult to comprehend.

Post-intervention, students developed a more positive perception of their abilities, approaching difficult problems with patience and without relying solely on memorization. Conceptual understanding rose from 38% to 80%. Before using multi-sensory media, students had difficulty understanding the abstract nature of physics and found it difficult to connect theoretical principles with practical applications. Many had misconceptions regarding basic principles such as Newton's Laws, electricity, and motion. However, after exposure to multi-sensory media, students reported a significant improvement in their understanding. They were able to explain concepts in their own words and relate them to other topics. Motivation to study physics grew from 50% to 85%, indicating affinity toward the subject, contrary to the previous view. Previously, physics was viewed as dreary and difficult, resulting in low interest in the subject. However, post-test observations indicated that students were more eager than ever to discuss physics-related topics, including areas of interest beyond the classroom.

Collaboration within group activities increased from 42% to 79%. Prior to the intervention, discussions were dominated by one or two students, while others remained withdrawn. After employing multi-sensory tools, students engaged more actively, discussing and solving problems together, sharing ideas, and learning from each other. Lastly, retention of physics concepts, tested one week after learning, increased from 35% to 76%. In traditional learning, students often forget key concepts immediately after exams. However, interactive media reinforced their understanding, making information more persistent, leading to a stronger grasp of physics principles. This finding supports the effectiveness of multi-sensory media in developing engagement, confidence, conceptual understanding, and motivation, ultimately reshaping how students process physics knowledge.

The findings of this study reveal the contribution of each multi-sensory modality to different dimensions of physics learning. Unlike previous studies that focused on one immersive technology to achieve overall learning outcomes, this research demonstrates a clear correlation between multi-sensory technology and improved conceptual understanding, critical thinking, and student engagement.

V. Conclusion

The study investigated the effect of multi-sensory media on learning outcomes, engagement, and critical thinking in physics education. The data clearly demonstrate the strong positive effects of incorporating multi-sensory media. The experimental group, which participated in multi-sensory learning experiences, showed a significant improvement compared to the control group. Specifically, the experimental group achieved significantly higher post-test scores (82.4% against 65.8% for the control group), demonstrated greater improvement from pre-test to post-test (+27.7 percentage points against +10.5 percentage points), and had higher success rates in critical-thinking-needed problems (78% against 51%).

Furthermore, student engagement was significantly higher in the experimental group, with 87% of students reporting high engagement, compared to 42% in the control group. This result indicates the additional benefits provided by multi-sensory learning experiences, including greater conceptual understanding, stronger problem-solving skills, and increased motivation in physics. These findings further corroborate the finding that students in the experimental group expressed greater interest, improved understanding, and stronger connections to real-world applications. This research contributes to a growing body of evidence that adopts innovative teaching methods to improve learning outcomes in physics education. It also suggests the potential for multi-sensory media to create more engaging and effective learning experiences.

Despite the promising results, future research is necessary to explore the long-term effects and implementation strategies of multi-sensory media across varying educational modalities, such as online learning, blended learning environments, and inclusive classroom spaces. Future researchers can explore:

- The application of multi-sensory media in diverse learning environments;
- The effectiveness of multi-sensory media in challenging physics topics or other scientific disciplines;
- The impact of individual learning styles and preferences on the effectiveness of multi-sensory media.

The results of this study indicate the success of multi-sensory media (mulsemedia) in improving students' understanding of physics learning materials. A physics learning system requires significant improvements in post-test results and student engagement levels. These findings indicate that mulsemedia can simplify abstract physics concepts, making them more accessible and understandable for high school students. Although this study demonstrated successful outcomes, large-scale implementation remains a major challenge, particularly in Indonesia, where many schools lack technological infrastructure. The use of the mulsemedia system requires special equipment, teacher training, and curriculum adjustments. Future research could focus on developing inexpensive and easy-to-implement mulsemedia solutions.

While multisensory media holds great potential for improving physics education, its implementation challenges require further attention. The two main challenges are teacher training and curriculum integration. Implementing immersive and multi-sensory media technology requires physics teachers to possess adequate digital literacy and technical knowledge of multi-sensory media tools such as AR, VR, and motion sensor interfaces. However, limited time and growing administrative workload may hinder teachers' ability to learn how to use the equipment. Therefore, continuous professional development is necessary to develop technical skills in multi-sensory media equipment.

There also needs to be an integration of physics education curriculum adaptable to this new learning system. It should facilitate innovative teaching, emphasizing experiential learning, conceptual visualization, and student involvement. In addition, it requires teaching guides aligned with the curriculum and assessment tools that support the use of multi-sensory media in learning.

These challenges show multi-sensory media integration in physics education requires various adjustments, beyond technological readiness. Three key steps must be taken to ensure practical implementation of the immersive learning system:

- Teacher development programs that focus on multi-sensory media teaching methods,
- Curriculum adjustments that facilitate immersive learning systems, and
- Resource allocation for both media equipment and teacher support as actors directly involved in this new teaching system.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] S. R. Jivani, M. Chetehouna, S. Hafeez, and M. H. Adjali, "Effects of game-based learning on engagement and academic performance for undergraduate science and engineering students," *Int. J. Eng. Educ.*, vol. 40, no. 1, pp. 16–22, 2024.

