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Development of A Google Sites-Based Granular Mechanics E-Module to Facilitate Students' Conceptual Understanding

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Abstract: Granular Mechanics not taught directly in the core curriculum of physics majors because this field is still considered interdisciplinary advanced study. This study aims to develop a Google Sites-based Granular Mechanics e-Module that is feasible, practical, and has the potential to facilitate students' conceptual understanding in college. This study uses the Research and Development (R&D). However, this study only stops at the development stage. The limited trial subjects in this study were 36 students of the Physics and Physics Education Study Programs. The results showed that the e-Module obtained a material expert validation percentage of 84.43% with a valid category and a media expert validation percentage of 89.55% with a very valid category. The results of the practicality test obtained a percentage of 91.42% with a very practical Based on these results, the Google Sites-based Granular Mechanics e-Module was deemed feasible, practical, and has the potential to facilitate students' conceptual understanding.

Keywords: e-Module; Google sites; Granular mechanics; Conceptual understanding; 4D models

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Introduction

Education is crucial because it can transform human thought and morality; through education, knowledge is transferred, skills are honed, and character is shaped, thereby molding individuals who possess critical thinking abilities, innovate, and contribute to addressing global issues. Education is essentially a lifelong process of developing individuals into well-rounded, wise, and morally responsible human beings, including fostering students' character. This process begins at birth and continues throughout life. The prosperity of a nation can be achieved through the provision of quality education (Kamarudin et al., 2023).

The recognition of the importance of education is not merely a local matter; it is also enshrined in various international legal instruments and declarations. Article 26 of the 1948 Universal Declaration of Human Rights (UDHR) explicitly states that "everyone has the right to education." Furthermore, the UN's 2030 Agenda reinforces the role of education through the Sustainable Development Goals (SDGs), aiming to ensure inclusive and equitable quality education and to promote lifelong learning opportunities. Given this robust legal foundation at both global and national levels, it is evident that education is not simply a transfer of knowledge, but a strategic investment in shaping the nation's character.

National character traits fostered through education include strong moral character, creativity, and critical thinking skills. Physics education plays a role in achieving these goals; through the study of physics, students not only gain a conceptual understanding but also develop logical, critical, and creative thinking abilities, alongside discipline and a strong sense of curiosity.

Studying physics requires extra effort, as many students report difficulties with the subject due to complex formulas, challenging material, mathematical formulations, problem-solving requirements, and abstract concepts. These difficulties can be particularly relevant in mechanics, where students are required to connect mathematical formulations with physical phenomena. A previous study involving 43 first-year students from the Physics Education program Class C, Cohort 2022 at Yogyakarta State University revealed differences in students' conceptual understanding across physics courses, including Analytical Mechanics (Nur'Aini et al., 2023).

Physics instruction, particularly in mechanics, is often perceived as difficult by students because it involves numerous abstract concepts, mathematical analysis, and real-world applications. Such challenges may hinder students from gaining a deep understanding of concepts when instruction focuses primarily on theory and calculations. One branch of mechanics that relates to real-world phenomena, yet remains less commonly discussed in undergraduate physics education, is Granular Mechanics.

Granular Mechanics is not explicitly included as a core topic in the undergraduate physics curriculum considered in this study. Undergraduate physics curricula generally emphasize fundamental concepts such as classical mechanics, waves, thermodynamics, and electromagnetism as foundations for understanding various natural phenomena. In contrast, Granular Mechanics deals with systems composed of interacting particles and exhibits distinctive behaviors that can be investigated through observable physical phenomena. Therefore, rather than being introduced as an additional compulsory subject, Granular Mechanics can be positioned as supplementary or enrichment material that allows students to apply previously learned fundamental mechanics concepts to more complex physical systems. Previous studies have demonstrated the use of granular materials and phenomena as contexts for physics learning through classroom experiments and computational simulations (López et al., 2008; Muliyati et al., 2021). Thus, introducing Granular Mechanics as enrichment material can provide students with opportunities to connect fundamental mechanics concepts with observable and computational granular phenomena.

