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Development of STEM–Multirepresentation (STEM-MR) Learning Design to Enhance Undergraduate Students' Problem-Solving Skills in Mechanics

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Abstract: This study aims to develop a STEM–Multirepresentation (STEM-MR) learning design for Mechanics and examine its validity, practicality, and effectiveness in improving undergraduate students' problem-solving skills. The study employed a research and development approach using the ADDIE model. The participants were 37 undergraduate students in the Physics Education Study Program at Universitas Sriwijaya. Data were collected through expert validation sheets, observation sheets, student response questionnaires, interviews, documentation, and pretest–posttest assessments. The STEM-MR design was developed as a seven-phase learning model that integrates STEM inquiry with multirepresentational scaffolding to support problem-solving in Mechanics. The results showed that the design was highly valid, with an average expert validation score of 3.87 on a 4-point scale. It was also very practical, with with a practicality score of 91%. In terms of effectiveness, students' average scores increased from 52.25% on the pretest to 78.50% on the posttest. The normalized gain was 0.55, which falls into the medium category, and the effect size was 2.53, indicating a very large effect. These findings show that the STEM-MR learning design is valid, practical, and effective for enhancing undergraduate students' problem-solving skills in Mechanics.

Keywords: Higher education; Learning design; Mechanics; Multirepresentation; Problem-solving skills; STEM education

Introduction

Mechanics, as one of the oldest and most fundamental branches of physics, plays an essential role in helping students understand motion, force, and the mathematical description of physical phenomena (Marsden & Ratiu, 1999). However, many recent studies have reported that students continue to experience difficulties in interpreting kinematic and dynamic relationships, constructing motion or free-body diagrams, translating between verbal, graphical, pictorial, and mathematical representations, and applying mathematical relationships to solve motion problems (Amaliah et al., 2021; Becker et al., 2023; Putri & Sutopo, 2024; Shodiqin & Taqwa, 2021; Takaoğlu, 2024; Testa & Catena, 2022). These difficulties often result in surface-level reasoning, fragmented conceptual understanding, and inconsistent performance in problem-solving tasks (Yuliani et al., 2023). When entering higher education-level physics, many students are still unable to coordinate graphs, equations, and verbal descriptions, even though these skills are essential for mastering Mechanics (Chang et al., 2020; Wu & Liu, 2021).

Sarı et al. (2020) emphasized that representational fluency, including the ability to coordinate graphs, diagrams, symbolic equations, and verbal descriptions, is a key predictor of problem-solving success in physics.

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Nevertheless, students frequently struggle to construct free-body diagrams, interpret motion graphs, and connect mathematical expressions with conceptual meaning (Kurniasari & Wasis, 2021). This mismatch between the representational demands of university Mechanics and students' actual representational competence continues to create substantial barriers to meaningful learning.

At the same time, STEM education has become an influential approach for promoting scientific literacy, interdisciplinary thinking, and higher-order problem-solving skills. STEM-based interventions have shown positive effects on problem-solving, conceptual understanding, engagement, and students' ability to apply scientific and mathematical knowledge in real-world problems (Cao et al., 2025; Pratama et al., 2025; English, 2023; Ortiz-Revilla et al., 2022). In physics education specifically, STEM learning environments have been reported to improve students' analytical and higher-order thinking performance while fostering various 21st-century competencies such as critical thinking, creativity, and problem-solving skills (Bahtiar & Ibrahim, 2025; Cao et al., 2025; Knowles, 2021). However, although STEM instruction offers authentic and meaningful problem contexts, it does not automatically ensure that students develop the representational competence required for solving Mechanics problems effectively.

Parallel to STEM, the multirepresentation (MR) approach has been widely discussed as a pedagogical strategy for improving conceptual understanding and reducing cognitive load in complex physics tasks. MR-based learning encourages students to construct meaning by coordinating tables, graphs, diagrams, verbal explanations, and symbolic forms (Dianningrum & Sufian, 2025). MR-based instruction also has long been recognized as an important foundation for conceptual reasoning in Mechanics because it helps students move between descriptive and formal models of physical systems (Ismet, 2014). More recent studies have shown that MR interventions can improve visualization, interpretation of motion phenomena, and the ability to translate across representational modes (Fathonah et al., 2023; Fathonah et al., 2024; Rexigel et al., 2024). Despite these benefits, MR strategies are still often implemented in a fragmented way, focusing on particular representation types or isolated learning tasks rather than embedding representational reasoning within a broader problem-solving framework.

