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Science, Technology, Engineering, and Mathematics (STEM) and Research Skill Development (RSD) in Science Education in Higher Education: A Delphi-Based Model

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ABSTRACT

This study developed and validated a science learning model integrating Science, Technology, Engineering, and Mathematics (STEM) with the Research Skill Development (RSD) framework to strengthen students' research skills. A two-round Delphi study was conducted with experts to establish consensus on the model. The first round generated a conceptual synthesis through qualitative thematic analysis, while the second evaluated expert agreement using Aiken's V. Experts reached strong consensus on the model structure, the central role of science, integration of the engineering design process, contextual problem-based learning, and progressive research stages. The proposed model has high content validity and provides a systematic framework for developing research skills, supporting student independence, and strengthening research-oriented science learning across higher education contexts.

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1. INTRODUCTION

Advances in science and technology in the 21st century have fundamentally transformed the focus of higher education, particularly in science education, from mere mastery of content to the ability to generate new knowledge through authentic scientific processes. This transformation requires students not only to understand concepts but also to formulate problems, analyze data, and draw evidence-based conclusions independently and reflectively [1, 2]. The Science, Technology, Engineering, and Mathematics (STEM)-based learning approach is increasingly gaining attention as a pedagogical framework capable of integrating various disciplines to solve complex real-world problems [3, 4]. Because of its problem-solving and context-based characteristics, STEM is believed to develop higher-order thinking skills and enhance student engagement in learning. Although STEM is effective in promoting active and collaborative learning, this approach is often not explicitly designed to develop systematic research skills; consequently, the potential of STEM-based learning to foster students' research competencies has not yet been fully realised.

STEM education has been associated with the development of critical thinking, creativity, and problem-solving skills across various learning contexts [5]. On the other hand, the Research Skill Development (RSD) framework offers an approach specifically designed to develop research skills through structured and progressive stages, covering the process from problem identification to the communication of research results [6]. Structured research-oriented learning can support students' analytical development and greater autonomy in managing complex academic and research activities [7]. Research-based approaches, such as Course-based Undergraduate Research Experiences (CUREs), have also been associated with increased student engagement, research participation, and the development of research-oriented learning experiences [8, 9]. However, the existing literature still tends to position STEM and RSD approaches as two separate frameworks, thus failing to provide a comprehensive understanding of how their integration can synergistically optimise the development of students' research skills.

This disparity becomes even more complex when viewed in a local context, particularly in Indonesia. The main issue lies in the failure to optimally integrate contextual STEM approaches with a systematic framework for developing research skills. This situation is further complicated by the continuing challenges associated with STEM implementation and the development of research-oriented educational practices in higher education [10, 11]. Science education in Indonesia continues to face challenges in promoting learning approaches that move beyond conceptual mastery toward stronger scientific thinking and research-oriented competencies [12, 13]. Consequently, although students are involved in various learning activities, their level of independence in conducting research does not always improve. Project- or task-based activities do not automatically result in in-depth research competence without systematic and explicit scaffolding [14, 15].

Although research on STEM and the RSD framework is advancing, a fundamental pedagogical issue remains unresolved. STEM learning is effective for fostering engagement, problem-solving, and interdisciplinary thinking, but it often lacks a clear structure for developing systematic research competencies. Consequently, students may engage actively in projects without adhering to coherent stages of scientific inquiry. On the other hand, the RSD framework provides a structured approach to developing research skills [6]; however, it is often applied in contexts detached from real-world situations, failing to fully capture the complexities of the issues discussed in STEM education.

In light of this gap, this study aims to develop and validate a STEM-based science learning model integrated with the RSD framework within the context of higher education. This study employed a two-round Delphi approach to reach expert consensus regarding the structure, syntax, and components of the developed model [16, 17]. The first round produced a conceptual synthesis of the model based on expert exploration and reflection, whilst the second round was used to test the level of agreement using Aiken's V index. The developed model has high validity, as evidenced by strong expert consensus on the integration of STEM disciplines, the application of the engineering design process, and the systematic, tiered structure of the RSD stages. The novelty of this research lies in the development of an integrative STEM-RSD model that combines the two approaches and aligns the contextual, structural, and epistemological dimensions in science learning. Conceptually, this model offers a new pedagogical framework with the potential to reconceptualize research-based learning in higher education. In practical terms, this model provides lecturers with guidelines for designing learning experiences that develop students' research skills in a more systematic, reflective, and sustainable manner.

2. METHODS

This study employed the Delphi method, a qualitative and quantitative approach designed to achieve consensus amongst experts regarding the syntax of a STEM learning model using the RSD framework to develop research skills. The Delphi study was conducted in two rounds: the first round involved interviews, whilst the second round comprised a questionnaire developed based on the previous results, supplemented by reflections and revisions of the experts' opinions. The Delphi method was chosen because the development of a STEM-based science learning model using the RSD framework involved the integration of complex concepts and required assessment by multidisciplinary experts. It was supported by the fact that the Delphi method was used to achieve consensus amongst experts with differing opinions to resolve complex problems and enable joint decision-making [18].