When discussing granular mechanics, the phenomenon of granular material falling onto a floor follows principles similar to projectile motion; upon impact, the particles rebound at specific angles. While granular materials are highly relevant across science and engineering disciplines, the subject matter is vast. Dense granular flow remains a focus of research across various fields, yet due to the inherent complexity of these materials, many laws and flow characteristics remain undiscovered (Zhu, 2025). Examples of such materials include sand, rice, sugar, and salt. Granular materials are discrete in nature; at the microscopic level, particle velocities and inter-particle contact forces undergo inevitable changes during flow, leading to variations in macroscopic statistical parameters across time and space (Gross et al., 2015). These characteristics make granular phenomena relatively complex to represent and understand, particularly when students need to relate microscopic particle interactions to observable macroscopic behavior.

The development of an electronic module (e-Module) provides an opportunity to present supplementary learning materials in a flexible and interactive format. Digital learning materials can integrate various forms of representation, including text, images, videos, and interactive activities, which can support students in understanding complex physical concepts. Google Sites can also be utilized as a web-based learning platform that integrates learning materials and multimedia resources into an accessible learning environment. Previous research has demonstrated that Google Sites-based learning media can support physics learning and students' conceptual understanding (Jayanti & Handayani, 2025). Furthermore, the use of Google Sites as an interactive learning medium has also been explored at the university level for complex physics topics, indicating its potential as a platform for technology-integrated physics learning (Kurniawan et al., 2024). Therefore, Google Sites was selected in this study as a platform for integrating conceptual explanations, visualizations, videos, and experimental activities into the Granular Mechanics e-Module.

Addressing this issue requires supplementary teaching materials that can help students understand the fundamental concepts of Granular Mechanics. Such materials can help students relate the microscopic interactions among particles to the macroscopic phenomena that they observe. A module serves as an appropriate teaching tool because it can provide structured learning materials and support independent learning. Through a module, students can study the material systematically and revisit concepts that they have not yet fully understood. Therefore, the development of supplementary teaching materials in the form of an e-Module can provide students with accessible learning resources for exploring Granular Mechanics.

Research on teaching modules over the past five years indicates significant progress in motivating students to learn. Developing teaching modules that are contextually relevant to students' environments is crucial, as this can make the learning process more enjoyable and effective (Haryadi & Nurmala, 2021). Studies on granular materials in physics begin with the inherent complexity of these materials, which possess unique properties. Granular materials such as sand or rice exhibit unique and often unpredictable behavior.

They cannot be strictly classified as solids, liquids, or gases; instead, they display characteristics of all three phases of matter. One way to address this complexity is by creating teaching modules with engaging visual presentations. Visualizing concepts is highly beneficial for enhancing student concentration and attention regarding the material being taught (Khusniawati, 2024). Students find it easier to grasp the material and are more motivated to participate in learning activities when the content is presented in an engaging and innovative manner (Lastri, 2023).

A Systematic Literature Review (SLR) conducted across databases such as Google Scholar, Scopus, and Emerald Insight reveals a lack of existing teaching materials specifically modules on Granular Mechanics that integrate learning technology. Yet, physics instruction can be significantly enhanced through the use of appropriate media and technology, fostering a more comfortable learning environment for students (Purwaningsih et al., 2023). Technology enables the visualization of abstract concepts through animations, videos, simulations, and interactive displays, thereby making the material easier to comprehend. Furthermore, technology-integrated teaching materials facilitate independent study tailored to individual learning needs.

Developing a technology-integrated teaching module commonly referred to as an e-Module helps simplify complex subject matter and allows students to learn independently at their own pace. This demonstrates that e-Modules are more effective than conventional modules in creating interactive learning experiences. Google Sites allows for the integration of various media such as text, images, and video into a single, interactive, and easily accessible platform. Research indicates that Google Sites-based e-Modules possess high levels of feasibility and practicality, while effectively supporting students' conceptual understanding (Al Gifahri & Haris, 2026; Basudewa & Hayuhantika, 2022). Google Sites was selected as the development platform due to its ease of use, accessibility, and ability to present material in a structured manner. Web-based media enable independent learning free from spatial and temporal constraints, while also boosting student engagement (Nurfatah et al., 2025).

Furthermore, the selection of e-modules as teaching materials is based on considerations of cost-efficiency and environmental sustainability. e-modules eliminate the need for printing, thereby reducing the consumption of paper and ink, as well as the costs associated with reproducing and distributing teaching materials. The use of digital teaching materials also supports the implementation of "paperless learning," which contributes to reduced resource consumption and offers a more environmentally friendly alternative to conventional printed materials (Subaveerapandiyan & Maurya, 2022). Existing research has demonstrated the potential of granular materials and phenomena as contexts for physics learning through experiments and computational simulations (López et al., 2008; Muliyati et al., 2022). However, teaching materials specifically developed to introduce Granular Mechanics as supplementary learning material and to facilitate students in connecting fundamental mechanics concepts with granular phenomena remain limited. Therefore, this study aims to develop a Google Sites-based Granular Mechanics e-Module to facilitate students' conceptual understanding. Motivated by this need, the author undertook a study on the development of a Google Sites-based Granular Mechanics e-module designed to facilitate students' conceptual understanding.