For this reason, combining STEM and multirepresentation is a logical step in Mechanics learning. STEM provides authentic contexts in which students are required to investigate phenomena, analyze variables, and design solutions (Roehrig et al., 2021; Portillo-Blanco et al., 2024; Hallström et al., 2023), whereas multirepresentation provides the cognitive tools needed to express, test, and refine understanding across different forms (Ainsworth, 2006; Hahn & Klein, 2022; Seufert, 2009). In this sense, STEM creates meaningful problem situations, while MR supports students in translating those situations into conceptual, visual, graphical, and mathematical representations. Integrating these two approaches therefore has the potential to support not only engagement with real-world problems but also deeper conceptual and analytical reasoning in Mechanics.

Although STEM problem solving frequently requires learners to coordinate diagrams, models, simulations, and mathematical representations, recent literature suggests that guidance on how representational reasoning should be explicitly scaffolded and sequenced across learning phases remains limited (Edelsbrunner & Hofer, 2024; Zeng et al., 2025). On the other hand, MR-centered studies often emphasize representational competence as a relatively discrete learning target, while fewer studies embed representational work within sustained STEM inquiry or engineering-related problem contexts (Flores-Camacho & Gallegos-Cázares, 2025; Herder & Rau, 2022). As a result, there is still a need for an instructional design that deliberately interweaves STEM practices with multirepresentational reasoning in a coherent and systematic learning sequence.

This study addresses that need by developing a STEM–Multirepresentation (STEM-MR) learning design for undergraduate Mechanics. The design synthesizes STEM inquiry, engineering design-oriented thinking, and explicit representational scaffolding into a systematic seven-phase learning model. Through this model, students are guided from the observation of real-world phenomena to the construction, evaluation, and refinement of multiple representations in solving Mechanics problems. By developing this model, this study contributes a pedagogical framework that systematically supports students' transition from contextual physical situations to formal conceptual and mathematical representations.

Accordingly, this study examines the validity of the STEM–Multirepresentation learning design based on expert judgment, its practicality when implemented in an undergraduate Mechanics classroom, and its effectiveness in improving undergraduate students' problem-solving skills. These three aspects serve as the basis for evaluating the quality of the proposed design and its contribution to physics learning in higher education.

Method

This study employed a research and development (R&D) approach to develop a STEM–Multirepresentation (STEM-MR) learning design for undergraduate Mechanics and to examine its validity, practicality, and effectiveness. The development procedure adopted the ADDIE model, which consists of five phases: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic and iterative framework for designing, refining, and evaluating instructional products in accordance with learning needs, pedagogical principles, and empirical evidence (Aprilia et al., 2021; Craig et al., 2022; Shakeel et al., 2023; Başer & Şahin, 2025; Zhang et al., 2024). Furthermore, Purba et al. (2025) also demonstrated the continued application of ADDIE in STEM-based and technology-enhanced learning design, particularly in contexts that require iterative development, expert validation, and effectiveness testing.

The research was conducted in the Physics Education Study Program at Universitas Sriwijaya and involved 37 undergraduate students enrolled in the Mechanics course during the 2024 academic year. In addition, three expert validators in physics education, instructional design, and educational assessment were involved in evaluating the developed learning design. The overall development procedure of the STEM-MR learning design is presented in Figure 1.