Stage 1 involved interviews (initial exploration) with experts competent in STEM and inquiry to explore the relevance and integration of STEM in science, the inquiry approach in science learning, and the RSD stages in the research. These interviews aimed to identify key issues requiring further analysis and served as the basis for questionnaire development. Responses from the interviews were analyzed qualitatively using a thematic approach. The results of these interviews produced a list of items or factors to be included in the questionnaire for stage 2. In stage 2, we administered a consensus questionnaire to assess and verify consensus among the experts regarding the factors or items generated during the interview stage. This procedure began with the development of a questionnaire using a five-point Likert scale covering the list of items generated from the previous interviews. Participants were asked to rate each item. Once the data had been collected, we conducted a statistical analysis to assess the level of consensus among participants.

The subjects in this study were experts in the field of STEM education, selected via purposive sampling based on the criteria of having publications in Scopus-indexed journals covering articles on STEM education and possessing a minimum of two years' professional experience in the relevant field. The target number of experts for this study was eight, taking into account potential attrition or drop-outs in subsequent rounds; the number of experts involved in the study until the final stage was five. The instrument for Delphi stage 1 was an interview guide, whilst Delphi stage 2 utilized a model questionnaire. The questionnaire instrument for stage 2 was developed based on the results of exploratory interviews with experts in the fields of STEM, science education, and the inquiry approach. The questionnaire items were designed to represent the themes and factors identified in the thematic analysis. The experts were asked to rate the relevance of each item using a 5-point Likert scale (1 = very irrelevant to 5 = very relevant). The analysis of the interview data was conducted qualitatively, using an inductive approach. The first step in analyzing interview data was to transcribe the interview results. This transcription was essential to ensure that the data obtained from the interviews could be analyzed in detail. We recorded every word and verbal expression uttered by the participants to preserve the authenticity of the data. Once the transcription was complete, the next step was data coding. Data coding was carried out openly by analyzing every word or sentence in the transcript to identify patterns or themes that emerge naturally. Analysis of the questionnaire results was carried out by measuring the level of agreement among experts regarding the components/models developed using Aiken's V index (Equation (1)). This technique was used to quantify the degree of agreement among experts regarding each indicator or aspect assessed in the questionnaire.

$$V = \frac{\sum s}{n(c-1)} \quad (1)$$

where Aiken's V is calculated using the formula $s = r - l_o$, r is the score given by the assessor, l_o is the lowest score, n is the number of assessors, and c is the number of scale categories. The V value ranges from 0 to 1, with higher values indicating greater expert agreement. In this study, an Aiken's V value of ≥ 0.80 was interpreted as strong consensus, meaning the item was deemed suitable for retention, whilst values below this were used as a basis for revision [19]. A summary of the research methodology is presented in **Figure 1.**

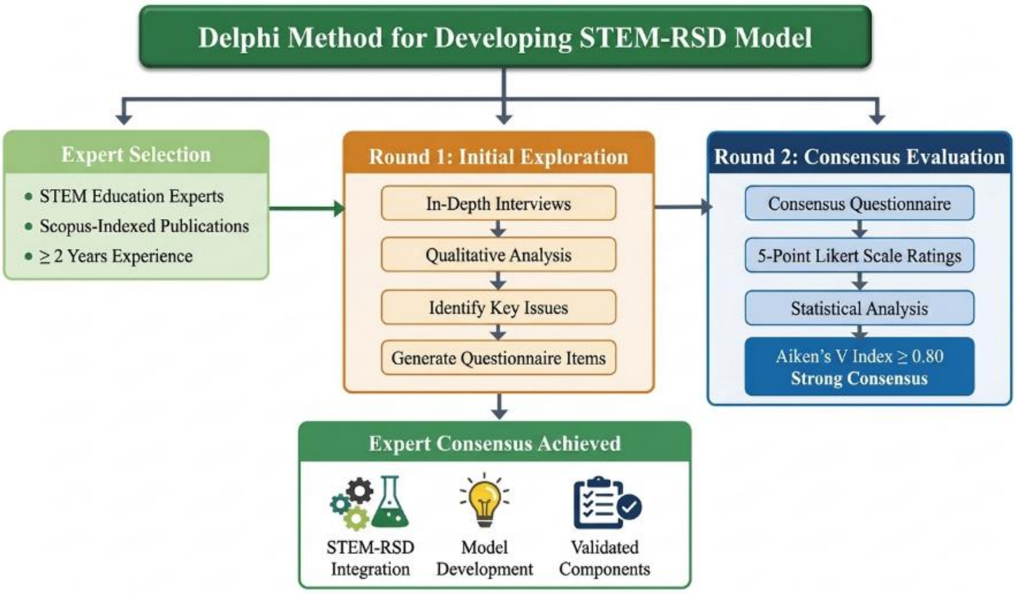

Figure 1. Research methodology diagram.

3. RESULTS

3.1. Results of the First Round of the Delphi Study

The experts reached a consensus on the conceptual, theoretical, and practical foundations for integrating the STEM approach with the RSD framework in science education. A thematic analysis of the interview results identified several key aspects, including the relevance of

STEM in science education, the underlying learning theories, principles for effective implementation, the integration of STEM within the RSD framework, and key components in the development of a structured learning model. The research findings also emphasize the importance of contextual problem-based learning, the systematic integration of STEM elements, and the role of inquiry and scaffolding in supporting the development of students' research skills. To present the results more systematically, the experts' consensus has been organized into main themes and sub-themes, along with their implications for model development. This synthesis summarizes the core findings of the qualitative analysis and serves as the basis for developing the STEM-RSD learning model. A detailed summary of these findings is presented in **Table 1**.

