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Needs Analysis for Designing Dynamic Game-Based Learning Media on Motion and Force in Junior High School Science

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ABSTRACT

Understanding Motion and Force remains challenging for junior high school students, particularly due to the abstract and multi-representational nature of the concepts. This study aimed to systematically identify learning difficulties, learner characteristics, media usage patterns, and digital habits through the Define stage of the 4-D development model as the foundation for designing game-based learning media. A mixed-methods needs analysis was conducted using classroom observations, a teacher interview, and a questionnaire administered to 93 seventh-grade students. Triangulated findings reveal persistent conceptual difficulties, especially in interpreting motion graphs, distinguishing types of motion, and understanding Newton's Second Law. Classroom instruction was dominated by teacher-centered practices and static media, which constrained visualization and increased cognitive load. Despite frequent daily smartphone use, students had limited exposure to digital or interactive tools. Nevertheless, 98.9% expressed strong interest in educational games, indicating high readiness for game-based learning environments. The synthesis of front-end, learner, and task analyses highlights critical representational needs, including dynamic visualizations, interactive manipulation of variables, scaffolded conceptual tasks, real-time feedback, and mobile-friendly accessibility. These results provide explicit design specifications that will guide the next stage of media development, ensuring that the resulting game-based learning tool aligns with students' cognitive, pedagogical, and technological needs.

Keywords: *Game-Based Learning, Needs Analysis, Multimedia Learning, Motion and Force, Science Education*

INTRODUCTION

Science learning at the junior high school level often faces challenges in helping students understand abstract and relational concepts, particularly in the topic of Motion and Force. Previous studies have shown that many students struggle to make sense of the relationships between force, mass, and acceleration; to interpret motion graphs; and to apply Newton's laws in various contexts (Clark & Mayer, 2023; Lai & Bower, 2019; Yang et al., 2020). These challenges become even more complex when classroom instruction continues to rely on text, static images, and verbal explanations, which fail to provide the dynamic visual support necessary for deep understanding of physical phenomena.

In science learning, conceptual understanding is strongly influenced by students' ability to shift between representations such as graphs, diagrams, verbal models, and mathematical equations (Çeken & Taşkın, 2022; Posner et al., 1982). When learners must integrate multiple representations without appropriate media support, cognitive load increases and the likelihood of misconceptions grows (Martella et al., 2024; Rexigel et al., 2024; Sukmawati et al., 2024). The topic of Motion and Force demands visual representations that can explain temporal and causal relationships between variables. Therefore, selecting learning media that support dynamic representations is crucial for bridging students' understanding and reducing extraneous cognitive load (Mayer, 2019; Rzabayeva et al., 2024).

Advances in educational technology offer opportunities to present dynamic visualizations through simulations, animations, and interactive environments, all of which have been shown to effectively improve science conceptual understanding (Candido et al., 2025; McElhaney et al., 2015; Setiawan & Harahap, 2024). One prominent approach is game-based learning, which integrates challenge, rapid feedback, and visual exploration, enabling students to interact with abstract concepts in more concrete ways (Mikrouli et al., 2024; Plass et al., 2015). Educational games also allow for repeated, guided, and contextualized learning experiences, making them a potential tool for helping students overcome difficulties in understanding Motion and Force concepts.

However, the effectiveness of game-based media heavily depends on how well the design aligns with students' characteristics, the learning gaps they experience, and the readiness of the school's learning environment (Haleem et al., 2022; Mikropoulos & Iatraki, 2023). Numerous studies indicate that media development often focuses immediately on the design stage without first conducting a systematic needs analysis, resulting in products that lack relevance to the learning context and students' needs. This condition highlights the importance of conducting a comprehensive preliminary analysis before developing game-based media.

