International Journal of Innovative Research and Scientific Studies, 8(12) 2025, pages: 1-10

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Development of a multiple representation digital platform for STEAM-based deep learning with the 3DE model

Tri Isti Hartini[1], Imas Ratna Ermawati[1*], Martin[1], Nuraeni Nanda Sari[1], Elsa Sagita[1], Dede Padli[1]

[1]*Faculty of Teacher Training and Education, Muhammadiyah University Prof. DR. HAMKA, Indonesia.*

Corresponding author: Imas Ratna Ermawati (*Email: imas_re@uhamka.ac.id*)

Abstract

This research is motivated by the limited digital learning platforms capable of integrating various forms of representation to support STEAM-based in-depth learning, particularly in physics subjects that require high conceptual understanding. To address this need, this study aims to describe the feasibility of the Digital Multiple Representation Platform (DMRP) as an innovative learning medium designed to facilitate conceptual understanding and encourage interdisciplinary integration in the STEAM context. This research method uses a Research and Development (R&D) design based on the DDDE (Decide, Design, Develop, and Evaluation) model to systematically guide the platform creation and validation process. Data were collected using an expert validation questionnaire covering aspects of content feasibility, pedagogy, interface appearance, interactivity, and technical aspects. Validation was carried out by learning media experts and physics material experts to assess the quality and suitability of the platform for instructional purposes. In addition to quantitative data, the study also involved qualitative feedback from educators and students through open-ended interviews to obtain an in-depth overview of the platform's practicality and acceptability. Quantitative data were analyzed using descriptive techniques to calculate a feasibility score, while qualitative data were analyzed to identify suggestions for improvement and aspects that support the platform's effectiveness. The results of the study show that the DMRP achieved an average media validation score of 80% and a content validation score of 79%, both of which are categorized as very feasible to be implemented in learning. The conclusion of this study shows that integrating various representations in a digital environment can effectively improve conceptual understanding, creativity, and student engagement in STEAM-oriented physics education. Overall, the developed DMRP offers a pedagogically grounded model to support deep learning and interdisciplinary thinking, which contributes to the development of digital innovation in STEAM education.

Keywords: Digital Platform, Models 3DE, Multiple Representations, Steam.

DOI: 10.53894/ijirss.v8i12.10983
Funding: This research was funded by the Directorate of Research, Technology, and Community Service, Ministry of Higher Education, Science, and Technology of the Republic of Indonesia.
History: Received: 6 October 2025 / **Revised:** 17 November 2025 / **Accepted:** 21 November 2025 / **Published:** 1 December 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

The development of digital technology has driven a paradigm shift in science learning in higher education, from lecture-based learning to experiential and exploration-based learning. Physics learning demands innovation that not only presents conceptual material but also supports students in building in-depth understanding through multiple representations involving symbolic, visual, and mathematical aspects [1, 2]. However, the reality on the ground shows that many students still experience difficulties in connecting these various forms of representation, so their conceptual understanding is often fragmented.

Deep learning is one approach that can improve the quality of education. Deep learning is defined as a student's approach to critically analyzing new ideas and linking them to previous concepts and principles, resulting in meaningful learning [3]. In principle, the deep learning approach has three basic elements or foundations: mindful, meaningful, and joyful [4]. The focus of deep learning is to provide students with opportunities to explore and elaborate on their knowledge constructively. Deep learning equips students with competencies, both at a personal and professional level [5].

Multiple representation is an important approach in modern science learning that emphasizes the use of various forms of representation to understand concepts in depth. Ainsworth explains that multiple representations include the presentation of information in verbal, visual, mathematical, symbolic, and graphic forms that function to complement each other in the learning process [1]. This diversity of representations helps students see a concept from various perspectives so they can connect abstract phenomena with real contexts. In line with this, Gilbert emphasized that representation plays a key role in science because it functions as a mental model that helps students build bridges between physical phenomena and complex theoretical concepts [6]. One learning approach that can be implemented is multiple representation. Multiple representation is a learning approach that uses various forms to describe concepts or processes and is effective in improving students' understanding of physics [7, 8]. Then, students' representational abilities can be escalated through the implementation of STEAM integrated learning [9]. In addition, the use of STEAM can develop creative, critical, collaborative, and problem-solving thinking skills [10]. Therefore, the STEAM approach is very effective when used in conjunction with the application of technology in physics learning [11].

Along with this, technological advances in the digital era are also seen as the right media to support the learning process. Digital transformation has become one of the main foundations in the development of the world of education in the 21st century. Technological advances have influenced various aspects of learning, from the preparation of learning tools, lesson delivery, interaction forums between teachers and students, to the learning evaluation process [12]. One contribution of the application of digital technology is the provision of digital platforms. In the field of education, digital platforms are very important for the transition from universal methods to personalized methods that support explanatory teaching and student-centered approaches [12, 13]. The use of digital technology has a positive influence on students' in-depth learning outcomes because by understanding something so that it is not easily forgotten, it provides a meaningful and enjoyable learning experience [14, 15]. Therefore, the publication of digital education transformation has an important role played by the in-depth learning approach [16].