Table 1. Synthesis of Delphi round 1 findings on STEM-RSD integration.

KEY DIMENSIONS	SUB-DIMENSION	KEY FINDINGS	IMPLICATIONS FOR MODEL DEVELOPMENT
The Relevance of STEM in Science Education	Philosophical basis	STEM aligns with the integrated and multidisciplinary nature of science	STEM is a natural approach to science education
	The Role of Science (S)	Science as the core; T, E, M as supporting elements	The model must be based on scientific inquiry
	Meaningful learning	Linking concepts to real life	Boosting student motivation and engagement
	Status STEM	Regarded as an approach, not yet a model	It needs to be developed into a systematic model (STEM-RSD)
Theoretical Framework of Learning	Main theory	Constructivism (Piaget & Vygotsky)	Student-centered and collaborative learning
	Supporting theory	Information processing, empiricism, behaviorism, cognitivism	The model must take into account cognitive processes, experience, and reflection
Principles of STEM Implementation	Analysis of the material	Not all topics are suitable for STEM	There is a need for context-based and application-oriented material selection
	Contextual problem	Based on real and relevant issues	Developing scientific thinking and problem-solving skills
	STEM Integration	Flexible (not all elements need to be included at once)	Integration must be systematic, not forced
	Technical Planning Process	The design must be in place before the product	A key feature of STEM education
	Learning environment	Not limited to the laboratory	Focus on the scientific method, not the location
Integration of STEM in RSD	Integration of stages	STEM is integrated at all stages of RSD	Supporting the development of comprehensive research skills
	STEM Distribution	S-T dominates at the start, E in design, M in analysis	Integration is dynamic and context-dependent
	Inquiry	STEM is inquiry-based	Inquiry is at the heart of learning
	Student independence	Step-by-step: guided → independent	RSD supports greater autonomy

Table 1 (continue). Synthesis of Delphi round 1 findings on STEM-RSD integration.

KEY DIMENSIONS	SUB-DIMENSION	KEY FINDINGS	IMPLICATIONS FOR MODEL DEVELOPMENT
Components of the Developed Model	Main components	Curriculum analysis, STEM integration, EDP, RSD	Forming the basis of the model's syntax
	Characteristics	Systematic, contextual, research-based	The model supports research-based learning
	Expert consensus	Strong consensus on all key aspects	The model is worth taking forward to the validation stage
The Syntactic Principles of the STEM-RSD Model	Syntactic structure	Progressing from simple to complex	Supporting gradual mastery
	Problem-based	Based on real-world problems	Encouraging inquiry and exploration
	STEM Integration	Distributed across every stage	They do not have to appear at the same time
	Scaffolding	Aid decreases as self-reliance increases	Supporting skills development
	Mind-on & hands-on	Thinking and practice go hand in hand	Strengthening scientific skills
The Distribution of STEM in Syntax	Early stages	Science and technology dominate	Identification of the problem
	Exploration phase	S & M	Concept study
	Design phase	E & S	Solution design
	Implementation	S, T, E, M	Experiment/laboratory/field
	Analysis	M & S	Data interpretation
	Communication	All elements	Presentation and reflection
Recommended Learning Topics	Contextual topics	Environment, energy, biotechnology, local knowledge	Simplifying STEM integration
	Example topics	Green chemistry, eco-printing, biogas, water filtration	Supporting project-based learning

Figure 2 presents the synthesis of learning materials derived from the Delphi study, organized into four contextual domains: environment, energy, biotechnology, and local knowledge. This organization is significant because it reflects expert consensus on the types of content that naturally support interdisciplinary integration and real-world problem-solving, which are essential for effective STEM implementation. The identified domains provide a structured foundation for aligning learning materials with the progressive stages within the RSD framework. By integrating these domains into the learning process, students are not only exposed to contextual problems but are also guided through systematic inquiry and solution development. The selection of these materials is not merely thematic but pedagogically strategic, as it enables the simultaneous development of conceptual understanding, engineering design thinking, and research competence.