Needs analysis is a fundamental step for identifying learning problems, learner characteristics, and the gap between actual and ideal conditions (Jurc et al., 2020; Stewart & Cuffman, 1998). In the 4-D model, the Define stage plays a strategic role as the foundation that determines the direction of subsequent media development (Thiagarajan, 1974). This stage not only maps students' difficulties but also examines the appropriateness of existing instructional media, student preferences for learning formats, and unmet representational needs. Thus, the Define stage ensures that the media developed truly addresses the conceptual and pedagogical requirements of science learning.

Furthermore, recent literature suggests that today's students have strong digital habits and high levels of smartphone use, particularly for gaming (Mikrouli et al., 2024; Nurdin et al., 2023; Sukmawati et al., 2025). Yet, most have not been exposed to educational games or the use of digital tools for understanding science concepts. The gap between students' digital readiness and conventional instructional practices indicates the need for a needs analysis that not only focuses on conceptual aspects but also considers the potential of leveraging students' digital habits as learning assets. A needs analysis that integrates these factors can provide a more relevant and effective foundation for designing game-based learning media.

Given this urgency, the present study aims to identify students' learning difficulties, characteristics of classroom instruction, patterns of media use, and digital habits related to the topic of Motion and Force through the Define stage of the 4-D model. The findings are expected to serve as a strategic foundation for designing game-based learning media that match the representational demands of the content, student profiles, and the instructional ecosystem of science learning in schools.

METHODS

This study employed the 4D development model consisting of Define, Design, Develop, and Disseminate stages as introduced by Thiagarajan (1974). The present study focused specifically on the Define stage because this stage identifies learning problems, student characteristics, and media needs which form the foundation for designing a game based learning medium for the topic of Motion and Force. The Define stage was carried out through three systematic analyses known as front end analysis, learner analysis, and task or concept analysis. These analyses are aligned with recommendations in instructional design and multimedia learning research which highlight the importance of understanding representational requirements before selecting or developing instructional media that support conceptual learning in science (Çeken & Taşkın, 2022; Mayer, 2014).

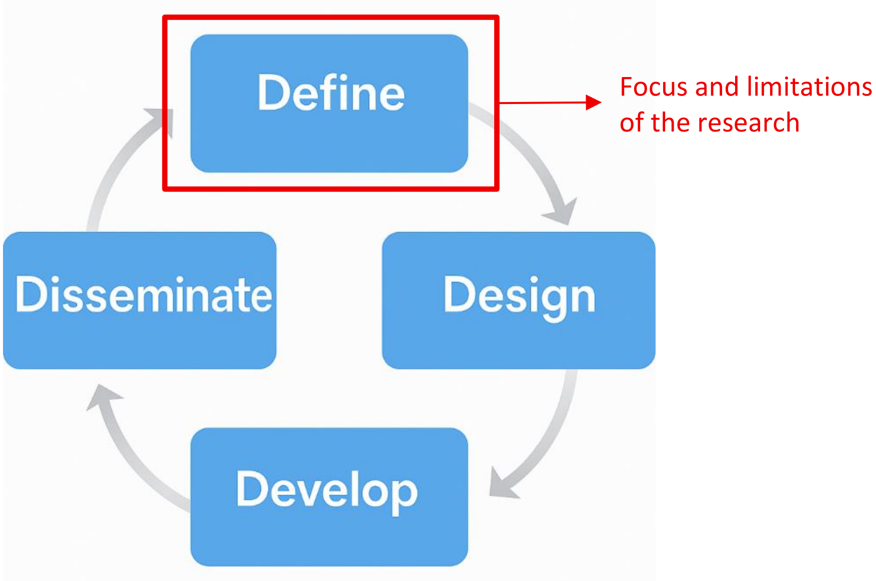

Figure 1. Steps of development using 4D models

The study was conducted at a public junior high school in Sukoharjo Regency Indonesia. A total of 93 seventh grade students participated in the study. The participants were selected using purposive sampling based on three considerations. The school implemented a curriculum that includes competencies related to Motion and Force. The students demonstrated heterogeneous academic characteristics. The school also represented common instructional conditions found in Indonesian public schools where conventional learning media are still predominantly used (Fuchs et al., 2021; Lai & Bower, 2019; Yang et al., 2020). Because the purpose of the Define stage is to identify authentic contextual needs rather than produce broad generalizations, the use of one representative school was considered appropriate for this early stage of development (Stewart & Cuffman, 1998).