This problem is reinforced by the findings of several previous studies showing that limited digital learning media is one of the causes of low higher-order thinking skills in students [17, 18]. Most e-learning platforms used in higher education still focus on presenting textual and evaluative content, not optimally supporting the integration of deep learning and student scientific creativity. This is a barrier to the development of 21st-century competencies such as critical thinking, collaboration, creativity, and communication [19].

To address these challenges, the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach is relevant because it provides an interdisciplinary framework that encourages students to connect science with technology, engineering, and art in the context of authentic problem-solving [20]. STEAM-based learning emphasizes not only conceptual mastery but also creative thinking processes through design, innovation, and cross-disciplinary collaboration. In the context of physics learning, the integration of the STEAM approach through a digital multiple representation (PDMR) platform is expected to foster students' ability to understand physics phenomena holistically through various interconnected scientific representations. In addition, digital learning media innovations need to be designed with a systematic instructional design approach so that their effectiveness can be tested empirically. One relevant model for the development of digital educational products is the DDDE (Decide, Design, Develop, Evaluate) model proposed by Alessi and Trollip [21]. This model emphasizes a balance between user needs analysis, instructional design, technology development, and continuous evaluation. Through the application of this model, platform development can take place adaptively and be oriented towards the learning needs of students.

The novelty of this research lies in the conceptual and methodological integration of the multiple representations approach, the STEAM framework, and the DDDE (3DE) development model in a single interactive digital platform specifically designed to support deep learning in physics courses. This research not only produces an innovative digital product but also offers a new theoretical model for implementing multiple representations in a STEAM-based digital learning environment. This approach makes an important contribution to the digital science education literature by presenting an empirical framework on how digital media design can foster integration between conceptual understanding, creativity, and scientific collaboration of students.

2. Methodology

2.1. Research Design

This study uses a Research and Development (R&D) approach that aims to produce a product in the form of a Digital Multiple Representation Platform (PDMR) that is suitable for use to support STEAM-based in-depth learning. This approach was chosen because it is able to combine theoretical and empirical processes in producing innovative and tested educational products [22]. The development model used refers to DDDE (Decide, Design, Develop, Evaluate) proposed by Alessi and Trollip [21]. This model was chosen because it provides a systematic and flexible framework for developing digital learning media based on interactivity and user experience.

2.2. Research Subjects and Context

The research was conducted in high schools across both public and private schools. The subjects included two instructional media experts, two physics subject matter experts, and several schools in Jakarta and Tangerang that participated in the limited trial phase. Subjects were selected purposively to obtain representative input on the feasibility of the design, content, and implementation of the platform.Penelitian dilaksanakan pada sekolah menengah atas di salah satu sekolah negeri maupun swasta. Subjek penelitian terdiri atas dua ahli media pembelajaran, dua ahli materi fisika, dan beberapa sekolah di Jakarta dan tangerang yang terlibat dalam tahap uji coba terbatas. Pemilihan subjek dilakukan secara purposif untuk memperoleh masukan yang representatif terhadap kelayakan desain, isi materi, dan implementasi platform.

2.3. Research Instruments

The instruments used in this study included:

a. Media expert validation sheet, to assess aspects of display design, interactivity, navigation, and technological suitability.
b. Material expert validation sheet, to assess the validity of physics concepts, STEAM integration, and the suitability of multiple representations.
c. User response questionnaire, to assess the platform's ease of use, attractiveness, and usefulness from the learner's perspective.

All instruments were developed by adapting the learning product validation format from Sugiyono [23] and Thiagarajan, et al. [24]. The assessment scale used a Likert scale of 1–4, which was converted into a percentage of suitability.

2.4. Development Procedure

The digital platform development process follows the four main steps of the DDDE (3DE) model:

a. Decide: the needs analysis and formulation of STEAM-based learning objectives.
b. Design: the design of the navigation structure, interface, and mapping of multiple representations (visual, symbolic, and conceptual).
c. Develop: the platform prototype creation stage with the integration of interactive components and digital learning features.
d. Evaluate: the validation stage by experts and limited trials to assess the product's feasibility and initial effectiveness.

2.5. Data Analysis Techniques

The quantitative data from expert validation were analyzed using descriptive statistics in the form of average scores and percentages of eligibility, as shown in Table 1.

Table 1.
eligibility Presentation

Percentage	Interpretation
0% - 25%	Not really worth it
26% - 50%	Not feasible
51% - 75%	Worth it
76% - 100%	Very worthy

Qualitative data from expert comments and student responses were analyzed descriptively and narratively to strengthen the quantitative findings and provide recommendations for design improvements. This approach was used to provide context for the numerical findings and generate recommendations for product improvements [25].

The results of both analyses were then synthesized to assess the final feasibility of the digital platform, both from a media and content perspective, and to conclude the platform's potential effectiveness in supporting STEAM-based immersive learning.

3. Result

This research was conducted in the odd semester of 2025/2026. This section explains the research process and results obtained along with a discussion based on the research that has been conducted. The main result of this research is the final product in the form of a digital platform multiple representations to support STEAM-based in-depth learning. Based on data from validation tests on material experts, media experts, physics educators and student response tests conducted on 300 grade XI science students in high schools throughout Greater Jakarta, it states that the digital platform that has been developed is suitable for use. This research produced a product in the form of a Digital Platform Multiple Representations (PDMR) which was developed through four main stages according to the DDDE model: Decide, Design, Develop, and Evaluate.

