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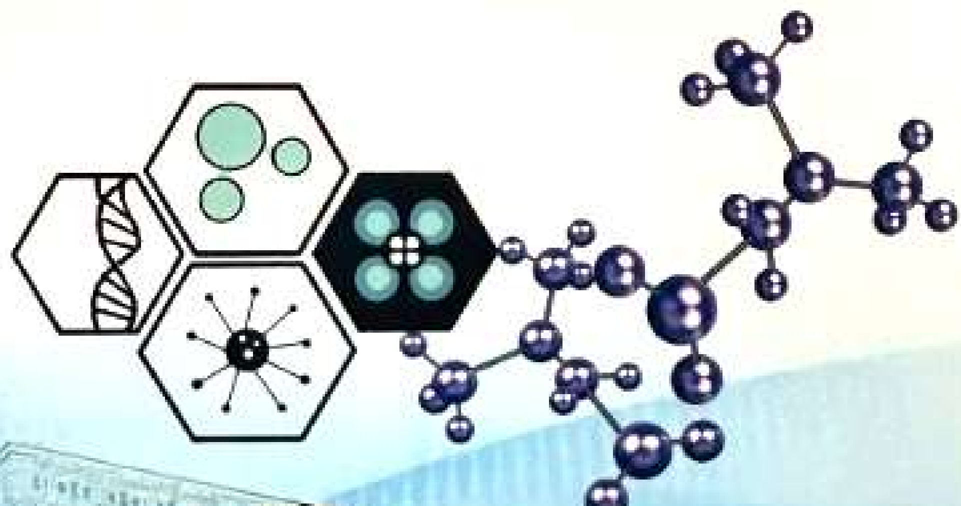

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From theory to practice: a framework for High school scientific research competence

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Abstract. Although scientific research activities among high school students in Vietnam are increasingly encouraged, a significant gap persists between academic, school-based projects and the problem-solving competency requirements of practical production. This lack of connection limits the potential application of projects and students' career orientation capabilities. This study aims to develop and validate a comprehensive Scientific Research Competency Framework, specifically designed to connect the research activities of high school students with the contexts and demands of practical production. An exploratory sequential mixed-methods research design was employed. The initial qualitative phase involved a literature review and 18 in-depth interviews with education experts, business professionals, and teachers to build a draft competency framework.

The subsequent quantitative phase used a two-round Delphi technique with 35 experts to validate and achieve consensus on the framework's content. The result of the study is a validated competency framework, comprising 5 main competency domains and 18 specific component competencies. These competency domains cover the entire process of a practice-oriented project, from (1) Identifying and Contextualizing Problems, (2) Designing and Planning Solutions, (3) Implementing and Prototyping, (4) Analyzing, Evaluating, and Optimizing, to (5) Communicating and Transferring Results. The validation results showed a very high level of consensus among experts on the importance and appropriateness of all components in the framework (Mean ≥ 4.63; SD ≤ 0.55). The proposed competency framework provides a useful theoretical and practical tool for policymakers, educational administrators, teachers, and students. It not only helps guide the design and evaluation of application-oriented scientific research projects but also contributes to strengthening the link between schools and businesses, thereby improving the quality of science education and better meeting socioeconomic development needs.

Keywords: Competency Framework, scientific research competency, high school education, practice-oriented learning, STEM education, practical production.

1. INTRODUCTION

In the context of the Fourth Industrial Revolution, equipping the young generation with 21st-century competencies - especially critical thinking, complex problem-solving, and creativity - has become an urgent requirement for global education systems [1]. Scientific research competency is no longer an activity reserved for scientists or university students but has become an effective learning method for high school students to comprehensively develop these skills. Advanced educational models such as STEM (Science, Technology, Engineering, and Mathematics) and Project-Based Learning both emphasize the importance of allowing students to actively engage in inquiry and knowledge discovery processes, similar to real scientists [2, 3].