The Define stage began with front end analysis through classroom observations and a semi structured interview with the science teacher. Two observations were conducted during lessons on Motion and Force. The observations focused on instructional strategies used by the teacher, the types of media employed in the classroom, interaction patterns, and student responses during the learning process. The observations indicated that lessons relied heavily on static and text based materials which is consistent with previous studies showing a lack of representational support in science classrooms (Mayer, 2019; Rexigel et al., 2024). The interview with the science teacher provided additional insight into the difficulties students commonly face such as understanding acceleration and the relationship among force mass and acceleration. These difficulties are widely reported in physics education research (Çeken & Taşkın, 2022;

McElhaney et al., 2015). Findings from the observations and interview were used as the basis for constructing the questionnaire for the learner analysis.

The learner analysis aimed to examine student characteristics, conceptual difficulties, media preferences, digital habits, and their readiness to use educational games. Data were collected using a structured questionnaire developed according to five major indicators derived from needs analysis frameworks in science education (Haleem et al., 2022) and from representational principles in multimedia learning (Çeken & Taşkın, 2022; Mayer, 2019). Each indicator was represented by one or more questions as shown in Table 1 which ensured systematic coverage of students' learning needs.

Table 1. Instrument Learner Analyis

No	Indicator	Question/Statement
1	Perception of the Subject	• Difficulties or obstacles during science learning • Reasons why the topic of Motion and Force is difficult to understand
2	Types of Learning Media	• Most frequently used science learning media • Availability of access to review the learning media after class
3	Students' Competence	• The part of the Motion and Force topic that is most difficult to understand • How students solve problems related to force and motion
4	Educational Technology	• Frequency of teachers using technology/innovative media (videos, simulations, educational games) • Frequency of students using smartphones for learning
5	Students' Opinions	• Habit of playing games on smartphones • Knowledge about educational games • Interest in using educational games in science learning • Need for developing educational game media for the topic of Motion and Force

Following the learner analysis the task or concept analysis was conducted to identify specific conceptual components within Motion and Force that require enhanced representational support. This analysis focused on Newton's laws, motion graphs, relationships among mass force and acceleration, and context based problem solving. This approach followed recommendations from McElhaney et al. (2015) which emphasize the importance of interactive visualizations for helping students understand dynamic physical phenomena. The results of the task analysis informed decisions about the kinds of simulations, animations, and multimodal representations that should be integrated into the game based learning media.

The primary instrument used in this study was the student needs questionnaire which had been validated by two experts in Science Education and Educational Technology. Expert validation assessed indicator relevance, clarity of wording, and internal consistency. The final questionnaire included fifteen multiple choice items. Observation and interview protocols were also prepared to ensure consistency and accuracy during qualitative data collection in the front end analysis.

Quantitative data from the questionnaire were analyzed descriptively using percentage calculations based on (Creswell & Creswell, 2017). Qualitative data from observations and the teacher interview were analyzed using categorical content analysis which is a commonly used method in educational needs assessment for identifying conceptual and pedagogical challenges (Stewart & Cuffman, 1998). Triangulation was applied by integrating qualitative and quantitative findings so that data from observations and interviews could provide contextual support for interpreting questionnaire results. This triangulated approach follows recommended practices in mixed method needs analysis to produce a comprehensive understanding of students' learning needs (Pambudi et al., 2024; Park, 2021).