3.1. Decide

This stage resulted in a learning needs analysis conducted through observations and interviews with teachers and students. It was found that 86.7% of students stated that they had difficulty understanding physics concept 2, namely magnetism and electricity, conceptually due to a lack of visualization and integration between mathematical, verbal, and graphical representations. Educators also revealed that available learning media did not support project-based or collaborative activities as per the STEAM learning principles. These results became the basis for determining the need for a digital platform that can integrate interactive simulations, multiple representations of physics concepts, and collaborative activities based on STEAM projects.

3.2. Design

This stage results in a design of the platform's structure and interface. The initial design includes two main modules:

3.2.1 Determining Learning Materials

Before determining the learning materials to be developed, an analysis was first conducted on what materials could be integrated with in-depth learning and STEAM through a multiple representation approach. The materials in question were high school physics materials that could be made into teaching modules by paying attention to verbal, mathematical, graphical and visual aspects and linked to phenomena in everyday life. Actually, most physics materials could be made into these criteria, but after filtering the Physics materials in grades 10, 11 and 12, suitable materials were found, namely Measurement, Speed & Acceleration, Hooke's Law, Mathematical Pendulum, Length Expansion, Static Electricity, Dynamic Electricity, Optics, Lorentz Force and RLC Circuits. These materials were chosen because they are included in the basic Physics groups 1 and 2 and are often encountered in everyday life, such as the activity of measuring mass quantities carried out in buying and selling activities. In addition, these materials can be presented in the form of images, simulated in graphic form and practiced using a virtual lab, to then be created as learning modules and included in a digital platform.

3.3. Initial Design

This digital platform is designed as an alternative platform that can be used by teachers and students as a companion platform in the physics learning process, accessible anywhere and anytime. In the design process, the immersive learning approach, STEAM, and Multiple Representation are integrated to enrich the learning experience. Immersive learning ensures students understand concepts comprehensively, not just memorize them. The STEAM approach (Science, Technology, Engineering, Arts, Mathematics) encourages interdisciplinary connections and their application in real life. Meanwhile, the Multiple Representation strategy allows abstract concepts to be explained through various forms such as text, images, simulations, videos, and virtual experiments. With the combination of these three approaches, the learning flow activities that have been designed can be seen in Table 2.

Table 2.
Learning activity flow

Stage	Student Activity	Media/Tools	Objectives
1. D – Diagnose Prior Knowledge	Answer quizzes & create concept maps	Interactive quizzes, mind map	features Prior knowledge activation
2. I – Immerse in Phenomena (STEAM Contextualization)	Watch the video: "Measuring the Length of a Ship with Measuring Tools"	Contextual video	Connecting physics to real life
3. S – Select and Explore Multiple Representations	Explore videos, graphs, tables of units and measuring tools	Interactive simulations, images, animations	Understanding from multiple angles
4. T – Test Ideas Through Experimentation (Virtual Labs)	Conduct simulations measuring mass, volume, time	PhET/HTML5 Simulations	Improve scientific skills
5. E – Engineer Solutions (Project-Based Task)	Designing simple measuring tools from used objects	LMS project space	Developing creativity and application
6. A – Articulate Understanding(Presentation & Reflection)	Create videos or posters of project results	Poster editor, upload media	Scientific communication and reflection
7. M – Measure & Reflect (Assessment and Feedback Loop)	Adaptive quizzes, peer review	LMS project quiz + peer assessment	Formative and summative evaluation

Evaluations are also conducted during the initial design stage. These evaluations are conducted to ensure that the selected digital platform, the designed learning flow, and the learning modules align with the objectives of the product being developed. Furthermore, this stage also addresses any deficiencies identified before entering the development phase.

3.4. Development

3.4.1. Initial Product

The initial product in this research was developed based on the design prepared in the previous design stage. The following presents the components of the resulting initial product, as shown in the image below.