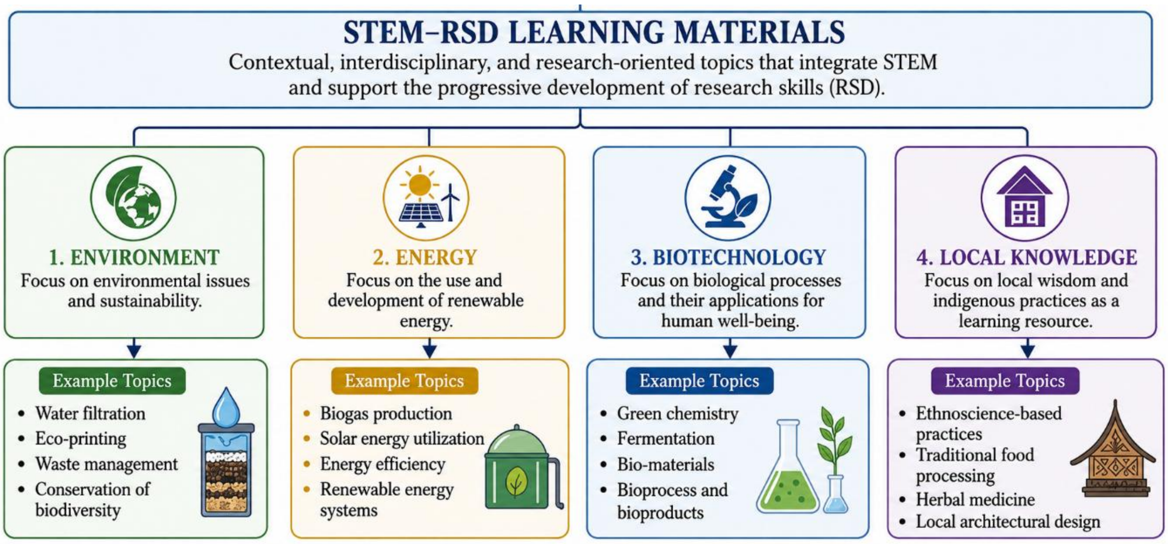

Figure 2. Learning material domains for STEM-RSD implementation based on Delphi analysis.

3.2. Results of the Second Round of the Delphi Study

The results of the second round of the Delphi study were used to test the content validity of the developed learning model. The assessment was carried out by five experts on 42 items organized across six evaluative stages and seven levels of research independence. A summary of the results of the Aiken's V analysis is presented in **Table 2**. All stages of the learning process obtained positive Aiken's V values, with an overall average of 0.810, indicating a high level of expert agreement across the evaluated components. The "Initiating and Clarifying Research" stage achieved the highest score ($\bar{V}$ = 0.836), whilst the "Communicating and Applying Results" stage had the lowest score ($\bar{V}$ = 0.786), although it remained within the valid category. These results indicate a generally consistent model structure and a high level of expert agreement across the evaluated stages. The relatively high Aiken's V values in the early stages indicate strong expert agreement regarding the formulation of problems and research orientation, whilst the relatively lower scores in the final stages suggest a need for improvement in the aspect of scientific communication. These findings are consistent with previous research stating that the communication stage in the research process is often the most complex part for students [6].

Table 2. Summary of the average Aiken's V by stage of learning.

NO	LEVEL OF LEARNING	AVERAGE V-AIKEN	RANGE V	CATEGORY	STATUS
1	The initial and clarification stages of research	0.836	0.750 - 0.950	High	Valid
2	The stage of identifying and developing solutions to problems	0.814	0.750 - 0.850	High	Valid
3	The evaluation and reflection stage	0.814	0.750 - 0.900	High	Valid
4	The stage of organising and managing the problem-solving plan	0.800	0.700 - 0.850	Moderate	Valid
5	The analysis and synthesis stage	0.807	0.750 - 0.850	High	Valid
6	The stage of communicating and implementing problem-solving outcomes	0.786	0.750 - 0.850	Moderate	Valid
Overall V-Aiken average		0.810	0.700 - 0.950	High	Valid

In addition to quantitative assessments, the five assessors provided written feedback via the open-comment section of the questionnaire. **Table 3** comprehensively summarises the qualitative feedback by stage, organised according to the types of issues identified and the proposed revision recommendations.

Table 3. Summary of qualitative expert input and recommendations for revision by learning stage.

STAGE	SUMMARY OF EXPERT INPUT	REVISION RECOMMENDATIONS
Stage 1: Initiating and Defining the Research	The grading of levels is not yet consistent; the definition of 'complex' at Level 7 is not yet operational; and Levels 6 and 7 require more explicit clarification regarding design adaptations and the expansion of variables, samples and methodologies.	The level descriptors need to be revised to make them more progressive, with the addition of an operational definition of 'extension' at Level 7, and a clear emphasis on the integration of STEM in every activity.
Stage 2: Identifying and Developing Solutions to Problems	The distribution of STEM subjects is currently unbalanced (Engineering dominates at Levels 1-2, whilst Technology is not explicitly addressed at Level 4); Level 6 requires clarification regarding integration, and the literature review must be consistent across all levels.	Levels 1-2 need to be holistically revised, technology should be incorporated into Level 4, literature reviews should be consistent across all levels, and the integration of STEM in Level 6 should be clarified.
Stage 3: Evaluating and Reflecting on the Method	Level 1 is not yet structurally equivalent; the evaluation at Level 3 remains weak and unclear; and the gradation between levels is not yet consistent.	There is a need to add activities at Level 1, strengthen self-assessment at Level 3, clarify the focus of the assessment, and emphasise reflection at each level regarding methodology and the validity of the instruments.
Stage 4: Organising and Managing the Problem-Solving Plan	The integration of STEM at Level 6 is not yet explicit; Level 4 does not yet cover measurement; Level 1 requires clarification regarding data tabulation; and the aspect of student independence still needs to be clarified.	There is a need to clarify the integration of STEM at Level 6, to specify the assessment activities at Level 4, to include data tables at Level 1, and to strengthen the progression of student autonomy across levels.
Stage 5: Analysing and Synthesising	Overall, the activities are well-structured, with a coherent progression; teaching aids should be further developed at the advanced level.	No major revisions are required; optional learning outcomes should be added in the form of the development of teaching aids/materials at Levels 6-7.
Stage 6: Communicating and Implementing the Results of Problem Solving	Communication activities at Levels 1-2 are not yet adequate; the term 'guided' at Level 3 needs to be clarified; the integration of STEM is not yet clear; and digital presentation options are required.	The Level 1-2 activities need to be revised to reflect communication outcomes, replace the term 'guided' with operational guidance, integrate STEM-based communication, and include digital media as a means of presentation.