However, a major challenge in general education today is the existence of a significant "gap" between the academic scientific knowledge taught in schools and the diverse, complex problems of the real world, especially in the fields of production and industry [4]. In Vietnam, although scientific and technical research activities for high school students are increasingly encouraged, as evidenced by the hundreds of projects participating in the national Science and Engineering Fair (VISEF) each year [5], the majority of projects remain heavily theoretical or are limited to simulations in a laboratory setting. A review of recent competitions shows that while the number of projects is increasing, only a small percentage demonstrate clear applicability or potential for real-world implementation [6]. This leads to a situation where students, despite having foundational knowledge, lack the practical skills to identify, analyze, and propose solutions for problems arising from real-world p2roduction. This disconnection not only reduces the significance of scientific research activities but also directly impacts their future career orientation, as students cannot see the practical relevance of their studies to actual job requirements [7]. This situation not only limits students' creative potential but also fails to meet the demands of the country's socioeconomic development strategy, which urgently requires a high-quality workforce capable of applying science and technology to optimize production processes and create valuable products [8].

Recognizing this issue, this study argues that a more systematic approach is needed to integrate the requirements of practical production into students' scientific research activities. Therefore, the development of a well-structured, practice-oriented scientific research competency framework is an important and necessary task to create a solid bridge between theory and practice.

To address the aforementioned gap, this study focuses on answering the following questions:

- What are the core competency components that constitute scientific research competency linked to practical production for high school students?

- How can these competency components be organized and structured into a comprehensive, systematic competency framework?

- What is the level of appropriateness and feasibility of the proposed competency framework as assessed by experts in the fields of education, science, and industry?

The main objective of this paper is to develop and propose a Scientific Research Competency Framework linked to practical production for high school students. To achieve this objective, we will undertake the following specific tasks: (1) Review and analyze the theoretical foundations of competency, competency frameworks, and existing scientific research education models; (2) Conduct qualitative research through expert interviews and focus groups to identify necessary competency components; and (3) Develop and validate the competency framework through expert-based methods.

This study is expected to make significant contributions both theoretically and practically. Theoretically, the paper contributes to enriching the theoretical system of competency development in general education by introducing a new, integrated competency framework. Practically, this framework will serve as a useful reference tool for educational managers in policy innovation, for teachers in designing teaching and assessment activities, and will help students have a clearer roadmap for developing the necessary skills for their future careers in science and technology.

2. LITERATURE REVIEW

2.1. Theories of Competency and Competency Frameworks in Modern Education

The concept of "competency", though initiated by McClelland [9], has been continuously developed and enriched in the context of a globalized and digitized education. Competency is no longer understood merely as the integration of knowledge, skills, and attitudes, but also includes values and the ability to apply them flexibly to solve unprecedented problems [10, 11]. The shift towards Competency-Based Education (CBE) is now not just a trend but a mandatory requirement, aimed at preparing learners for adaptability and lifelong learning in a volatile world [12]. This trend is clearly reflected in Vietnam's 2018 General Education Curriculum. This is a landmark reform, shifting the education system from a focus on knowledge transmission to the comprehensive development of qualities and competencies for students. The curriculum identifies 10 core competencies (including 3 general and 7 subject-specific competencies), with scientific competency and problem-solving and creative competency as central components [13]. However, the practical implementation of this curriculum still faces many challenges. A study by Le and Nguyen [14] indicated that although teachers are aware of the importance of competency-based teaching, they still struggle to design experiential learning activities and effectively assess students' competency manifestations.

To specify and operationalize competency-based education, "competency frameworks" play a pivotal role. Beyond their descriptive function, effective competency frameworks must be able to guide the entire educational ecosystem, from curriculum development and pedagogical innovation to revolutionizing the assessment system [15]. Recent globally influential frameworks like the OECD Learning Compass 2030 not only list skills (e.g., critical thinking, creativity, collaboration) but also emphasize "student agency" the ability of students to set goals, reflect, and act responsibly to create change [16]. This indicates that a modern competency framework must be both well-structured and open, flexible enough to promote the personalized development of learners.

2.2. Scientific Research Competency in the Context of High School Education

Incorporating scientific research into high school education is a pedagogical strategy aimed at "democratizing" science, transforming it from an academic field into a thinking tool for all citizens [17]. Recent empirical studies have provided convincing evidence of its benefits. For example, a meta-analysis by Sadler et al. [18] showed that Course-based Undergraduate Research Experiences (CUREs), when adapted for the high school level, have a positive and significant impact on students' self-confidence, problem-solving skills, and academic persistence. International theory emphasizes developing scientific research competency through "scientific practices" rather than just mechanically following methodological steps [19, 20].