[2] M. S. Ramli and N. A. Bakar, "Evaluating the effectiveness of an enhanced intervention model using augmented reality approach: A structural equation modeling," *Int. J. Inf. Educ. Technol.*, vol. 14, no. 12, pp. 1698–1705, 2024. doi: 10.18178/ijiet.2024.14.12.2200

[3] F. Mufit, W. S. Dewi, S. Riyasni, and M. Dhanil, "Augmented reality with a cognitive conflict model and STEM integration on newton's universal law of gravitation: Does practicing practical learning support scientific literacy?" *Int. J. Inf. Educ. Technol.*, vol. 15, no. 2, pp. 255–271, 2025. doi: 10.18178/ijiet.2025.15.2.2239

[4] J. Patero, "Integrating technology in physics and math instruction: A pedagogical approach," *Int. J. Adv. Res. Sci. Commun. Technol.*, vol. 3, no. 1, pp. 786–790, 2023. doi: 10.48175/IJARSCT-12371

[5] A. Shirazi and A. H. Behzadan, "Technology-enhanced learning in construction education using mobile context-aware augmented reality visual simulation," in *Proc. 2013 Winter Simulations Conf. (WSC)*, 2013, pp. 3074–3085. doi: 10.1109/WSC.2013.6721675

[6] C. A. Mrani, A. Hajjami, and K. Khattabi, "Effects of the integration of PhET simulations in the teaching and learning of the physical sciences of common core (Morocco)," *Univers. J. Educ. Res.*, vol. 8, no. 7, pp. 3014–3025, 2020. doi: 10.13189/ujer.2020.080730

[7] P. Santos, M. Calvera-Isabal, A. Rodríguez, and K. Aadmi, "The impact of design thinking, maker education, and project-based learning on self-efficacy of engineering undergraduates," *Int. J. Eng. Educ.*, vol. 40, no. 4, pp. 851–862, 2024.

[8] J. Quintero, S. Baldiris, R. Rubira, J. Cerón, and G. Velez, "Augmented reality in educational inclusion. A systematic review on the last decade," *Front. Psychol.*, vol. 10, no. 1835, pp. 1–14, 2019. doi: 10.3389/fpsyg.2019.01835

[9] M. C. Wijaya, Z. Maksom, and M. H. L. Abdullah, "Novel framework for translation algorithms in multimedia authoring tools," *IAENG Int. J. Comput. Sci.*, vol. 49, no. 3, pp. 628–636, 2022.

[10] L. N. Walsh, R. G. Howard, and B. Bowe, "Phenomenographic study of students' problem solving approaches in physics," *Phys. Rev. Phys. Educ. Res.*, vol. 3, no. 2, 020108, 2007. doi: 10.1103/PhysRevSTPER.3.020108

[11] T. Saiseenin, T. Nern-Ngarm, and P. Chatwattana, "The outcomes of the development of an immersive virtual reality environment laboratory based on the VRChat platform," *World Trans. Eng. Technol. Educ.*, vol. 22, no. 2, pp. 122–128, 2024.

[12] S. Surjoo and S. Simelane-Mnisi, "Effect of audio-visual simulations on physical science learners' ability to solve higher order thinking problems in high school," *World Trans. Eng. Technol. Educ.*, vol. 22, no. 4, pp. 332–337, 2024.

[13] M. C. Wijaya, Z. Maksom, M. Haziq, and L. Abdullah, "A brief review: Multimedia authoring modeling," *J. Inf. Hiding Multimed. Signal Process.*, vol. 13, no. 1, pp. 39–48, 2022.

[14] P. Tazabekova, A. Nurbekov, Z. Nurbekova, and T. Sembayev, "The use of generated 3D models in teaching the development of AR/VR applications," *World Trans. Eng. Technol. Educ.*, vol. 22, no. 4, pp. 241–247, 2024.

[15] C. E. Wieman, W. K. Adams, and K. K. Perkins, "PhET: Simulations that enhance learning," *Science*, vol. 322, no. 5902, pp. 682–683, 2008. doi: 10.1126/science.1161948

[16] K. Perkins, "Transforming STEM learning at scale: PhET interactive simulations," *Child. Educ.*, vol. 96, no. 4, pp. 42–49, 2020. doi: 10.1080/00094056.2020.1796451

[17] L. Nurhidayah and S. Suyanto, "Integrated of Technological Pedagogical and Content Knowledge (TPACK) for pre-service science teachers: Literature review," in *Proc. the 6th International Seminar on Science Education (ISSE 2020)*, 2021, pp. 98–106. doi: 10.2991/assehr.k.210326.014

[18] İ. Aktaş and H. Özmen, "Investigating the impact of TPACK development course on pre-service science teachers' performances," *Asia Pacific Educ. Rev.*, vol. 21, no. 4, pp. 667–682, 2020. doi: 10.1007/s12564-020-09653-x

[19] A. Solihin, F. C. Wibowo, and I. M. Astra, "Review of Trends Project Based Learning (PjBL) integrated STEM in physics learning," *J. Phys. Conf. Ser.*, vol. 2019, no. 1, 12031, 2021. doi: 10.1088/1742-6596/2019/1/012031

[20] L. Uden, F. Sulaiman, G. S. Ching, and J. J. Rosales, "Integrated science, technology, engineering, and mathematics project-based learning for physics learning from neuroscience perspectives," *Front. Psychol.*, vol. 14, 1136246, pp. 1–15, 2023. doi: 10.3389/fpsyg.2023.1136246

[21] G. Cooper, L. P. Thong, and K.-S. Tang, "Transforming science education with virtual reality: An immersive representations model," *EMI. Educ. Media Int.*, vol. 61, no. 3, pp. 229–251, 2024. doi: 10.1080/09523987.2024.2389348

[22] E. Shittu, T.-R. Sikorski, E. Wortham, U. Singh, and J. Starita, "Undergraduate student views on social innovation in engineering," *Int. J. Eng. Educ.*, vol. 41, no. 1, pp. 75–87, 2025.