Expert feedback indicates that key improvements are required in terms of the clarity of gradation between levels, the explicit integration of STEM in each stage, and the clarity of activity descriptors at the initial and final levels. In general, the experts emphasised the importance of structural consistency and clarity of indicators to ensure the model is implemented effectively.

The final structure of the STEM-RSD learning model is illustrated in **Figure 3.** The model reflects an engineering-oriented learning process by integrating the engineering design process (EDP), iterative problem-solving, and system-based thinking across learning stages.

This study presents the validated STEM-RSD learning process model, operationalized through eight progressive learning stages from problem identification to reflection and improvement. These stages represent the instructional sequence of the model, while the Delphi evaluation was organized around the broader evaluative dimensions used to assess its content and structure. The diagram shows the expected outputs at each stage, ensuring a systematic, outcome-oriented learning process. The feedback loop emphasizes the model's iterative nature, reflecting an engineering design approach where solutions are continually assessed and refined. The model provides a practical framework for implementing STEM-based research learning in higher education.

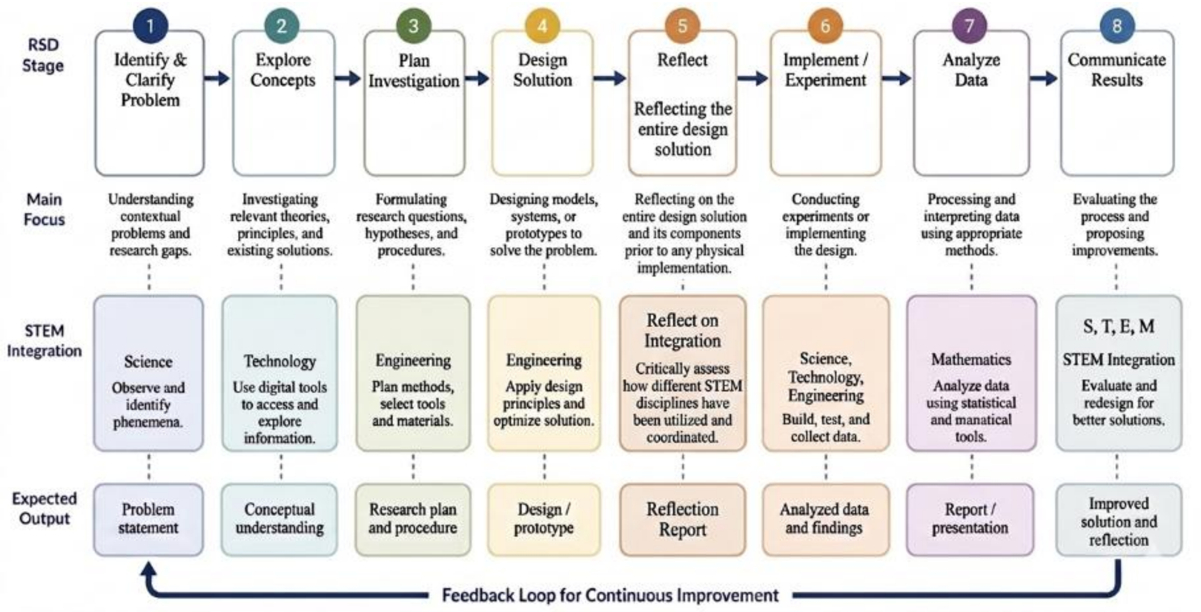

Figure 3. STEM-RSD learning process model.

4. DISCUSSION

This study yielded two complementary sets of findings: qualitative findings from the first round of the Delphi study, which established the conceptual foundation for a STEM-based science learning model incorporating the RSD framework; and quantitative findings and qualitative expert feedback from the second round of the Delphi study, which confirmed the content and syntactic validity of the model developed in the first round. These two sets of findings provide complementary evidence that the integration of STEM and RSD is relevant, theoretically grounded, and content-valid, thereby providing a basis for subsequent implementation and empirical evaluation in university-level science education.

Figure 4 shows the conceptual contribution of this study by comparing the RSD framework, existing STEM-based learning models, and the proposed STEM-RSD model. This comparison highlights the distinctive features, strengths, and limitations of each approach and clarifies the rationale for their integration. STEM education focuses on solving problems across disciplines and getting students involved in the real world. However, it often does not have a clear way to help students learn research skills. As a result, students may engage in learning activities without advancing through structured phases of scientific inquiry. The RSD framework, on the other hand, offers a structured, gradual approach to improving research skills, allowing students to progress from guided inquiry to independent research. However, RSD is often used in settings that are not very contextualized, and it does not automatically include STEM elements from different fields. The STEM-RSD model developed in this study addresses these problems by combining contextual problem-solving with a structured research process. This integration creates a dual-scaffolding system that helps students not only understand real-world problems but also follow the research process systematically. Consequently, the model provides a more extensive pedagogical framework that integrates interdisciplinary learning with the enhancement of research skills and student independence.