Methods

The method employed in this study is the Research and Development (R&D) method. This approach focuses on product creation by identifying potential problems and subsequently designing and developing the optimal solution. This aligns with the perspective of Borg & Gall (1983), who stated that development research originates from a problem that is then addressed through the development of a product or model. Key characteristics of this development method include problem analysis, product development, product validation, product testing, and product revision. The specific research model utilized within this R&D framework is the 4D model (Define, Design, Develop, Disseminate). Developed in the early 1970s by Thiagarajan *et al*., this model evolved from pre-existing methods such as analysis, design, and evaluation. A

primary advantage of this model is its simplicity, which minimizes the time required for development. However, it should be noted that the model extends only to the dissemination stage and does not include an evaluation phase to measure the quality of the tested product.

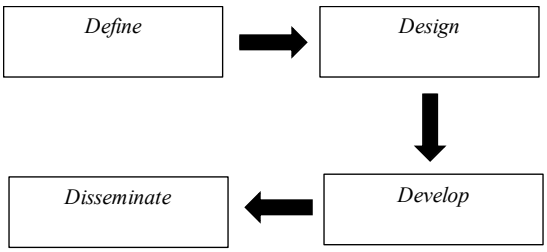

Figure 1. 4D model framework

The define stage or the problem definition phase aims to formulate the core research problem. Granular materials are often characterized as systems exhibiting complex behavior distinct from that of ordinary materials. However, the subject of Granular Mechanics is generally not taught as a specific component of the core curriculum in physics education study programs. University-level physics instruction tends to focus on fundamental concepts such as Classical Mechanics, Thermodynamics, Waves, Electricity and Magnetism, and Modern Physics. Consequently, students have limited exposure to physical phenomena associated with granular systems, despite their prevalence in everyday life. The target audience for the development of the Granular Mechanics e-Module consists of physics education students who have already completed the Physics I and Mechanics I courses. To study Granular Mechanics, students require certain foundational skills, including an understanding of physics concepts and the ability to analyze phenomena occurring in particle systems. The Google Sites-based module has met the necessary feasibility criteria regarding its media aspects. Therefore, the product is deemed suitable for revision based on validator feedback and subsequent field testing with students.

The design process aims to establish comprehensive guidelines for developing the e-Module. Based on an analysis of the course syllabi (RPS) for Basic Physics I and Mechanics I within the Physics Study Program at Universitas Negeri Semarang, the content selected for the e-Module focuses on mechanics concepts that best support students' understanding of granular phenomena—specifically granular mechanics, momentum, collisions, the coefficient of restitution, the derivation of the coefficient of restitution formula, and granular mechanics experiments. This content selection ensures that students not only gain general knowledge of granular material characteristics but also understand the physical processes involved in particle interactions, collisions, and changes in motion. Google Sites was chosen as the delivery platform because it is a web-based tool that allows developers to systematically organize learning pages and integrate various content types—such as text, images, videos, documents, hyperlinks, and Google Forms—into a single, interconnected site. The learning flow guides students to first understand usage instructions, then study the core material, observe experiments, and finally complete an assessment. This structure was adopted to ensure students are not immediately confronted with evaluation questions but instead first acquire the necessary conceptual understanding and visual context.