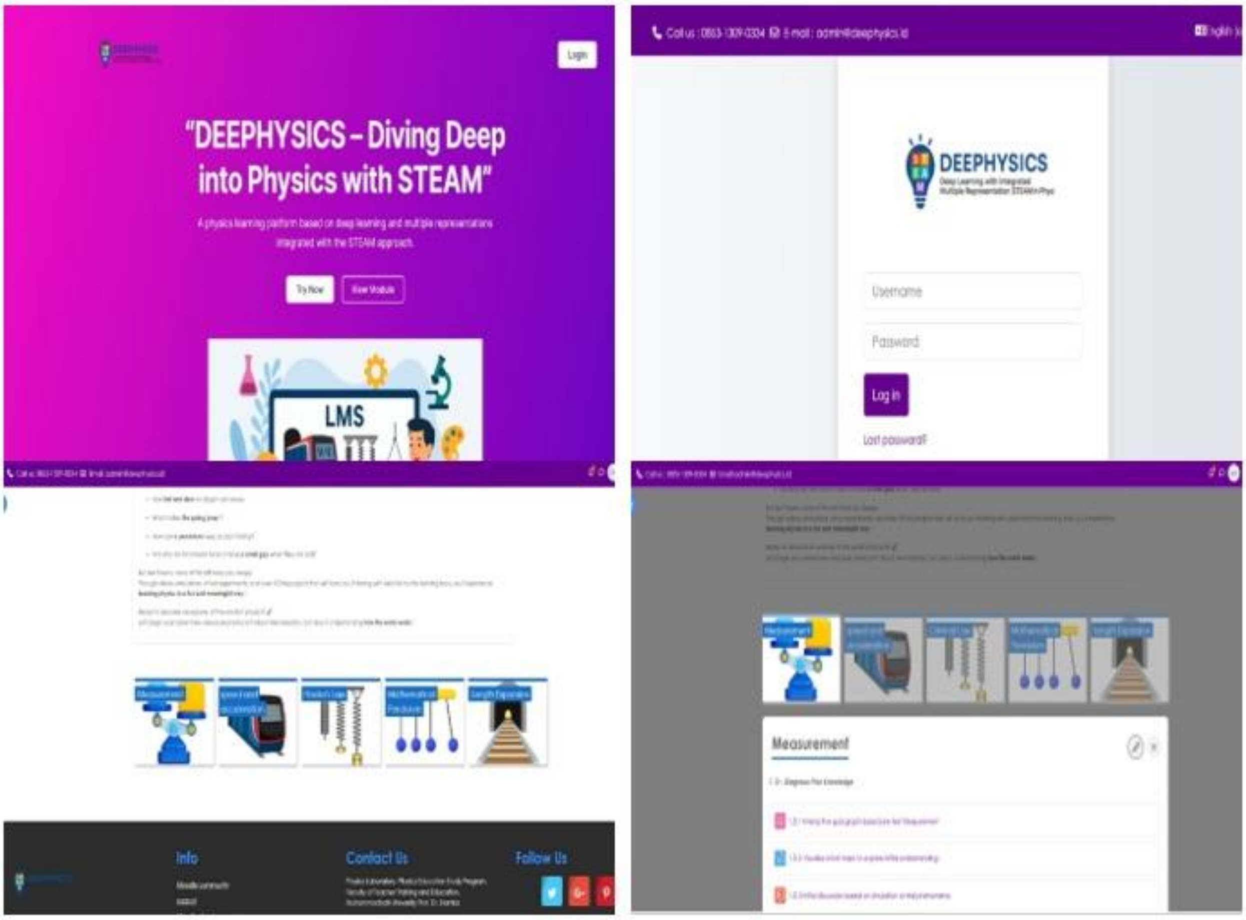

Figure 1.
Home page, login, learning materials, and activities.

3.4.2. Product Validation

At this development stage, validation of the developed digital platform was also carried out. Product validation was carried out to determine the validity of the developed product. The validity test was carried out by 4 experts, namely 1 informatics engineering lecturer from Muhammadiyah University Prof. DR. HAMKA and 1 physics education lecturer from Nurul Huda University for validation on the media aspect and 2 physics education lecturers each from Makassar State University and Lampung University for validation on the material aspect. This validation was also carried out to determine the feasibility of the developed product before being tested on students. Data from the results of the media expert validation assessment, where the average percentage of product feasibility assessment was 93.85% with a very feasible category. The results of the media expert validation can be seen in Table 3 and Figure 1.

Table 3.
Results of the digital platform media expert feasibility test.

Assessment Aspect	Response	
	Score	Qualitative Category
Learning Media Design	93%	Very Feasible
Appearance Suitability Aspect	94%	Very Feasible
Appearance Design	92%	Very Feasible
Appearance Suitability	95%	Very Feasible
Font Design	93%	Very Feasible
Font Suitability	92%	Very Feasible
Media Usability Aspect	98%	Very Feasible