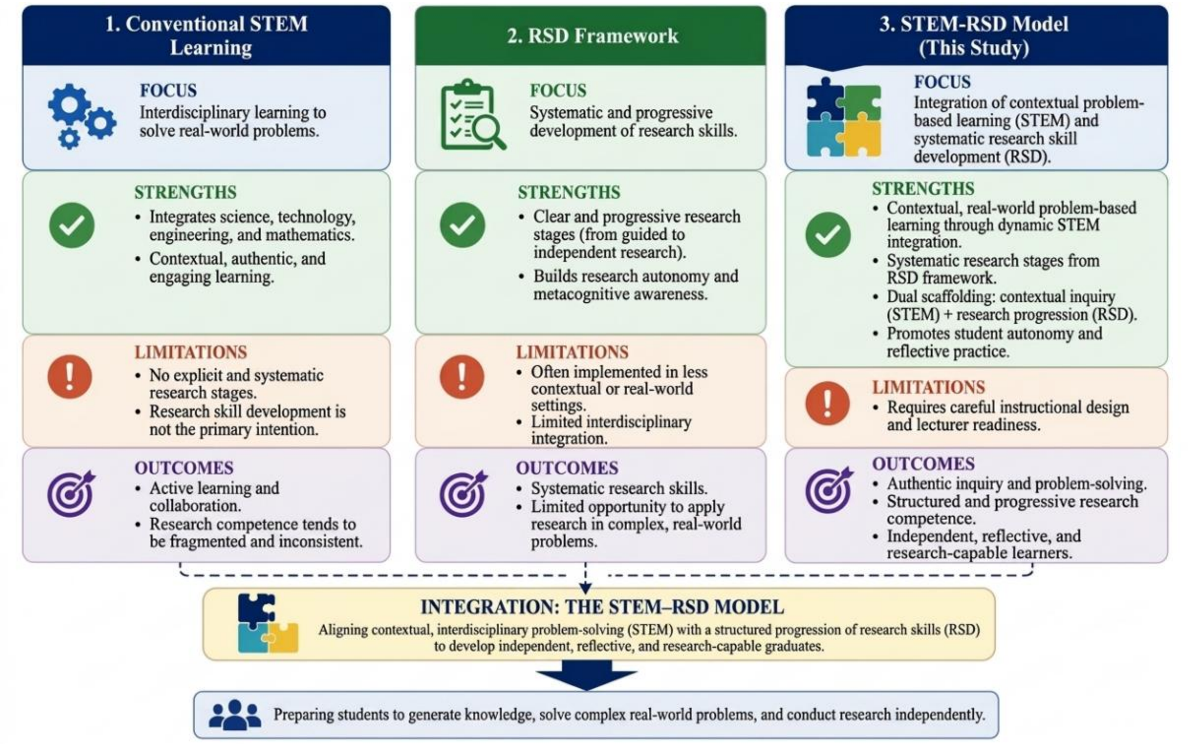

Figure 4. Conceptual comparison of STEM learning, the RSD framework, and the proposed STEM-RSD model.

The consensus among experts in the first round of the Delphi study that STEM is highly relevant to university-level science education reinforces the view that scientific inquiry is inherently connected with technological, engineering, and mathematical practices. When experts state that "STEM is relevant because the concepts of science itself are integrated" and "in product engineering, science is a prerequisite or foundation", they are articulating a philosophical position: that science learning can be meaningfully connected with technology, engineering, and mathematics in interdisciplinary problem-solving contexts. This position is consistent with studies emphasizing interdisciplinary integration in STEM education and the importance of connecting science concepts with technological, engineering, and mathematical applications in meaningful learning contexts [2, 20, 21]. However, the relevance of STEM to science is not generic or uniform, but rather contextual and tiered. This relevance depends on the characteristics of the subject matter being studied, the level of research autonomy students possess, and the current phase of learning. STEM integration must be dynamic across each phase, with S and T dominant in the problem-orientation phase, E dominant in the design phase, and all four elements fully present in the implementation phase. This expert consensus highlights a difference from existing STEM models, which tend to view STEM integration as a static condition that must be consistently applied at every stage of learning.

The terminological debate over whether STEM is an approach or a model positions STEM as an approach because it "does not yet meet the characteristics of existing learning models. This view aligns with the criticism raised in their systematic review of 80 articles on STEM education. The majority of STEM studies remain at a descriptive level, without clear, structured operationalization [20]. The second Delphi finding, showing an overall average Aiken's V value of 0.810 across all 42 items, is interpreted as evidence that this model operationalises STEM education within a structured, tiered learning framework possessing recognisable internal coherence. Content validation is essential for determining whether the components of an educational model adequately represent the construct being evaluated and are suitable for further development [22].