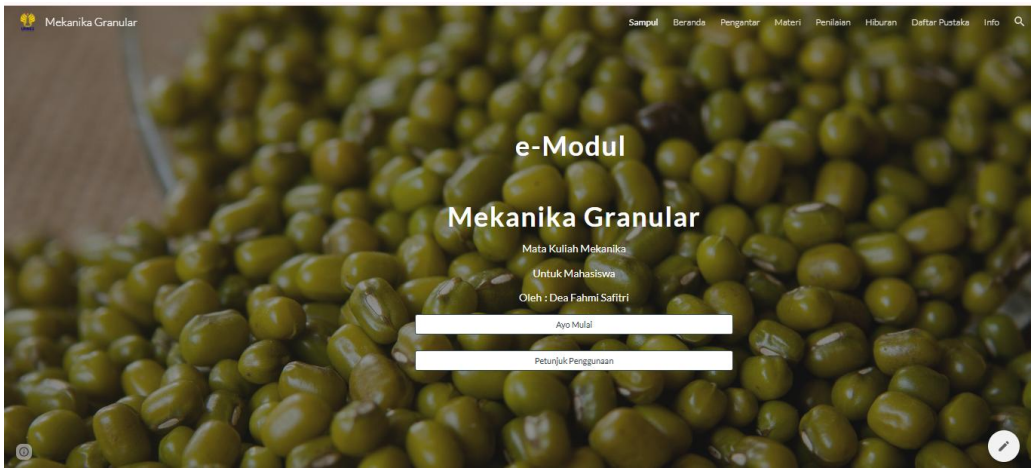

Figure 2. Interface of the Granular Mechanics e-Module

The development one of the key components developed for this e-Module is the content regarding granular mechanics experiments. This experimental content was developed to provide students with a tangible visualization of collision behavior and inter-granular interactions. In addition to the experimental content, the development phase also involved creating the core subject matter for the e-Module. This material was developed to ensure students established a conceptual foundation before observing the experiments and completing the conceptual understanding assessments. The material within the e-Module comprises five main sub-topics: granular mechanics, momentum, collisions, the coefficient of restitution, and the derivation of the coefficient of restitution formula. Another component developed during this phase was the content for assessing conceptual understanding. This assessment was designed to gauge students' level of understanding after they had studied the material, observed the experiments, and completed the activities in the student worksheets. Once all e-Module components were fully developed, the next step was expert validation. Expert validation aimed to determine the product's suitability before it was tested with students. In this study, validation focused on two primary aspects: content validation and media validation. The validation process involved five validators, consisting of university lecturers and education practitioners. Each validator evaluated specific indicators using a 1–4 Likert scale. After the Google Sites-based Granular Mechanics e-Module was deemed suitable based on the results from content and media experts, a limited trial with students was conducted. This limited trial aimed to assess the practicality of using the e-Module and to gather student feedback on the developed learning product. The limited trial involved 36 students from the Physics Education Study Program.

Results and Discussion

The result of this development research is a Google Sites-based e-module on granular mechanics.

Table 1. Media Validation Results

Aspect	Percentage (%)	Category
Visualization	91.25	Very Valid
Usability	90.00	Very Valid
Compatibility and Efficiency	92.50	Very Valid
Consistency and Completeness	82.50	Very Valid
Mean Score	89.55	Very Valid

Based on the assessment results from five validators covering five aspects and eleven indicators an average feasibility rate of 89.55% was achieved, placing the e-Module in the "Very valid" category. These

results indicate that, in terms of media, the e-Module features an engaging design, user-friendly navigation, and effectively functioning links and media integration. The highest-scoring indicators each achieving 95% were found in the aspects of supportive illustrations, clear usage instructions, and cross-device compatibility. Conversely, the lowest score (80%) was recorded for the indicator regarding formatting and numbering consistency. Overall, the findings demonstrate that the developed learning medium is highly suitable for use, although there are minor areas requiring refinement regarding the consistency of presentation.

From the media perspective, the high validity score indicates that Google Sites effectively supports the delivery of well-organized digital learning. All instructional components including learning materials, experimental activities, student worksheets, and assessments were integrated into a single platform with clear and intuitive navigation. This organization enabled students to follow the learning process more efficiently without the need to access multiple platforms separately. These findings are consistent with those of Ela and Dermawan, who reported that Google Sites is easily accessible, user-friendly, and effective for integrating various types of digital learning content (Ela & Dermawan, 2023).

Table 2. Content Validation Results

Aspect	Percentage (%)	Category
Content Feasibility	79	Very Valid
Presentation	83.75	Very Valid
Language	95	Very Valid
Evaluation	80	Very Valid
Mean Score	84.43	Very Valid

Based on the assessment results from five validators across five aspects, an average feasibility score of 84.43% was obtained, placing it in the "Very Valid" category. These results indicate that, in terms of content, the e-Module features material aligned with learning outcomes, sufficiently accurate concepts, and an easily understandable presentation. The highest-rated indicator was the use of easily understandable language (95%), while the lowest-rated indicator was the alignment of the material with learning objectives (75%). This suggests that, while the material is generally suitable for use, minor adjustments are still needed to make the connection between learning objectives and content more explicit.