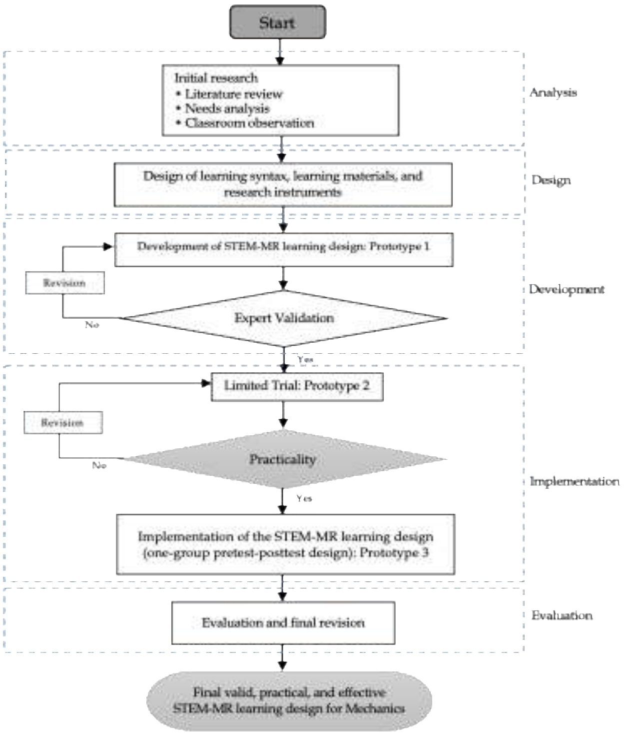

Figure 1. Research flow

As shown in Figure 1, the development process proceeded through the five ADDIE phases, beginning with literature review and needs analysis, continuing through prototype design and validation, and ending with practicality and evaluation of the final STEM-MR learning design.

Analysis Phase

The analysis phase began with a literature review and preliminary investigation of classroom conditions. At this stage, relevant literature on Mechanics learning, STEM education, multirepresentation, and problem-solving skills was examined to identify theoretical and empirical foundations for the development of the learning design. This review was followed by needs analysis and classroom observation to identify the main learning difficulties experienced by undergraduate students in Mechanics. Document analysis and informal interviews indicated that many students experienced difficulty interpreting motion graphs, constructing diagrams, and translating between symbolic and conceptual descriptions of physical phenomena. These findings are consistent with previous studies reporting persistent challenges in representational understanding in Mechanics learning (Becker et al., 2023; Yuliani et al., 2023, Testa & Catena, 2022).

The analysis also showed that many students were not yet able to coordinate verbal, visual, graphical, and mathematical representations effectively, even though these abilities are essential for solving university-level Mechanics problems (Chang et al., 2020; Wu & Liu, 2021). The output of this phase was needs analysis data and interpretation, which became the basis for designing the STEM-MR learning syntax and supporting materials.

Design Phase

The design phase focused on preparing the design of learning syntax, learning materials, and research instruments. Based on the results of the analysis phase, the conceptual structure, learning trajectory, instructional syntax, and representational tasks that would support the integration of STEM practices and multirepresentational reasoning in Mechanics learning were formulated.

The STEM-MR learning design was organized into seven phases: Phenomenon Presentation, Concept Identification, Exploration, Representation Construction, Concept Consolidation, Evaluation, and Re-representation. These phases were designed to guide students from contextual physical phenomena toward structured conceptual, graphical, symbolic, and verbal representations. The structure of the STEM-MR learning syntax is presented in Table 1.

Table 1. STEM-MR Learning Syntax

STEM-MR phase	Main learning activities	Instructional purpose
Phenomenon Presentation	Students observe contextual mechanical phenomena and identify relevant problems through real-world situations.	To activate prior knowledge and situate learning in meaningful STEM-related contexts.
Concept Identification	Students identify key physical concepts, variables, and relationships related to the observed phenomena.	To help students define the conceptual basis needed for further analysis.
Exploration	Students investigate relationships between variables through experiments, simulations, or guided inquiry activities.	To encourage inquiry-based exploration and initial reasoning about the problem situation.
Representation Construction	Students construct and translate among diagrams, graphs, equations, and verbal explanations to model the problem.	To develop multirepresentational fluency in expressing and analyzing Mechanics concepts.
Concept Consolidation	Students refine and validate their representations through discussion, feedback, and comparison of alternative ideas.	To strengthen conceptual understanding and improve the coherence of representations.
Evaluation	Students examine solution strategies and the accuracy of their representations through problem-solving tasks.	To assess the appropriateness of reasoning and the consistency of the generated representations.
Re-representation	Students revise and improve their representations based on reflection and evaluation results.	To support refinement of understanding and reconstruction of more accurate problem representations.

Table 1 shows that the STEM-MR learning syntax was designed as a sequential learning framework that begins with students' engagement with contextual phenomena, continues through concept identification and guided exploration, and then emphasizes the construction, consolidation, evaluation, and refinement of multiple representations in solving Mechanics problems. Through this sequence, students are gradually guided from initial problem recognition toward more coherent conceptual, visual, graphical, and mathematical understanding. In this syntax, the Evaluation phase refers to students' examination of solution strategies and the adequacy of the representations they have constructed during learning, whereas Re-representation functions as the follow-up phase in which those representations are revised and improved based on the results of evaluation and reflection. Thus, Re-representation serves as the culmination of the refinement cycle within the learning process rather than as a repetition of evaluation.