RESULTS AND DISCUSSION

The Define stage of the 4-D development model includes front-end analysis, learner analysis, and task analysis to identify instructional problems, learner characteristics, and representational needs that guide media development. The findings presented here integrate classroom observations, teacher interviews, and student questionnaires, interpreted through the lens of instructional design theory and multimedia learning principles (Çeken & Taşkın, 2022; Mayer, 2014)

Front-End Analysis: Actual Conditions of Science Learning

Classroom observations revealed that science instruction at SMP Negeri 1 Grogol remains dominated by teacher-centered methods. Five notable conditions were recorded: (1) instruction relied heavily on lectures with minimal student exploration; (2) learning media were primarily static, such as textbooks, worksheets, and PowerPoint slides, which limited visualization of dynamic phenomena; (3) student participation was low and tended to be passive; (4) interaction was mostly one-directional with limited formative feedback; and (5) digital facilities such as projectors and Wi-Fi were available but underused. These findings are consistent with previous studies showing that static, text-heavy instruction increases cognitive load and constrains students' ability to form mental models of scientific phenomena (Bunyamin et al., 2020; Mayer, 2019)

The teacher interview reinforced these observations. According to the teacher, the gradual implementation of the Merdeka Curriculum faces obstacles due to heterogeneous student readiness, learning losses caused by the pandemic, and limited laboratory equipment. Students frequently struggle with differentiating speed and velocity, understanding acceleration and friction, interpreting s–t and v–t motion graphs, and applying formulas in contextual problems. Nevertheless, the teacher noted that students responded positively when lessons incorporated digital media such as videos, interactive quizzes, or simple learning games. These qualitative insights align with the literature indicating that digital environments enhance motivation and support representational understanding (Karatay et al., 2024; Mayer, 2014)

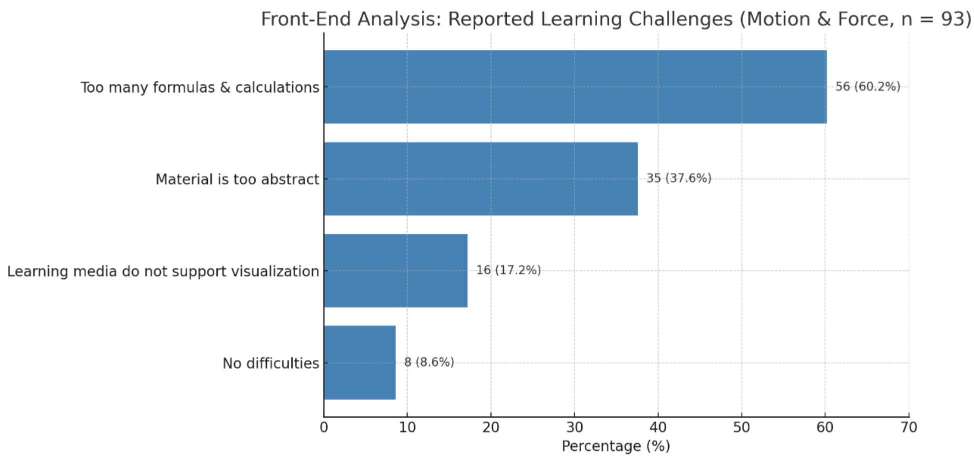

Figure 2. Front-End Analysis Result

A total of 60.2% of students reported difficulty due to the abundance of formulas and calculations, 37.6% cited the abstract nature of the material, and 17.2% indicated that existing media did not adequately support concept visualization. Only 8.6% reported no difficulty. These patterns confirm that representational challenges are widespread and not limited to isolated cases. The results reinforce the need for multimodal representation to support the abstraction inherent in Motion and Force concepts (Everett et al., 2008; McElhaney et al., 2015).

Learner Analysis

Learning Media Usage

Students reported that classroom learning was dominated by traditional media such as blackboards (89.2%), textbooks (52.7%), and worksheets (33.3%), while only 10.8% reported the use of digital media.