In terms of content, the validator assessed that the instructional materials were well aligned with the learning objectives and presented in a systematic manner. Rather than focusing immediately on Granular Mechanics, the material begins with fundamental concepts, including momentum, collisions, and the coefficient of restitution, which serve as the foundation for understanding the collision behavior of granular particles. This sequential organization was considered essential because students require conceptual connections to develop a more coherent understanding of relatively abstract topics (Hakim et al., 2022).

The high feasibility of the developed e-module can be attributed to the systematic and sequential development process employed throughout the study. This structured approach ensured that the content, instructional design, and learning objectives were well aligned, resulting in a higher-quality learning product. Furthermore, the step-by-step development model provided opportunities for validation at each stage, allowing weaknesses in the product to be identified and revised before proceeding to subsequent stages. Therefore, the systematic development of the e-module through well-defined phases contributed significantly to the high level of feasibility achieved in this study (Tarigan, 2025).

In addition, the integration of experimental activities into the instructional materials further enhanced the content feasibility by providing students with opportunities to construct conceptual understanding through direct experience. Experimental activities also promote science process skills and help students relate theoretical concepts to real-world phenomena, making learning more meaningful. This finding is consistent with previous research indicating that laboratory and experimental activities improve students' science process skills and deepen their conceptual understanding (Supatmi, 2022). In this study, students were not only provided with theoretical explanations but were also guided to observe the

distribution behavior of granular particles under different drop heights. Consequently, the physics concepts presented in the e-module extended beyond mathematical equations and were directly connected to observable physical phenomena.

Table 3. Summary of e-Module Practicality Test Results

Aspect	Percentage (%)	Category
Usability	92.4	Very Practical
Content Quality	91.4	Very Practical
Concept Understanding	92.5	Very Practical
Motivation and Independence	89.4	Very Practical
Mean Score	91.42	Very Practical

Based on the results of a practicality questionnaire administered to 36 students, an average score of 91.42% was obtained, placing it in the "Very Practical" category. These results indicate that the Google Sites-based Granular Mechanics e-Module is user-friendly regarding access, navigation, and the presentation of learning content. The high practicality score demonstrates that students encountered no difficulties in accessing available menus, understanding usage instructions, or studying the material independently. Furthermore, the integration of images, experimental videos, student worksheets, and assessments within a single platform was deemed to make the learning process more systematic and efficient. Particularly high scores were recorded for indicators such as ease of access, navigation clarity, visual appeal, and the utility of experiments in visualizing Granular Mechanics concepts. This suggests that using Google Sites as the e-Module platform supports flexible and easy-to-operate digital learning. In addition to quantitative data, students provided feedback in the suggestions section. Most students found the e-Module well-designed and engaging, though they offered minor suggestions such as including examples of everyday phenomena and refining certain sections of the text. These suggestions served as the basis for minor revisions to optimize the product. Thus, the limited trial results indicate that the Google Sites-based Granular Mechanics e-Module possesses a very high level of practicality and is suitable for use in the learning process.

One of the factors contributing to the high practicality score was the use of Google Sites, which can be accessed through both laptops and mobile phones without requiring the installation of additional applications. This finding is consistent with previous research indicating that Google Sites is an easy-to-use learning platform, readily accessible online through various digital devices, and well accepted by users (Bangun et al., 2022). Students only needed to open the e-module link, after which all learning components were available on a single webpage. This design made the learning process more efficient and flexible, as students did not have to switch between multiple files to access the learning materials, student worksheets, experimental videos, and assessments.

Table 4. Summary of Student Assessment Results

Description	Result
Amount of Respondents	36
Highest Score	95
Lowest Score	70
mean	83,3
modus	85
median	85
Achieved	33
Not Achieved	3
Achieved Percentage	92%

In addition to the practicality questionnaire, students were asked to complete a conceptual understanding assessment consisting of 20 multiple-choice questions. This assessment was administered to gauge the extent of the students' understanding of Granular Mechanics concepts after using the e-Module. Based on the students' performance, the average score was 83.3, with a high of 95 and a low of 70. The minimum mastery criterion for this study was set at 75. Of the 36 students who took the assessment, 33 achieved mastery, while 3 did not.