Development Phase

The development phase involved the development of the STEM-MR learning design as Prototype 1. In this phase, the initial design produced in the previous phase was developed into a more complete instructional product consisting of the learning syntax, learning materials, and research instruments. This prototype was then subjected to expert validation by three validators with expertise in physics education, instructional design, and educational assessment. Each indicator was scored on a 0–4 scale, with higher scores indicating better performance. The validity interpretation criteria are shown in Table 2.

Table 2. Validity Criteria of the STEM-MR Learning Design

Mean score range	Category
$3.25 \leq V \leq 4.0$	Highly valid
$2.50 \leq V < 3.25$	Valid
$1.75 \leq V < 2.50$	Less valid
$1.00 \leq V < 1.75$	Invalid

The validators assessed the product using structured validation sheets covering content appropriateness, construct alignment, and linguistic accuracy. The validation stage functioned as an important decision point in the development process. If the product had not yet met the expected validity criteria, revision was carried out based on the validators' suggestions. These revisions included improving conceptual explanations, refining learning instructions, strengthening representational scaffolds, and aligning the learning activities more closely with the intended problem-solving indicators. The problem-solving test instrument was also reviewed during this phase to ensure its suitability for pretest and posttest administration. Once the design was judged valid, the revised product became Prototype 2.0, which was considered appropriate for limited classroom trial.

Implementation Phase

The implementation phase involved the application of the STEM-MR learning design in an undergraduate Mechanics course. The participants were 37 undergraduate students from the Physics Education Study Program at Universitas Sriwijaya who had completed introductory physics courses but had not previously experienced learning through a STEM-MR framework. The participants were selected using purposive sampling, as the intervention was conducted in an intact class considered appropriate for testing the developed design.

Table 3. Practicality Criteria of the STEM-MR Learning Design

Percentage (%)	Category
81–100	Very practical
61–80	Practical
41–60	Moderately practical
21–40	Less practical
0–20	Impractical

The implementation was carried out in two stages within the same group of participants. The initial stage functioned as a limited trial, in which the practicality of the STEM-MR learning design was examined through classroom observation, student responses, and implementation feasibility. The results of this stage were used to identify aspects of the design that required revision. The criteria for practicality can be observed in Table 3.

After refinement, the learning design was implemented more fully in the same class as Prototype 3. At this stage, the implementation was conducted using a one-group pretest–posttest design to examine the effectiveness of the STEM-MR learning design in improving students' problem-solving skills. The pretest was administered before the implementation and the posttest was administered after the implementation. The implementation was conducted over 10 meetings, during which students engaged in the seven phases of the STEM-MR learning design through contextual problem-solving, representational tasks, conceptual discussions, and engineering-oriented reasoning activities.

Evaluation Phase

The evaluation phase involved evaluation and final revision of the STEM-MR learning design based on the findings obtained during implementation. This phase focused on examining the quality of the developed design in terms of validity, practicality, and effectiveness. In accordance with the ADDIE framework and the flowchart in Figure 1, the effectiveness data were collected during the implementation of Prototype 3, whereas the analysis and final interpretation of those data were conducted in the evaluation phase.

Evaluation was conducted in both formative and summative forms. Formative evaluation took place throughout the implementation process and was used to identify aspects of the learning design that still required revision, particularly those related to clarity of instruction, learning flow, classroom feasibility, and the suitability of representational tasks. The results of this formative evaluation informed the final revision of the STEM-MR learning design.

Summative evaluation focused on the three main criteria of product quality. Validity was determined from expert judgment during the development phase. Practicality was determined from classroom observations, student response questionnaires, interviews, and documentation obtained during the limited trial and implementation stages. Effectiveness was examined during the implementation of Prototype 3 using a one-group pretest–posttest design, in which the same group of students completed a pretest before the learning intervention and a posttest after the intervention. This design was selected because the primary purpose of the study was to develop and evaluate the feasibility of a new instructional design rather than to compare it with another instructional model. A one-group pretest–posttest design can provide initial empirical evidence regarding product effectiveness before wider comparative testing is conducted. This approach is consistent with Busyairi et al. (2021), who employed a one-group pretest–posttest design to evaluate a multiple-representation-based learning intervention, supporting the appropriateness of this design for an initial effectiveness study.