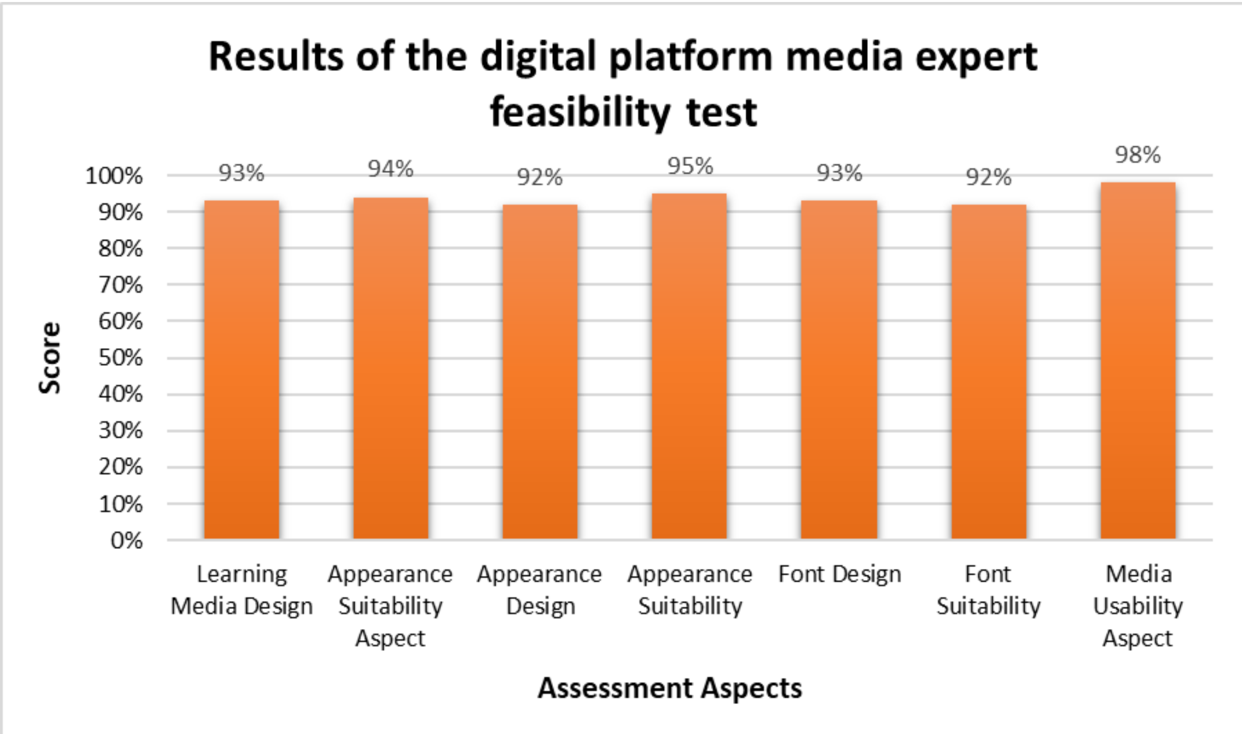

Figure 2.
Results of the digital platform media expert's feasibility test.

Meanwhile, data from the validation assessment by material experts showed that the average percentage of product feasibility was 79%, categorized as very feasible. The results of the media expert validation can be seen in Table 4.

Table 4.
Results of the digital platform material expert feasibility test.

Assessment Aspects	Response	
	Score	Qualitative Category
Content Suitability Aspect	80%	Very Feasible
Presentation Suitability Aspect	79%	Very Feasible
Language Suitability Aspect	78%	Very Feasible

3.4.3. Product Revision

This stage involves revising the digital platform product based on input and suggestions from validators, both regarding media and materials. This stage also forms part of the evaluation during the development phase. Based on the results of the digital platform feasibility validation, several inputs and suggestions received from the validators included the need for the pretest to remain on the same platform or not to move from the platform.

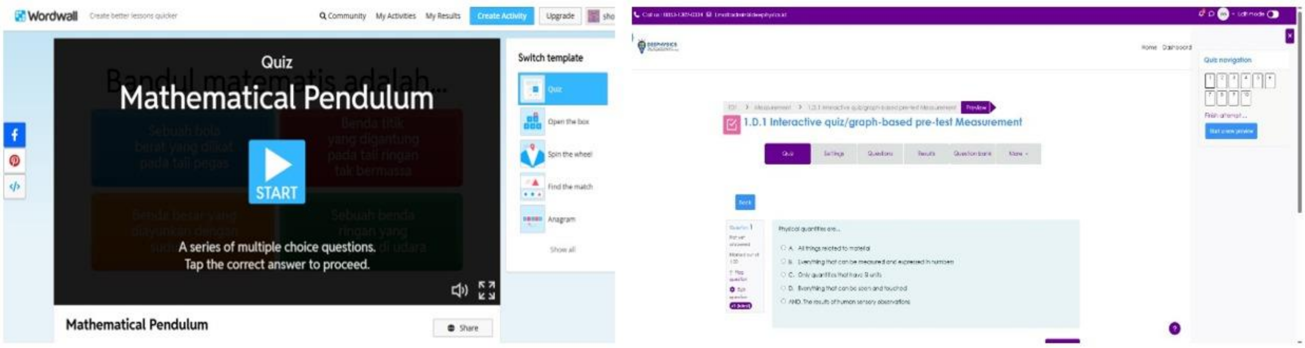

Figure 3.
View before the pretest on the platform and View after the pretest on the platform.

3.4.4. Small Scale and Large Scale Trials

After revising the digital platform, the next step was to conduct a small trial with 40 11th-grade high school students in Greater Jakarta (Jabodetabek). This small-scale trial aimed to gauge student reactions and comments regarding the digital platform. Student responses included platform usage intensity, platform materials, comprehensiveness of features, and motivation. Data from the small-scale trial yielded an average rating of 81%, categorized as very acceptable. The results of the small-scale trial can be seen in Table 5.

Table 5.
Results of the small-scale trial of the digital platform

Assessment Aspects	**Response**	
	Score	Qualitative Category
Platform Usage Intensity	78%	Very Feasible
Platform Content	81%	Very Feasible
Platform Feature Completeness	79%	Very Feasible
Motovation	80%	Very Feasible

After conducting the small-scale trial, the next stage was a large-scale trial with 347 eleventh-grade high school students in Greater Jakarta (Jabodetabek). This large-scale trial aimed to determine student reactions and comments to the digital platform based on revisions made in the small-scale trial. Student responses included platform usage intensity, platform materials, feature completeness, and motivation. Data from the large-scale trial yielded an average percentage of 80%, categorized as very acceptable. The results of the large-scale trial can be seen in Table 6.