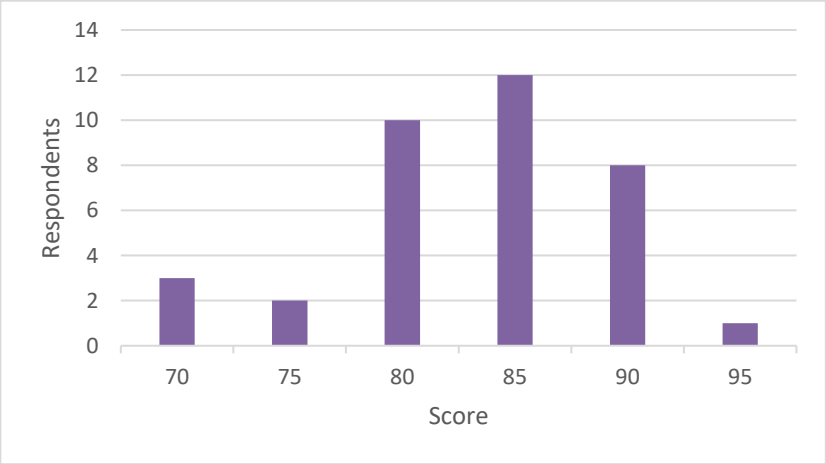

Figure 3. Graph of Granular Mechanics Assessment Scores

Since the mean approximates the median and the median equals the mode, the distribution of student scores tends to be stable and concentrated in the high-score range. This indicates that the majority of students achieved relatively consistent results within the "good" category after using the e-Module.

The feasibility of the Google Sites-based Granular Mechanics e-Module in this study was assessed through validation by subject matter and media experts. Validator assessments yielded a content validity score of 84.43% (categorized as "valid") and a media validity score of 89.55% (categorized as "highly valid"). These results demonstrate that the developed e-Module meets feasibility criteria regarding both content and media presentation, making it suitable for the implementation phase following minor refinements.

The practicality of the e-Module was determined through student response questionnaires administered after the product was used during the limited trial phase. Analysis of the questionnaire data yielded a practicality score of 92%, placing it in the "highly practical" category. This figure indicates a highly positive student response to the e-Module, particularly regarding ease of access, navigation clarity, visual presentation, and the utility of its learning features.

Furthermore, the students' positive response was also influenced by the varied presentation of content. The material was not merely presented as text but was supplemented with images, videos documenting experiments, analytical steps, and worksheets that required students to actively engage in observation. This varied presentation made it easier for students to follow the learning flow and prevented them from becoming bored quickly. These findings are supported by research conducted by Syah and Hidayatullah, which demonstrated that interactive learning media based on Google Sites received excellent feedback from users due to simple navigation, an attractive interface, and the ability to foster active learner engagement during the learning process (Syah & Hidayah, 2024). The potential of the e-Module to facilitate students' conceptual understanding was evaluated based on assessment results obtained after using the product. Test results showed an average student score of 83.3, with a mastery rate of 92%. Thirty-three out of 36 students achieved scores above the established Minimum Mastery Criterion, while only three students failed to meet the standard. This high mastery rate indicates that the majority of students were able to effectively grasp the material after using the e-Module.

These findings align with research by Maharani *et al.* (2024) on momentum and impulse, which demonstrated that the use of Google Sites-based learning media improved learning outcomes and facilitated students' understanding of physics concepts by presenting material in an interactive and contextual manner. Furthermore, the study by Maharani et al. indicated that utilizing Google Sites in instruction resulted in high levels of learning mastery, as students were more actively engaged throughout the learning process.

Thus, the assessment results indicate that the Google Sites-based Granular Mechanics e-Module holds significant potential for facilitating students' conceptual understanding particularly regarding momentum, collisions, the coefficient of restitution, and their application to granular mechanics phenomenon.

Conclusion

Based on the results of the study, the developed Google Sites-based Granular Mechanics e-module can be concluded to be feasible, practical, and potentially effective in supporting students' conceptual understanding. The results of expert validation indicate that the e-module meets the required standards of suitability in terms of content, material presentation, visual design, navigation, and the integration of learning media. Furthermore, the e-module demonstrates a very high level of practicality, as it is easily accessible, user-friendly, equipped with clear navigation, and capable of facilitating students' independent learning. In addition, the high level of students' conceptual mastery indicates that the e-module has great potential to facilitate conceptual understanding by integrating course materials, experiments, student worksheets, and assessments into a single learning platform, thereby enabling students to understand the relationships among momentum, collisions, the coefficient of restitution, and granular mechanics phenomena in a more concrete and meaningful manner.

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