Students' problem-solving skills in Mechanics were measured using contextual essay-based pretest-posttest items. Responses were scored using an analytic rubric adapted from Docktor et al. (2016), emphasizing problem analysis, strategy formulation, solution evaluation, and multi-representation use (Bunawan et al., 2023; Sari et al., 2023; Suryadi et al., 2023). The increase in students' problem-solving skills before and after the intervention using the STEM-MR learning design was measured by comparing the average gain (N-gain), the criteria of which are presented in Table 4.

Table 4. Normalized Gain Criteria (Hake, 1998)

N-gain (g)	Category
$g \geq 0.70$	High
$0.30 \leq g < 0.70$	Medium
$g < 0.30$	Low

Result and Discussion

This section presents the validity, practicality, and effectiveness of the STEM MR learning design. Each component is followed by a discussion that connects the findings with recent studies to demonstrate how the present research aligns with, extends, or challenges current knowledge in physics education.

Validity of the STEM MR Learning Design

The STEM-MR learning design was developed as a set of instructional materials consisting of learning syntax, learning materials, and problem-solving tasks that integrated STEM-based contexts with multirepresentational activities in Mechanics learning. An example of the interface of the developed product is presented in Figure 2.

Figure 2. Examples of the developed STEM-MR learning materials

Figure 2 shows the interface of the developed STEM-MR learning materials used during the implementation process. The product was designed to guide students through the seven phases of the STEM-MR learning design, namely Phenomenon Presentation, Concept Identification, Exploration, Representation Construction, Concept Consolidation, Evaluation, and Re-representation. Through this structure, the developed materials were intended to support students' movement from contextual physical phenomena to verbal, visual, graphical, and mathematical representations in solving Mechanics problems. This product organization became one of the main considerations in the expert validation process.

The expert validation results indicated that the STEM-MR learning design met the criteria of a highly valid product. The results of the expert validation are summarized in Table 5.

Table 5. Expert validation Results of the STEM-MR Learning Design

Validation aspect	Mean score	Category
Content	3.88	Highly valid
Construct	3.89	Highly valid
Language and presentation	3.86	Highly valid
Overall mean	3.87	Highly valid

As shown in Table 5, the STEM-MR learning design achieved an overall mean validity score of 3.87 on a 4-point scale, indicating that the product was highly valid. The highest score was obtained in construct validity (3.89), followed by content validity (3.88), while language and presentation validity (3.86) also fell within the highly valid category. These findings indicate that the developed learning design was conceptually appropriate, structurally coherent, and linguistically clear for use in undergraduate Mechanics learning. The validators also indicated that the integration of STEM inquiry with explicit multirepresentational tasks was relevant to the learning objectives and appropriately aligned with the characteristics of students in physics education.

These findings suggest that the high validity of the STEM-MR learning design was supported not only by the accuracy of the content, but also by the coherence between the learning syntax, instructional materials, and representational scaffolds embedded in the product. A learning design is more likely to be judged valid when its conceptual structure, instructional sequence, and task design are mutually aligned from the beginning. This result is consistent with Subramaniam et al. (2025) who emphasized that STEM-oriented learning designs become more meaningful when supported by strong conceptual structure and explicit scaffolding. It also aligns with Azzaroiha et al. (2025), who reported that structured scaffolding improves concept understanding, HOTS, and problem-solving skills.

Busyairi et al. (2021) reported that a multiple-representation approach supported by e-modules was feasible for implementation and contributed positively to conceptual understanding. Likewise, Zikri et al. (2024) found that electronic worksheets based on multiple representations reached high levels of validity and practicality after expert validation and field testing. Nurani et al. (2024) also showed that multiple representation-based electronic teaching materials developed through a structured research and development process achieved strong feasibility for classroom use. Taken together, these findings strengthen the interpretation that the high validity of the STEM-MR learning design reflects the importance of systematic product development, conceptual alignment, and explicit representational support in physics learning.

Practicality of the STEM MR Learning Design

The practicality analysis showed that the STEM-MR learning design was very practical for classroom implementation. Practicality data were obtained from lecturer observation, worksheet readability, syntax implementation observation, and student response questionnaires during the limited trial and implementation stages. To provide a more detailed picture of product practicality, the results are presented both by assessment aspect and by broader practicality dimension. The practicality results by assessment aspect are shown in Figure 3, while the broader dimension practicality results of student response are presented in Table 5.