The theoretical foundations of learning identified in the first phase of the Delphi study indicate that a combination of theories operates simultaneously at different stages. Personal constructivism (Piaget) comes into play when students individually construct new knowledge schemas through STEM-based problem-solving. Social constructivism (Vygotsky) emerges when that knowledge is reinforced and validated through collaborative interaction within the zone of proximal development. Previous research on STEM integration has emphasized the importance of collaborative learning, instructional structure, and teacher practices in supporting meaningful STEM learning experiences [23]. This study provides a strong empirical foundation for the principle of gradual scaffolding derived from the first Delphi. Empiricism operates in the data collection and field observation phases. Cognitivism emerges in the analysis and conclusion-drawing phases. This interpretation is consistent with studies showing that STEM implementation is influenced by how interdisciplinary integration, instructional practices, teacher characteristics, and learning contexts are coordinated within the learning process [24, 25].

The STEM-RSD model operationalizes this multi-theory principle through its progressive learning sequence, with different stages predominantly activating distinct learning mechanisms within the model's syntactic architecture. The statement on social constructivism that higher education must move from lectures to a case method or project-team approach carries transformative implications for the design of science education in higher education. This statement directly challenges the dominance of the transmissive learning model, which is still widely practised in higher education, and positions collaboration not merely as a learning strategy, but as an epistemological necessity. Students engaged in team-based STEM learning exhibit higher intrinsic motivation and a stronger sense of ownership of the learning process than those engaged in individual learning. In the context of developing this model, these results provide a strong empirical basis for positioning collaboration as an integral component at every level within the RSD framework, rather than merely an adjunct.

The principles of contextual problem-based learning agreed upon in the first round of the Delphi study have significant implications for implementation strategies. The experts' assertion that problems must be solvable through a STEM approach and that students need to be involved as problem-solving agents indicates a high epistemological standard in problem selection. Thus, the problems used must not only be engaging but also require structural multidisciplinary integration. This aligns with the views of those who emphasize the importance of authentic problems in STEM learning [26]. The findings of the second Delphi round, which showed that Stage 1 (Initiating and Clarifying Research) achieved the highest average Aiken's V score ($\bar{V}$ = 0.836) with a peak at Level 4 (V = 0.950), confirm that the problem orientation has been formulated appropriately and is implementable. This high score at Level 4 indicates a stage at which students begin to exercise greater autonomy in formulating problems within authentic STEM learning activities.

Furthermore, the position of the Engineering Design Process (EDP) within the model, established in the first round of the Delphi study, was further explored in the second round. The experts stated that without the design process, a learning activity cannot be categorized as STEM; consequently, the EDP is positioned as an essential element, rather than an optional one. This view is more definitive than that found in the general literature, which often presents the EDP as merely one of several alternative approaches. Previous research provides theoretical support for the important role of the Engineering Design Process in integrating science, mathematics, and technology within a structured problem-solving cycle [27]. In the STEM-RSD model, this is reflected in Stage 3 (Evaluating and Reflecting on Methods), which operationalizes the epistemological aspects of design. Aiken's V value of 0.900 at Level 6 indicates that the design evaluation has been formulated appropriately, whilst reinforcing EDP's position as the primary distinguishing element within the model.

The distribution pattern of Aiken's V values in the second round of the Delphi study revealed a gradient, with the upper-middle levels (Levels 4-6) tending to have higher values than the initial levels (Levels 1-3). This pattern suggests a fundamental relationship between STEM and RSD, in which the integration of the two becomes increasingly optimal as students' independence in the research process increases. The lower levels of the RSD framework, where students are still heavily guided and research procedures are still determined entirely or largely by lecturers, structurally provide limited scope for authentic STEM integration, as the autonomy required to make meaningful design choices is not yet available.

Conversely, at the upper-intermediate level, where students have sufficient autonomy to make genuine choices, they naturally create conditions for STEM integration to occur organically. These findings quantitatively support the first-round expert view that STEM integration becomes more clearly established from Level 4 onwards. This does not mean that Levels 1-3 cannot integrate STEM, but that STEM integration at lower levels requires far more careful and explicit design to be recognizable and validated by experts. A similar perspective is reflected in research emphasizing that deeper forms of STEM integration are more likely to emerge when learners have sufficient autonomy to make meaningful interdisciplinary decisions [28].

The results of Delphi 2 for syntax stage 4 (Organizing and Managing Problem-Solving Plans) showed that this was the stage with the lowest mean score ($\bar{V}$ = 0.800) and the only stage with an item below V = 0.750 (Level 6, V = 0.700), indicating a conceptual challenge in the implementation phase. Qualitative input from experts identified that STEM integration at Level 6 is "not explicitly visible". Experts noted that in phases when students are engaged in procedural execution (data collection, instrument calibration, dataset management), the STEM connections that should be present in every element of the process become invisible. The difficulty of identifying STEM components within implicitly multidisciplinary activities has been recognized as a challenge in STEM implementation [29]. This leads both lecturers and students to fail to recognize and make explicit the STEM dimensions of what they are doing. These findings suggest that the model needs to reinforce STEM integration at this stage explicitly.

Stage 5 (Analyzing and Synthesizing) received the most positive qualitative feedback from the experts. Research on integrated STEM implementation has shown that maintaining interdisciplinary connections across different phases of learning can be challenging, particularly when instructional activities tend to emphasize individual disciplinary perspectives [30]. Meanwhile, the Delphi results for Stage 6 (Communicating and Applying Results) recorded the lowest average V ($\bar{V}$ = 0.786) and received the most intensive qualitative feedback from the experts. A key consideration at this stage is how to define and design scientific communication within a tiered, self-directed STEM context. Conventional conceptions view communication as the presentation of results or the reporting of findings to a passive audience.