In Vietnam, the scientific research movement among high school students has developed strongly, especially through the annual national Science and Engineering Fair (Visef). The competition has encouraged thousands of students to engage in inquiry and creative activities, helping to spread a passion for science [5]. Nevertheless, many domestic education analysts have pointed out the inherent limitations of the competing projects. A review by Tran and Huynh [21] in the Vietnam Journal of Education Sciences noted that the majority of topics still focus on familiar areas, tend to replicate previous studies on a smaller scale, and notably lack connection to the pressing issues of local businesses and communities. The products often remain at the model or laboratory level, failing to demonstrate their applicability and effectiveness in a real production environment. This situation reveals a gap in equipping students with application-oriented scientific research competency.

To overcome this barrier, educators are moving towards creating learning environments where students engage in comprehensive "scientific practices". The Framework for K-12 Science Education by the U.S. National Research Council identified 8 core scientific practices, which include not only "planning and carrying out investigations" but also "developing and using models", "engaging in argument from evidence", and "obtaining, evaluating, and communicating information" [19]. The emphasis on these "practices" indicates that scientific research competency is a complex, social process that requires continuous interaction, rather than a linear, isolated sequence of steps.

2.3. Bridging Education and Practice: From Situated Learning to Innovation Ecosystems

The theory of situated learning by Lave and Wenger [22] remains a crucial theoretical foundation, but recent studies have expanded and deepened this concept in the context of school-business collaboration. "Authentic learning" is seen as key, requiring not only that tasks have a real-world context but also that students interact with experts, use professional tools, and face complex, multifaceted problems with no single correct answer [23]. Successful models worldwide, such as P-TECH (Pathways in Technology Early College High School) in the US or the Dual VET system in Germany, have demonstrated the effectiveness of building an integrated learning ecosystem where the boundary between the classroom and the factory is blurred [24]. In these models, students do not just "learn about" the industry but "learn within" the industry through real projects, internships, and mentorship from experts. This approach helps form a positive feedback loop: problems from practical production become material for scientific research projects in schools, and the solutions from these projects have the potential to be applied back into practice [25].

Connecting schools with businesses and practical production is a major policy, reflected in many directives from the Government and ministries. Directive No. 10-CT/TW of the Politburo on strengthening career guidance and Resolution 29-NQ/TW on fundamental and comprehensive innovation in educat... and training both emphasize the need to enhance practical experience activities and integrate production and business content into the curriculum [26, 27]. However, the implementation of this policy still faces many obstacles. Research by Pham and Dang [28] has pointed out the main difficulties in collaboration between high schools and businesses, including the lack of a clear legal mechanism, differences in goals and culture between the two parties, and resource limitations (time, funding, personnel). Therefore, students' scientific research projects can become a potential "intermediate space", a flexible bridge for both sides to collaborate on solving specific problems, thereby promoting this link more naturally and effectively.

2.4. Identifying the Research Gap

Synthesizing international theories and the situation in Vietnam, the research gap becomes clear. Studies have clarified (1) the structure and role of modern competency frameworks, (2) the multifaceted nature of scientific research competency as a set of "scientific practices", and (3) the effectiveness of educational models that integrate school and practice. However, a significant research gap remains: the absence of a systematically constructed scientific research competency framework, specifically for high school students, that simultaneously integrates three elements: (a) the rigor of scientific practices, (b) the authenticity of problems sourced from practical production, and (c) a competency development pathway appropriate for the psychological age and context of high school education. Existing frameworks are either too general (like the 21st-century skills frameworks), too specialized for higher education (like the CUREs models), or focus solely on purely academic scientific research skills without encompassing other crucial competencies such as identifying innovation opportunities in an industrial process, design thinking and prototyping, or analyzing techno-economic feasibility.

Therefore, this study is conducted to fill this gap by developing a comprehensive competency framework that serves as a "roadmap" for both teachers and students on the journey of connecting scientific knowledge with the vibrant world of production.

3. METHODS

To achieve the objective of developing and validating the Scientific Research Competency Framework linked to practical production for high school students, an exploratory sequential mixed-methods design was applied [29]. This design consists of two main phases: (1) an initial qualitative research phase to explore and construct a draft competency framework, followed by (2) a quantitative research phase to validate and refine that framework. The overall research process is illustrated in Figure 1.