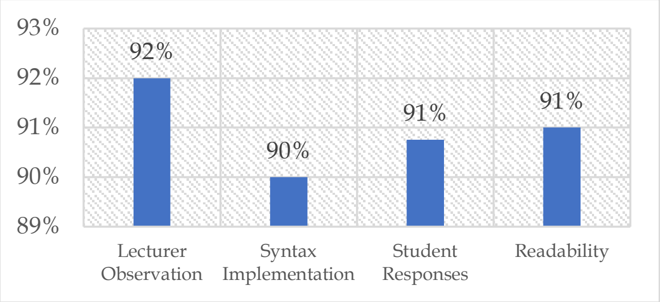

Figure 3. Practicality results

The results in Figure 3 indicate that all assessed aspects of practicality were categorized as very practical with an overall average of 91%. These findings show that the STEM-MR learning design was feasible to implement, understandable for students, and well supported by the developed learning materials. The lecturer observation and syntax implementation results indicate that the learning stages could be carried out smoothly in classroom practice, while the worksheet readability and student response results show that the materials were accessible and positively received during implementation.

Table 6. Broader Dimension of Practicality Result

Aspects	Percentage (%)	Category
Ease of use	90.60	Very practical
Clarity of instruction	89.80	Very practical
Attractiveness of learning materials	91	Very practical
Student engagement	90	Very practical
Usefulness for problem-solving	92.40	Very practical
Overall mean	90.76	Very practical

Table 6 shows that all broader practicality dimensions were also categorized as very practical. These findings indicate that the STEM-MR learning design was practical not only in terms of classroom feasibility, but also in terms of instructional clarity, student engagement, and usefulness for problem-solving. The high score for usefulness for problem-solving (92.40%) suggests that the developed learning design helped students work through Mechanics tasks in a more structured way, which is consistent with the findings of Niyomufasha et al. (2024) on the role of multiple representations in supporting mechanics problem-solving. The strong scores for ease of use and attractiveness indicate that the materials were accessible and supportive during implementation, in line with Almasri (2022), who reported that usable and well-designed learning media can increase students' engagement and satisfaction. The slightly lower, though still very practical, score for clarity of instruction suggests that minor refinement may still be needed to make transitions between learning tasks and representations more explicit. This interpretation is supported by Halawa et al. (2024), who emphasized that clear instructional design is a central element of effective STEM learning environments.

The practicality results also suggest that the learning design was able to sustain meaningful student participation during the learning process. This is consistent with De Loof et al. (2022), who showed that student engagement is closely related to the quality of integrated STEM learning experiences, and with Guzey et al. (2023), who found that engagement in integrated STEM settings contributes positively to science learning outcomes. Engell et al. (2021) reported that that practicality is a crucial determinant of successful implementation because even high quality designs will not be adopted if they are difficult to use or lack clarity. The high practicality score aligns with the findings of Gierczyk et al. (2025), Tytler et al. (2023), and Zeng et al. (2025) who concluded that STEM learning materials must include clear instructions and structured activities to maintain student engagement and reduce cognitive overload. Therefore, a learning design is more likely to be practical when its instructional flow is clear, its materials are readable and attractive, and its activities are perceived as useful for solving the target problems.

Effectiveness of the STEM MR Learning Design

The effectiveness analysis showed that the STEM-MR learning design improved undergraduate students' problem-solving skills in Mechanics. Effectiveness was measured using a pretest and posttest involving four key indicators of problem-solving skills. The pretest mean score was 52.25% and the posttest mean score increased to 78.50%. The normalized gain (N-gain) value was 0.55, which falls within the medium category. The effect size (Cohen d) was 2.53, indicating a very large effect. The very large effect size may be attributed to the explicit integration of multirepresentational construction and refinement across all learning phases of the STEM-MR design. This interpretation is supported by Dewi et al. (2023), who reported an overall effect size of 1.985 for problem-based learning on students' physics problem-solving ability, which was classified as very high. Thus, that study supports the interpretation that the very large effect size found in the present study reflects a strong and meaningful instructional impact rather than a trivial statistical difference.

To provide a more detailed picture of students' performance across the four assessed indicators, the pretest and posttest percentages for each problem-solving indicator are presented in Figure 4.