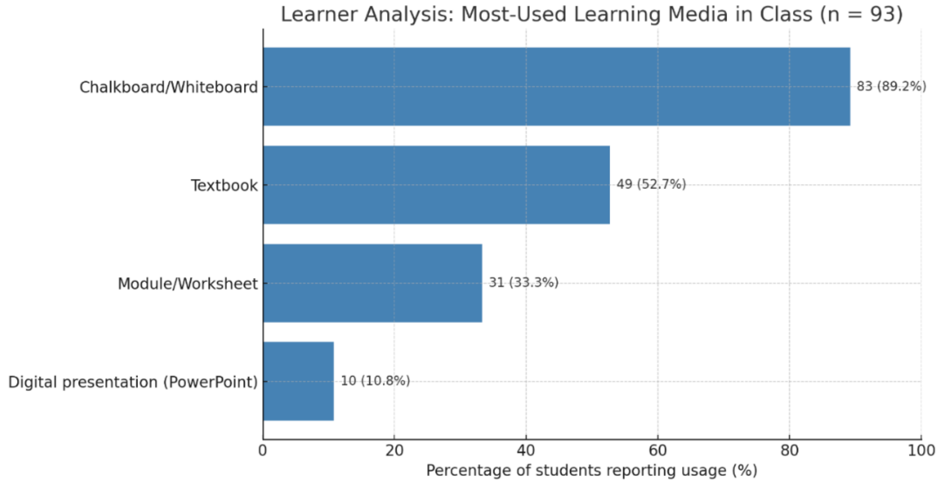

Figure 3. Learner Analysis Result

This limited integration of digital tools restricts opportunities to reduce cognitive load and provide representational flexibility. When learning relies on static materials, students struggle to connect symbolic, verbal, and graphical representations, especially in topics requiring dynamic reasoning (Hao, 2023; Mayer, 2014).

Conceptual Competencies

Students' conceptual difficulties are summarized in the following figure.

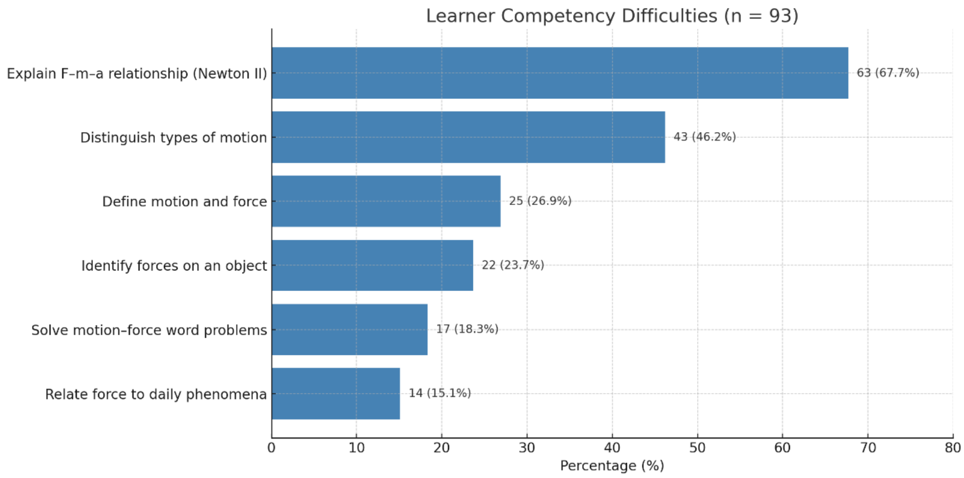

Figure 4. Learner Competency Difficulties

Newton's Second Law posed the greatest challenge (67.7%), indicating instability in coordinating the quantitative relationships among force, mass, and acceleration. Other difficulties included distinguishing types of motion (46.2%), explaining basic concepts (26.9%), determining forces (23.7%), solving word problems (18.3%), and relating concepts to daily contexts (15.1%). These findings align with research reporting frequent difficulties in representational transformation across equations, diagrams, and real-world scenarios (Çeken & Taşkın, 2022; McElhaney et al., 2015). Consequently, the learning media developed must provide dynamic simulations and manipulable representations to help students build coherent conceptual models.