3.1. Phase 1: Developing the Draft Competency Framework (Qualitative Research)

Objective: To identify the competency domains and component competencies necessary for high school students when conducting scientific research projects linked to practical production.

Methods:

- Systematic Literature Review: Analyzing existing competency frameworks, STEM education models, project-based learning, and studies on school-business collaboration to identify an initial set of competencies.

- Semi-structured In-depth Interviews: In-depth interviews were conducted with 18 experts. The selection of these experts was purposeful, based on predefined criteria to ensure a diversity of perspectives from academia, industry, and educational practice. The criteria included having at least 10 years of experience in their respective fields and direct involvement with student research, curriculum development, or industry-based training. Table 1 provides a detailed breakdown of the interview participants.

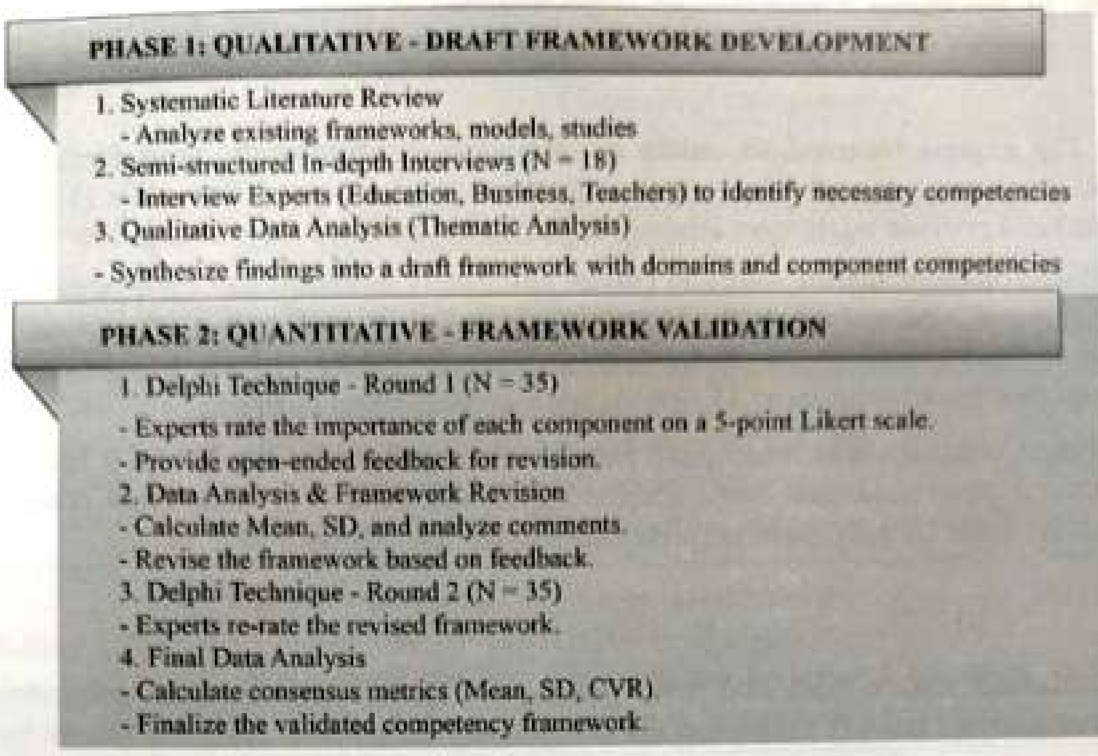

Figure 1. The Exploratory Sequential Mixed-Methods Research Design

Table 1. Characteristics of In-depth Interview Participants (N = 18)

Category	Sub-Group	Number	Professional Roles & Experience
Education Experts	University Professors	5	Professors in Chemistry Education, Pedagogy, and Educational Management with experience in curriculum design and guiding student research.
	Education Managers	3	Principals and vice-principals of high schools with established STEM programs; managers from Departments of Education and Training.
Business & Industry Professionals	R&D Managers	4	Managers from chemical, food processing, and environmental technology companies, directly involved in product development and innovation.
	Production Engineers	3	Engineers with extensive experience in optimizing production lines and solving technical problems in factories.
High School Teachers	Experienced Teachers	3	Veteran Chemistry teachers who have successfully mentored students in national science fairs (VISEF).