A conception more aligned with the epistemology of STEM and RSD views communication as a negotiation of meaning; that is, a process in which findings are tested, critiqued, and refined through dialogue with an active audience. Science communication in higher education involves more than the simple presentation of findings; it requires learners to organize, explain, discuss, and communicate scientific ideas effectively to different audiences [31]. In this sense, communication can function as an active component of the learning and knowledge-construction process. Experts' recommendations for integrating STEM-based communication formats at the upper secondary level emphasize dialogic communication that invites critical responses from the audience. The STEM-RSD model not only incorporates communication as the terminal phase of learning but also explicitly differentiates the forms and objectives of communication based on students' research autonomy.

The three key findings from the second Delphi qualitative input represent the three theoretical foundations underpinning the STEM-RSD instructional design. The first point to note is the clarity of gradation between levels, which reflects the scaffolding design. Differentiated scaffolding requires clear and operational criteria so that learners can be supported appropriately across different levels of independence and task complexity [32]. In STEM-RSD, this granularity issue has a dual dimension: differentiation between levels distinguishes the degree of independence in the research process (the RSD dimension) and distinguishes the complexity of STEM integration (the STEM dimension). The solution implied by these findings is the development of a behavior-based observation rubric that defines each level in terms of directly observable student actions. Effective support for complex learning requires clearly defined performance indicators, structured learning tasks, and progressive guidance that enables learners to develop greater independence over time. Experts recommend adding annotations of STEM components to each activity descriptor and incorporating metacognitive STEM prompt questions designed to actively encourage students to identify the STEM components of each activity they undertake. When students can consciously answer questions such as “What science am I using here?”, “What technology is mediating this process?”, “What engineering principles inform this design choice?”, and “How does mathematics quantify the phenomenon I am observing?”, they are not merely engaging in STEM activities; they are also developing transferable awareness of how STEM disciplines contribute to problem solving in different contexts. Thirdly, the operationalization of Levels 6 (Adopted Research) and 7 (Extended Research) raises questions that remain unanswered in both the RSD and STEM literature: how can we operationalize the distinction between students who adopt others' research and those who extend existing research within a STEM context? This distinction is not merely a matter of the degree of modification, but also of differing epistemological orientations: adoption is oriented towards the transfer of established methods to new contexts, whilst expansion is oriented towards the development of new knowledge that extends beyond previous research. The second Delphi finding that the boundary between these two levels is considered unclear by some experts indicates that the model needs to develop epistemological criteria as an additional dimension of differentiation alongside the existing procedural dimensions.

When the results of the first and second Delphi rounds are combined, they indicate that scaffolding in STEM learning must be two-dimensional: scaffolding for the development of research skills (the RSD dimension) and scaffolding for the complexity of STEM integration (the STEM dimension). This statement challenges the dominant paradigm in STEM learning design, which tends to treat all students as being at the same level of readiness for STEM integration and to design uniform STEM experiences without considering differences in students' research capacities. This 'one-size-fits-all' approach is unresponsive and epistemologically inaccurate. A student newly introduced to the research process cannot be expected to integrate the four STEM components creatively and independently as a student who has developed substantial research autonomy. The STEM-RSD model, which achieved an overall Aiken's V of 0.810 in the second Delphi round, reflects the principle that the depth and autonomy of STEM integration should be aligned with students' research capacities. STEM learning models that explicitly accommodate heterogeneity in student readiness are one of the most urgent research priorities [3].

The findings from both Delphi rounds highlight the distinctive contribution of integrating the STEM approach with the RSD framework within science education. These findings indicate a strong consensus among experts regarding the relevance of STEM in science education, affirming that science fundamentally functions as an integrated discipline. These results align with previous studies highlighting STEM as a framework that clarifies the interdisciplinary nature of science [2, 20]. However, unlike previous models that treated STEM integration as static, integration is dynamic and varies across different phases of learning. Effective STEM implementation requires adaptive integration strategies aligned with students' levels of research autonomy, thereby providing a more in-depth framework for higher education learning design. The findings of this study present a detailed and validated conceptual map of how STEM should be operationalized in science education at the university level. The recommendations for further research are clear: this content-validated model needs to be tested through design-based research focused on questions regarding how the model performs in real classroom contexts, how students with varying levels of research autonomy respond to and develop through the model, and what causal mechanisms link the model's design to outcomes such as improved research skills and STEM competencies.

5. CONCLUSION

This study produced a validated STEM-RSD-based science learning model that offers a new pedagogical framework for the development of research skills in higher education. Using a two-round Delphi method, the model achieved an Aiken's V score of 0.810, indicating high consensus among experts regarding the clarity of its structure and syntax. Integrating STEM without an explicit research structure is insufficient for the in-depth development of students' research competencies. Conversely, the STEM-RSD model systematically links real-world problem contexts with progressive research stages, thereby providing a structured framework for supporting students' independence and analytical capacity. Conceptually, this model repositions science learning from project-based activities towards structured research-based learning. Further studies are required to assess its impact on enhancing students' research skills and professional readiness.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper is free from plagiarism.

7. REFERENCES

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