Technology Utilization and Digital Habits

Despite high digital literacy, the integration of technology into science learning remains minimal.

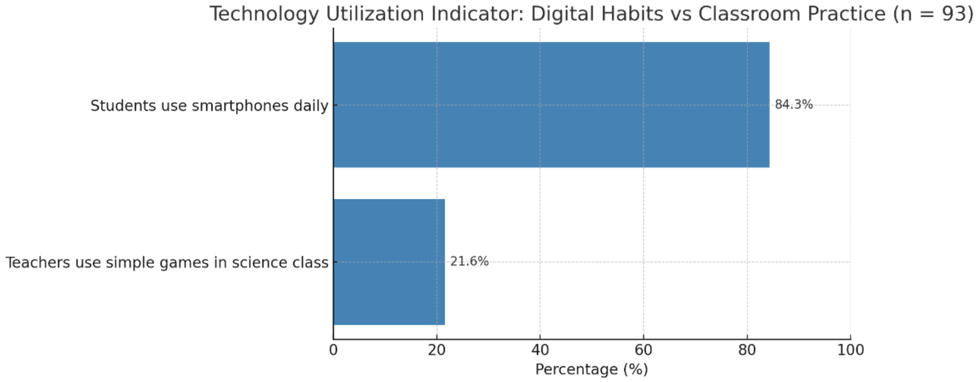

Figure 5. Technology Utilization Indicator

Only 21.6% of students reported that teachers used digital games or interactive tools in science learning, even though 84.3% of students use smartphones daily. This mismatch indicates that students' digital readiness is not reflected in the learning environment (Haleem et al., 2022). This suggests that the design of instructional media must leverage the devices students already use and be optimized for mobile access.

Students' Opinions on Educational Games

Students expressed strong readiness and interest in game-based learning.

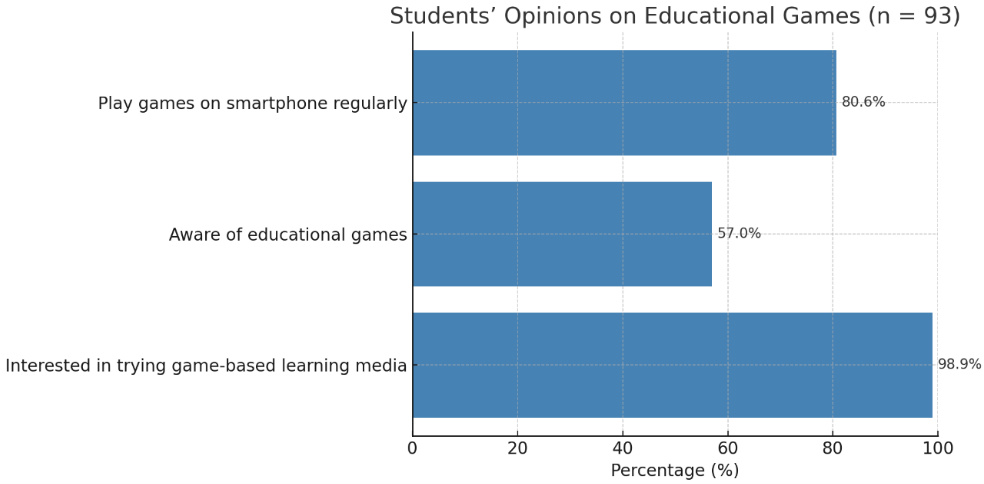

Figure 6. Student's Opinions on Educational Games

A total of 80.6% routinely play mobile games, indicating established digital habits, yet only 57% were aware of educational games, suggesting an exposure gap (Shute & Rahimi, 2021). Despite limited awareness, 98.9% of students expressed interest in using game-based learning media. This indicates strong motivational potential, provided that educational games include pedagogically aligned features such as scaffolded tasks, real-time feedback, and progressive challenges (Chen et al., 2023; De Jong & Van Joolingen, 1998; Huang et al., 2021).