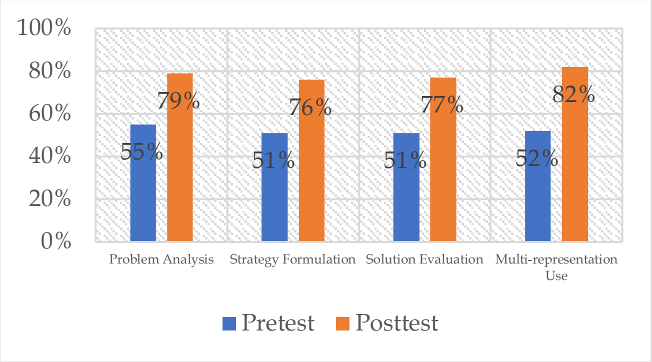

Figure 4. Indicator-level improvements in students' problem-solving skills

As shown in Figure 4, all four indicators showed higher posttest percentages than pretest percentages, with increases ranging from 24% to 30% percentage points. The highest increase was found in multi-representation use (30%), followed by solution evaluation (26%) and strategy formulation (25%). The lowest increase was observed in problem analysis (24%), although this indicator also showed substantial improvement. These results indicate that the STEM-MR learning design supported improvement across all components of problem-solving rather than only in a single skill area.

The strong improvement in multi-representation use suggests that the STEM-MR learning design effectively supported students in moving across verbal, visual, graphical, and symbolic forms during Mechanics problem-solving. This interpretation is consistent with Niyomufasha et al. (2024), who found that the use of multiple representations in mechanics helped engineering students solve both physics and real-world problems more effectively, and with Hahn and Klein (2022), who showed that multi-representational tasks supported deeper understanding of abstract physics concepts through simulations and sketching activities.

The substantial improvement in solution evaluation indicates that the learning design also strengthened students' ability to judge the suitability of their strategies and the coherence of their answers. This interpretation is in line with Ibrahim and Ding (2023), who showed that successful sensemaking in synthesis physics problems depends on how learners coordinate relevant principles, intermediate variables, and diagrammatic information during the solution process. It is also consistent with Sirnoorkar et al. (2023) who argued that physics problem-solving is strengthened when learners engage in iterative refinement of their models and reasoning rather than relying on direct equation matching alone.

At the same time, the positive gains in problem analysis and strategy formulation suggest that the STEM-MR learning design supported earlier stages of problem-solving, including identifying relevant information, selecting appropriate concepts, and formulating workable solution paths. This interpretation is supported by Tong et al. (2024), who found that students' performance in physics problem-solving depends not only on conceptual knowledge but also on the mathematical skills required to interpret and apply physical relationships. Munfaridah et al. (2022) showed that multiple-representation-based instruction can support richer physics understanding by encouraging learners to connect different forms of reasoning and representation.

Almujaddid et al. (2025) also reported that an experiential learning approach combined with STEM-computational thinking improved students' problem-solving skills, supporting the value of structured STEM-oriented learning for higher-order reasoning. Puspita et al. (2024) found that a Project-Based Learning model assisted by PhET simulation improved students' problem-solving abilities in physics, which is relevant to the present finding that structured tasks and supportive media can strengthen performance. In addition, Nasir et al. (2025) concluded that physics problem-solving ability is influenced by instructional methods, student factors, and the learning environment, which supports the broader rationale for using an integrated design such as STEM-MR.

Overall, the results indicate that the STEM-MR learning design was effective in improving undergraduate students' problem-solving skills in Mechanics. The study contributes a specific seven-phase instructional design that makes the integration of STEM learning and multirepresentational reasoning more explicit within Mechanics instruction. This contribution adds to the growing body of research on structured approaches that support students' movement from contextual understanding to formal problem-solving representations.

Conclusion

This study developed a STEM–Multirepresentation (STEM-MR) learning design for undergraduate Mechanics and found that it met the criteria of validity, practicality, and effectiveness. The design was judged highly valid by experts, very practical for classroom implementation, and effective in improving students' problem-solving skills, as shown by the increase from 52.25% on the pretest to 78.50% on the posttest, a medium normalized gain (g = 0.55), and a very large effect size (d = 2.53). These findings indicate that the STEM-MR learning design can support students in moving from contextual physical phenomena to coordinated verbal, visual, graphical, and mathematical representations in Mechanics problem-solving. Future research is recommended to examine the implementation of this learning design in broader instructional contexts, involve comparison groups, and explore its application in other physics topics.

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Author Contributions

Ismet: Conceptualization, methodology;, Ketang & Taufiq: formal analysis; Maghfira: writing—original draft preparation, collecting data, project administration.

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Conflicts of Interest

The authors declare no conflict of interest.

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