Table 6.
Results of the large-scale trial of the digital platform.

Assessment Aspects	**Response**	
	Score	**Qualitative Category**
Platform Usage Intensity	79%	Very Feasible
Platform Content	82%	Very Feasible
Platform Feature Completeness	80%	Very Feasible
Motovation	84%	Very Feasible

The majority of students, with a score of 82%, stated that the use of multiple representations in the platform helped them understand the relationship between formulas, graphs, and physical phenomena. The overall results of the small-scale and large-scale trials are shown in Figure 4.

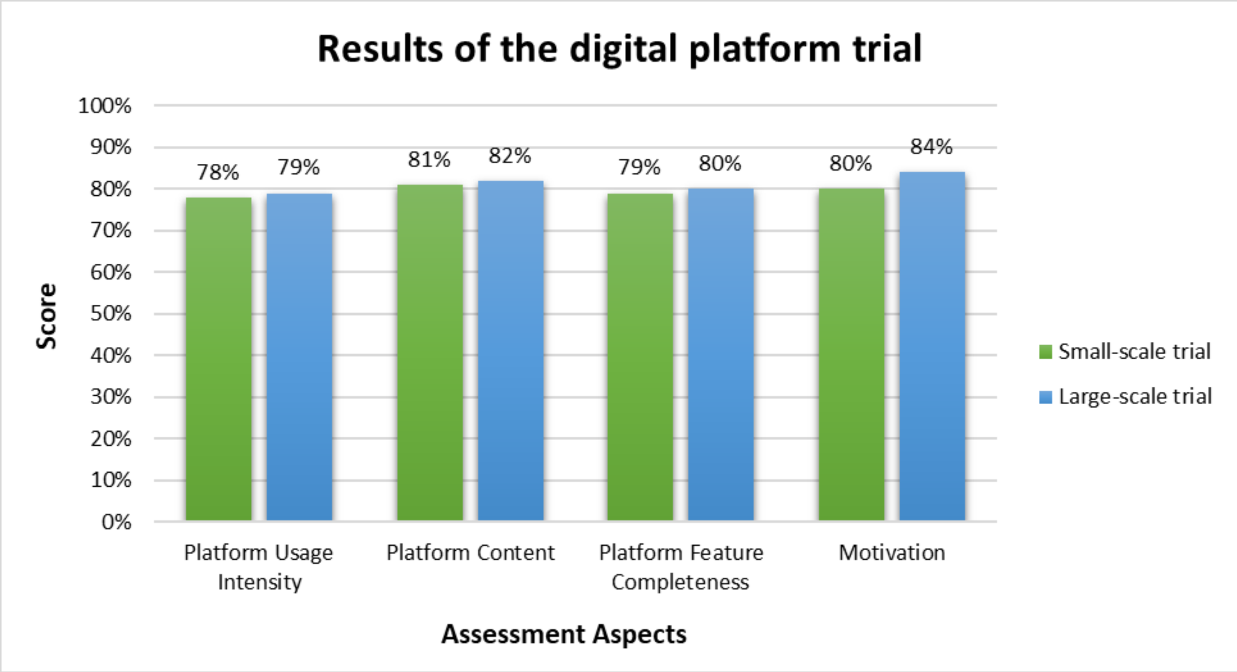

Figure 4
Small-scale and large-scale trial results

3.5. Evaluate

The evaluation phase is conducted at each stage of research and development. This phase is conducted to evaluate the developed digital platform by conducting a large-group trial of 11th-grade high school students in Greater Jakarta (Jabodetabek). During the evaluation phase, questionnaires were also distributed to teachers to determine their responses to the developed digital platform. Furthermore, to assess the effectiveness of the developed digital platform, questionnaires were distributed to 347 high school students in Greater Jakarta. Effectiveness refers to how well the digital platform is accepted by students, engaging, easy to use, and beneficial in the physics learning process.

4. Discussion

The results of this study indicate that the Digital Platform for Multiple Representations (PDMR) developed through the DDDE / 3DE (Decide, Design, Develop, Evaluate) model has a high level of feasibility in both media and material aspects. Expert validation showed an average feasibility of 79% with a very feasible category, while student trials resulted in a positive response of 80% with a very good category. These data indicate that the integration between the multiple representation approach and STEAM-based learning in a digital platform can provide a more in-depth, interactive, and meaningful learning experience.

The high feasibility of the media aspect reflects the success of the Design and Develop stage in the DDDE model. The developed interface design utilizes aesthetic principles and intuitive navigation, making it easier for students to explore conceptual, mathematical, and visual representations simultaneously. This is in line with Ainsworth's findings which confirm that the use of various representations in physics learning can strengthen the integration of conceptual and procedural knowledge [24]. In the context of learning electromagnetic fields which are full of abstract symbols and phenomena, the existence of multiple representations becomes an important bridge to build a complete conceptual understanding.