Task and Concept Analysis

The task and concept analysis revealed several high-load conceptual areas requiring enhanced representational support, including Newton's Second Law (F–m–a relationships), different types of motion (uniform, accelerated, and directional change), interpretation of motion graphs (s–t and v–t), and the application of these concepts in real-life situations. These topics possess high intrinsic cognitive complexity and therefore demand dynamic visualization and multimodal representation to support students' conceptual integration (Mayer, 2019). The findings emphasize that instructional media should allow students to manipulate variables, observe real-time changes, and engage in deeper conceptual reasoning.

Synthesis of Learning Needs

Three primary categories of learning needs emerged from the Define stage. First, representational needs highlight the necessity for interactive media such as simulations, animations, and manipulable motion graphs to help students visualize abstract physics concepts. Second, pedagogical needs indicate that students require guided exploration, scaffolded progression, and structured feedback that support transitions from basic understanding to complex applications. Third, technological needs reflect the importance of providing mobile-friendly, lightweight instructional media that align with students' high levels of smartphone use and can be accessed beyond classroom settings.

Implications for Game-Based Learning Media Design

The Define stage provides explicit specifications for the Design stage of the 4-D model. Media development should incorporate real-time simulations of Newton's Second Law, interactive motion graph tools, level-based challenges aligned with learning objectives, and immediate formative feedback to strengthen conceptual understanding. Additionally, mobile-friendly interfaces and narrative or reward features should be integrated to reflect students' gaming habits and enhance engagement. These implications are consistent with multimedia learning principles and address reviewer expectations that the Define stage meaningfully guide the subsequent design process.

Limitations

This study relied on self-reported questionnaire data and involved a single school context, which may limit generalizability. However, triangulation through classroom observations, teacher interviews, and student questionnaires strengthens the validity of the findings. Future studies should include diagnostic assessments and multi-site sampling to obtain a broader understanding of misconceptions and learning needs.

CONCLUSION

The Define stage of this study provides a comprehensive understanding of the learning problems, learner characteristics, and representational needs related to the topic of Motion and Force in junior high school science. The triangulation of classroom observations, teacher interviews, and student questionnaires reveals that learning difficulties arise from the abstract nature of the concepts, limited visualization support, the predominance of static instructional media, and the lack of opportunities for students to interact with dynamic representations. Students experience significant challenges in understanding Newton's Second Law, interpreting motion graphs, and applying scientific principles to real-life situations, despite demonstrating strong digital literacy and considerable interest in game-based learning.

These findings emphasize the critical role of the Define stage in aligning instructional media development with actual learner needs. The results indicate the importance of incorporating interactive and multimodal representations, structured guidance, and mobile-friendly delivery formats into the media to be developed. The specifications identified in this stage, including real-time simulations, interactive motion graphs, scaffolded conceptual challenges, and immediate feedback mechanisms, provide essential guidance for the Design stage of the 4-D model and support the development of game-based learning media that can strengthen students' conceptual understanding of Motion and Force.

Although the study was conducted in a single school and relied partly on self-reported data, triangulation across methods enhances the credibility of the findings. Future research should employ broader sampling and diagnostic assessments to obtain a deeper understanding of students' misconceptions and to test the generalizability of the identified learning needs. Overall, the Define stage findings establish a solid foundation for subsequent development phases and contribute to the systematic design of instructional media that more effectively supports student learning in science.

CONFLICT OF INTEREST

The authors declare no financial, institutional, commercial, or personal conflicts of interest in the execution, authorship, or publication of this article. All research activities were conducted independently and in accordance with academic integrity.

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