Data Analysis: The interviews were audio-recorded, transcribed, and analyzed using thematic analysis [30]. A set of initial codes was derived from the literature review, and new codes emerged from the interview data. These codes were then grouped into broader themes, which formed the basis for the competency domains and component competencies of the draft framework.

3.2. Phase 2: Validating and Finalizing the Competency Framework (Quantitative Research - Delphi Technique)

Objective: To assess the importance and appropriateness of each component in the draft competency framework, thereby achieving a high level of consensus among experts.

Method:

The Delphi technique: A two-round Delphi survey was conducted. This method is highly effective for achieving consensus among a group of experts on a complex issue without face-to-face interaction, thus minimizing bias [31].

Participants (Delphi Panel): A panel of 35 experts was established. These experts were selected based on similar rigorous criteria as in Phase 1, but with an added requirement of having published articles, patents, or managed recognized innovation projects. The panel included 15 university professors in relevant fields, 10 industry professionals (R&D, production), and 10 experienced high school teachers and educational managers. None of the Phase 1 interviewees were included in the Delphi panel to ensure independent validation.

Procedure:

Round 1: The experts received an online questionnaire containing the draft framework. They were asked to rate the importance of each component competency on a 5-point Likert scale (1 = Not important, 5 = Very important) and provide qualitative comments for any component they rated below 4.

Round 2: Based on the statistical analysis (Mean, Standard Deviation) and the qualitative feedback from Round 1, the framework was revised. Items with low consensus or constructive suggestions were rephrased or clarified. The revised questionnaire, along with a summary of the group's anonymous responses from Round 1, was then sent back to the same 35 experts for a second round of rating.

Data Analysis: Consensus was determined based on two criteria for the Round 2 results: a mean score (M) of ≥ 4.0 on the 5-point scale and a low standard deviation (SD) of ≤ 1.00. The Content Validity Ratio (CVR) was also calculated for each item to further strengthen the validation.

4. RESULTS

The study obtained results from two main phases: (1) Developing the draft competency framework through qualitative analysis and (2) Validating the competency framework using the Delphi technique.

4.1. Phase 1 Results: Developing the Draft Competency Framework

Thematic analysis of the literature and interview data resulted in a draft framework comprising 5 main competency domains and 18 specific component competencies. The structure was designed to mirror the entire lifecycle of a practice-oriented research project, moving from problem identification to solution transfer.

4.2. Phase 2 Results: Validating the Competency Framework

The two-round Delphi process yielded a high degree of consensus among the 35 experts. In the final round, all 18 component competencies achieved a mean score above 4.63 (out of 5) and a standard deviation below 0.55, far exceeding the pre-set consensus thresholds ($M \geq 4.0$, $SD \leq 1.00$). This indicates strong agreement from the expert panel on the importance and appropriateness of all elements within the framework.

The validated Scientific Research Competency Framework for High School Students (Practice-Oriented) is summarized in Table 2.

The validation process was carried out through two online Delphi rounds with 35 experts. The reliability of the evaluation scale was very high, with Cronbach's Alpha values of 0.945 (Round 1) and 0.958 (Round 2), indicating strong consistency and stability in expert ratings.

Round 1 Results

In the first round, most of the proposed competencies were rated highly in terms of importance and relevance. Based on expert feedback, overlapping competencies were merged, and less context-appropriate ones for the high school setting were removed. Specifically, the competencies "Economic feasibility analysis" and "Intellectual property analysis" were combined and revised into a new competency: "Assessing application potential and product development orientation". The revised framework (version 2.0) consisted of five main domains and 18 component competencies for use in the second round of evaluation.

Round 2 Results and Final Framework

In the second round, experts continued to evaluate the revised framework. The results showed a very high level of consensus. All 18 component competencies achieved mean scores ranging from 4.63 to 4.91 on a 5-point scale, with very low standard deviations (0.29–0.55). These results confirm the experts' strong agreement on the importance and appropriateness of all competencies in the framework. Detailed statistics are presented in Table 3, and the final version of the competency framework comprises five main domains with 18 component competencies.