In addition, the Develop stage plays a crucial role in ensuring that the resulting product is not only technically functional but also relevant to the characteristics of 21st-century students. The integration of features such as interactive simulations, 3D visualizations, and STEAM-based collaborative projects provides opportunities for students to play an active role in the knowledge construction process. This finding reinforces Jonassen's view that digital media should be designed as a constructivist learning environment that allows students to construct meaning through exploration, reflection, and authentic problem-solving [26].

The Evaluate stage in the DDDE/3DE model demonstrates the importance of continuous feedback from experts and users. Expert validation ensures the quality of the platform's content and functionality, while student trials provide input on user experience aspects. This evaluation process makes platform development not only technology-based, but also pedagogically-based. Thus, the DDDE model has proven effective as a systematic approach to developing digital learning media that is responsive to user needs, as emphasized by Alessi and Trollip [21].

From a STEAM-based learning perspective, PDMR plays a crucial role in fostering students' critical, creative, and collaborative thinking skills. Each learning module is designed not only to theoretically understand physics concepts but also to apply them in simple design projects involving aspects of science, technology, engineering, art, and mathematics. This aligns with Perignat and Katz-Buonincontro's idea that STEAM integration can create a holistic learning experience through creative inquiry and design thinking processes [27].

Thus, this platform encourages students to not only understand concepts but also to create innovative science-based solutions and works.In addition to enhancing conceptual understanding, the use of multiple representations in the STEAM context also strengthens the realization of deep learning. Students are encouraged to connect previous knowledge with new contexts, reflect on their thinking processes, and relate theoretical concepts to real-world applications. This condition demonstrates the creation of meaningful learning as proposed by Biggs and Tang, where the learning process is not only reproductive but also transformational [28].

Overall, the results of this study, a combination of the DDDE/3DE model, the STEAM approach, and the concept of multiple representations, are innovations that have significant theoretical and practical contributions in the field of science education technology. Theoretically, this study expands the application of the DDDE/3DE model, which was originally widely used for multimedia development, into an effective framework for the development of a digital learning platform based on multiple representations. Practically, the results of this platform development provide an innovative alternative for educators/teachers and educational developers in designing more interactive, collaborative, and creative physics learning.

Thus, it can be concluded that the developed Multiple Representation Digital Platform is not only feasible to use but also makes a significant contribution to improving the quality of STEAM-based physics learning. This platform can serve as an initial model for the development of similar digital learning systems in other science fields, especially those that require integration between conceptual understanding and students' creative-critical thinking skills.

5. Conclusion

This research has produced a multiple representation digital platform to support STEAM-based immersive learning. It has undergone expert validation across various aspects, including media and materials, as well as platform effectiveness. Based on the validation results, the digital platform was deemed suitable for use as a learning support tool. A trial of the digital platform demonstrated its effectiveness in supporting physics learning. Furthermore, students responded positively to the learning experience using this platform. Therefore, it can be concluded that the multiple representation digital platform to support STEAM-based immersive learning is highly suitable as a self-study platform, as it can be accessed anytime and anywhere and can strengthen student understanding. For further development, it is recommended to expand the application to other physics materials.

6. Theoretical and Practical Implications

From a theoretical perspective, the results of this study enrich the study of learning media development by extending the application of the DDDE model to the realm of digital learning based on multiple representations and STEAM. The resulting platform strengthens Ainsworth's theory regarding the effectiveness of multiple representations in deepening conceptual understanding and supports Jonassen's constructivist approach, which emphasizes the importance of exploration- and reflection-based learning experiences.

Meanwhile, from a practical perspective, the development of PDMR provides an alternative digital learning medium relevant to the needs of the hybrid and transformative learning era. This platform can be used by lecturers and science educators to create interactive, visual, and collaborative learning experiences without relying entirely on face-to-face learning. Furthermore, this platform can also function as a learning hub that integrates materials, simulations, STEAM projects, and conceptual reflection into one integrated digital system.

7. Further Research Recommendations

Further research is recommended to expand the pilot to a large-scale implementation stage involving various science courses, so that the platform's effectiveness can be measured in more diverse contexts. Furthermore, future research could add artificial intelligence (AI)-based features for personalized learning and learning analytics to monitor students' cognitive development in real time.

References

[1] S. Ainsworth, "DeFT: A conceptual framework for considering learning with multiple representations," *Learning and instruction,* vol. 16, no. 3, pp. 183-198, 2006. https://doi.org/10.1016/j.learninstruc.2006.03.001

[2] D. F. Treagust, R. Duit, and H. E. Fischer, *Multiple representations in physics education*. Cham, Switzerland: Springer International Publishing, 2017.

[3] E. M. Alwafi, "The effect of learner-generated digital materials on learners' deep learning approach and self-efficacy," *Journal of Education and E-Learning Research,* vol. 10, no. 3, pp. 415-420, 2023.

[4] B. Prahani *et al.*, "A profile of physics multiple representation ability of senior high school students on heat material," in *Journal of Physics: Conference Series (Vol. 1760, No. 1, p. 012020). IOP Publishing*, 2021.