Table 2. The Validated Scientific Research Competency Framework

Competency Domain	Component Competencies
D1: Identifying and Contextualizing Problems	C1. Observe and explore problems from the real production context. C2. Collect and review multi-source information C3. Analyze context and identify boundaries/stakeholders C4. Develop practically significant research problems.
D2: Designing and Planning Solutions	C5. Propose hypotheses or technical solutions. C6. Select appropriate research methods and tools. C7. Design experimental or fabrication processes C8. Plan and manage the project (time, resources, personnel)
D3: Implementing and Prototyping	C9. Conduct experiments, surveys, or investigations. C10: Develop models, prototypes, or products. C11. Apply specific principles and techniques according to the object (e.g., ensuring safety in chemical experiments, using simulation software).
D4: Analyzing, Evaluating, and Optimizing	C12. Analyze and visualize data C13. Evaluate the effectiveness and limitations of the solution/prototype. C14. Identify and resolve errors and limitations. C15. Propose improvements and optimizations
D5: Communicating and Transferring Results	C16. Write a well-structured scientific report C17. Present and defend results persuasively C18. Assess application potential and product development orientation

Table 3. Validation results of the Scientific Research Competency Framework (Delphi Round 2)

Competency Domain	Component Competency	Mean	SD
D1: Identifying and Contextualizing Problems	C1. Observe and explore problems from the real production context.	4.91	0.29
	C2. Collect and review multi-source information	4.86	0.35
	C3. Analyze context and identify boundaries/stakeholders	4.77	0.42
	C4. Develop practically significant research problems.	4.89	0.32
D2: Designing and Planning Solutions	C5. Propose hypotheses or technical solutions.	4.83	0.38
	C6. Select appropriate research methods and tools.	4.74	0.44
	C7. Design experimental or fabrication processes	4.80	0.41
	C8. Plan and manage the project (time, resources, personnel)	4.69	0.47
D3: Implementing and Prototyping	C9. Conduct experiments, surveys, or investigations.	4.86	0.35
	C10: Develop models, prototypes, or products.	4.91	0.29
	C11. Apply specific principles and techniques according to the object (e.g., ensuring safety in chemical experiments, using simulation software).	4.80	0.41

Competency Domain	Component Competency	Mean	SD
D4: Analyzing, Evaluating and Optimizing	C12. Analyze and visualize data	4.71	0.46
	C13. Evaluate the effectiveness and limitations of the solution/prototype.	4.83	0.38
	C14. Identify and resolve errors and limitations.	4.63	0.55
	C15. Propose improvements and optimizations	4.77	0.42
D5: Communicating and Transferring Results	C16. Write a well-structured scientific report	4.89	0.32
	C17. Present and defend results persuasively	4.86	0.35
	C18. Assess application potential and product development orientation	4.66	0.54

Note: 5-point Likert scale (1 = Not important, 5 = Very important). N = 35.

The final validation confirmed a comprehensive and logically structured scientific research competency framework, comprising 5 competency domains and 18 component competencies, ready for application in educational practice.

5. DISCUSSION AND IMPLICATIONS

The validation of the practice-oriented scientific research competency framework marks a significant step towards bridging the gap between academic learning and industrial practice in Vietnamese high school education. The strong consensus from a diverse panel of experts confirms the framework's relevance and structural integrity. This section discusses the theoretical contributions, practical implications, and inherent limitations of the study.

5.1. Theoretical and Practical Contributions

Theoretically, this framework enriches the literature on competency-based education by offering a model that is not only grounded in established theories of situated and authentic learning [22, 23] but is also specifically tailored to the context of a developing nation's educational reform goals. Unlike general 21st-century skills frameworks or those designed for higher education, this framework operationalizes the entire research process from an industry-facing perspective, integrating elements of design thinking, prototyping, and techno-economic feasibility analysis (C4, C10, C14), which are often absent in purely academic research models.

Practically, the framework provides a concrete roadmap for multiple stakeholders. For policymakers, it offers a structured model to inform the design of programs aimed at strengthening school-business partnerships, a key objective of Vietnam's national education strategy [26, 27]. For educators, it serves as a curriculum design tool for developing STEM and Project-Based Learning modules that are authentically linked to local industries. The inclusion of a detailed guide with assessment rubrics and behavioral indicators directly addresses the critique of many frameworks being too abstract for classroom use [14], providing teachers with a ready-to-use tool for evaluation.

Furthermore, the framework's design inherently addresses the need for subject-specific application. For instance, when applying this framework to Chemistry, Component Competency C11 (Apply subject-specific principles and techniques) becomes critical. This would involve students demonstrating proficiency in areas unique to chemical research, such as handling chemicals safely, performing stoichiometric calculations, operating laboratory equipment (e.g., titration, distillation apparatus), interpreting spectroscopic data, and using chemical modeling software. This adaptability ensures the framework is not a one-size-fits-all solution but a versatile scaffold that respects the unique methodologies of different scientific disciplines.

5.2. Challenges and Proposed Solutions for Implementation in Vietnam

Despite its potential, the successful implementation of this framework within the Vietnamese context faces considerable challenges. The discussion with experts in Phase 1 highlighted several critical barriers:

Systemic Constraints: The current high school curriculum is often perceived as overloaded, leaving little room for extensive, project-based activities. Furthermore, a lack of robust legal and financial mechanisms often hinders the establishment of sustainable partnerships between schools and businesses [28].

Resource Limitations: Many schools, particularly in rural areas, lack the modern laboratory facilities and equipment necessary for students to conduct industry-relevant research.

Teacher Capacity: While dedicated, many teachers may not have the training or practical industry experience required to guide students effectively in practice-oriented projects.

Rather than merely identifying these problems, this study proposes a multi-pronged approach to mitigate them, based on expert suggestions:

1. Establish School-Business Networks: Creating regional networks facilitated by local Departments of Education and business associations could formalize partnerships, making it easier for schools to find mentors and project opportunities for students.

2. Leverage Technology to Overcome Resource Gaps: For schools with limited physical labs, the use of virtual laboratories and simulation software can provide a cost-effective alternative for students to learn experimental design and data analysis. The integration of AI-powered tools can also support students in literature searches, data processing, and even hypothesis generation, democratizing access to advanced research capabilities.

3. Professional Development for Teachers: Implementing "teacher externship" programs, where educators spend time in industrial settings, could provide them with invaluable practical insights to bring back to the classroom.

5.3. Limitations of the Study

The primary limitation of this research is the absence of a pedagogical experiment to test the framework's effectiveness in a real-world classroom setting. While the framework has been robustly validated by experts, its impact on student competency development, engagement, and career orientation has not yet been empirically measured. The feasibility of implementing such a comprehensive framework, given the challenges discussed above, also remains to be demonstrated through practice. Secondly, while designed to be adaptable, the current study did not conduct a deep comparative analysis of how the framework would manifest across different science subjects (e.g., Chemistry vs. Biology vs. Physics), which could reveal important subject-specific nuances.

6. CONCLUSIONS

This study has successfully developed and validated a comprehensive Scientific Research Competency Framework oriented toward practical application for high school students. By integrating the demands of practical production with the rigor of scientific practices, this competency framework provides a clear roadmap for enhancing the quality and relevance of scientific research activities in schools. It not only equips students with the necessary skills to succeed in the 21st century but also contributes to strengthening the crucial link between education and industry, thereby promoting the country's socioeconomic development.

This framework, however, should not be viewed as a static endpoint, but rather as a dynamic catalyst for pedagogical innovation. Its true value lies in its potential to be integrated into the national 2018 General Education Curriculum, serving as a foundational guide for redesigning STEM education modules, fostering authentic project-based learning, and providing meaningful career guidance for students.

The proposed competency framework can be used as a versatile tool for policymakers, educational administrators, teachers, and students. It can guide curriculum development, design project-based learning activities, and create more authentic assessment criteria. More importantly, it can inspire a generation of young innovators who are capable of seeing the connections between the knowledge they learn in the classroom and the challenges and opportunities in the world around them.

To fully realize the potential of this competency framework, a collective commitment from all stakeholders is needed. Schools need to create flexible and supportive learning environments, businesses need to be more open to collaborating with educators, and policymakers need to create favorable conditions for this collaboration. By working together, we can build a solid bridge between theory and practice, and empower students to become problem solvers and change makers for the future.

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