[5] T. I. Hartini, I. R. Ermawati, M. Martin, N. N. Sari, N. D. Septiyani, and E. Sagita, "Effectiveness of Multiple Representation-Based Mechanics Lectures Using YouTube Video Content on Concept Mastery," *JURNAL PENELITIAN PEMBELAJARAN FISIKA Учредители: Universitas PGRI Semarang,* vol. 15, no. 3, pp. 317-323, 2024.

[6] J. K. Gilbert, *The role of models and modeling in science education*. New York: Routledge, 2010.

[7] S. Khairillah and T. I. Hartini, "The effect of collaborative teamwork learning model on work and energy matter based of multi representations on physics learning outcomes," *Omega J. Fis. and Educator. Phys,* vol. 6, no. 2, pp. 14–20, 2020.

[8] V. R. Wardani, N. R. Dewi, and S. B. Waluya, "Implementation of the STEAM-integrated challenge-based learning model on students' mathematical representation skills," presented at the Proceedings of the National Mathematics Seminar, 2024.

[9] I. Budiati, M. S. Hayat, and S. Fatonah, "The potential of STEAM-SDGs integration in science project learning at SMK Bina Utama Kendal," *Jurnal Pendidikan MIPA,* vol. 15, no. 1, pp. 148–155, 2020. https://doi.org/10.37630/jpm.v15i1.2451

[10] W. Mubarok and S. Anugrah, "Analysis of virtual reality-based learning media through the steam approach to improve high school students' understanding of concepts," *Al-Irsyad Journal of Physics Education,* vol. 3, no. 2, pp. 57-68, 2024. https://doi.org/10.58917/ijpe.v3i2.118
[11] M. Y. Kua, A. Gelu, S. Kusairi, and F. Ngongo, "Optimizing the online physics learning platform through teacher training to increase middle school students' learning motivation," *I-Com: Indonesian Community Journal,* vol. 5, no. 3, pp. 1279-1288, 2025. https://doi.org/10.70609/i-com.v5i3.7782
[12] M. Shchevliagin and D. Koroleva, "Four scenarios of personalized learning integration mediated by a digital platform," *Turkish Online Journal of Distance Education,* vol. 25, no. 2, pp. 76-95, 2024. https://doi.org/10.17718/tojde.1267577
[13] D. Vaillant, E. R. Zidán, and G. Bentancor-Biagas, "Plan CEIBAL and the incorporation of digital tools and platforms in the teaching of mathematics according to the teachers' perceptions," *Eurasia Journal of Mathematics, Science and Technology Education,* vol. 17, no. 12, p. em2037, 2021. https://doi.org/10.29333/ejmste/11307
[14] J. M. Czum, "Dive into deep learning," *Journal of the American College of Radiology,* vol. 17, no. 5, pp. 637-638, 2020.
[15] X.-Y. Wu, "Exploring the effects of digital technology on deep learning: a meta-analysis," *Education and Information Technologies,* vol. 29, no. 1, pp. 425-458, 2024. https://doi.org/10.1007/s10639-023-12307-1
[16] S. Hastuti, A. Ansar, and N. Hermawan, "Application of deep learning technology in digital education," *Journal of Research. Educator Science. Indonesia,* vol. 4, no. 2, pp. 359–365, 2025.
[17] A. Widodo and N. Hidayah, "Technology integration in science learning: Analysis of the need for multiple representation media," *Indonesian Journal of Science Education,* vol. 10, no. 4, pp. 563–578, 2022.
[18] A. Hidayat, D. Rahmawati, and R. Purwanti, "Digital learning challenges in science education: Between conceptual understanding and technological adaptation," *Journal of Physics Education Research,* vol. 11, no. 2, pp. 45–58, 2023.
[19] S. Z. Beers, *21st century skills: Preparing students for their future*. Columbus: Pearson, 2011.
[20] G. Yakman and H. Lee, "Exploring the exemplary STEAM education in the US as a practical educational framework for Korea," *Journal of the korean Association for Science Education,* vol. 32, no. 6, pp. 1072-1086, 2012.
[21] S. M. Alessi and S. R. Trollip, *Multimedia for learning: Methods and development*, 3rd ed. Boston: Allyn & Bacon, 2001.
[22] M. D. Gall, J. P. Gall, and W. R. Borg, *Educational research: An introduction*, 7th ed. Boston: Pearson, 2003.
[23] Sugiyono, *Research and development (R&D) methods*. Bandung: Alphabeta, 2019.
[24] S. Thiagarajan, D. S. Semmel, and M. I. Semmel, *Instructional development for training teachers of exceptional children: A sourcebook*. Bloomington: Indiana University, 1974.
[25] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative data analysis: A methods sourcebook*, 3rd ed. Thousand Oaks, CA: Sage Publications, 2014.
[26] D. H. Jonassen, *Designing constructivist learning environments*. New Jersey: Lawrence Erlbaum Associates, 1999.
[27] E. Perignat and J. Katz-Buonincontro, "STEAM in practice and research: An integrative literature review," *Thinking skills and creativity,* vol. 31, pp. 31-43, 2019.
[28] J. Biggs and C. Tang, *Teaching for quality learning at university*. Maidenhead, UK: McGraw-Hill Education, 2011.