

A STRUCTURAL MODEL OF SCIENTIFIC CREATIVITY COMPETENCE FOR HIGH SCHOOL STUDENTS: THEORETICAL FOUNDATIONS AND A PRELIMINARY SURVEY FRAMEWORK

UM MODELO ESTRUTURAL DA COMPETÊNCIA EM CRIATIVIDADE CIENTÍFICA PARA ALUNOS DO ENSINO MÉDIO: FUNDAMENTOS TEÓRICOS E UM QUADRO DE PESQUISA PRELIMINAR

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Abstract

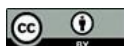
This article proposes a structural model of scientific creativity competence (MSCC) for high school students grounded in competency-based education and the methodological characteristics of school scientific activity. Drawing on an analysis and synthesis of studies on scientific creativity, creativity in STEM education, competency assessment, and general education, the study conceptualizes scientific creativity competence as the ability to mobilize knowledge, skills, attitudes, and higher-order cognitive processes to generate ideas, solutions, or products that are both novel and consistent with scientific standards at a level appropriate for high school students. The proposed model comprises four dimensions: identifying and detecting scientific problems (PRB), generating and proposing ideas for solving scientific problems (IDE), designing and implementing problem-solving plans (DES), and evaluating, revising, and refining scientific solutions (EVA). Based on this structure, the article introduces a set of 16 behavioral indicators and a preliminary survey framework to examine the model's initial appropriateness, clarity, and feasibility in the context of high school science teaching.

Keywords: Scientific Creativity Competence. High School Students. Stem Education. Structural Model. Behavioral Indicators.

Resumo

Este artigo propõe um modelo estrutural da competência em criatividade científica (MSCC) para alunos do ensino médio, fundamentado na educação baseada em competências e nas características metodológicas da atividade científica escolar. Com base na análise e síntese de estudos sobre criatividade científica, criatividade na educação STEM, avaliação de competências e educação geral, o estudo conceitua a competência em criatividade científica como a capacidade de mobilizar conhecimentos, habilidades, atitudes e processos cognitivos de ordem superior para gerar ideias, soluções ou produtos que sejam inovadores e consistentes com os padrões científicos, em um nível adequado para alunos do ensino médio. O modelo proposto compreende quatro dimensões: identificar e detectar problemas científicos (PRB), gerar e propor ideias para a resolução de problemas científicos (IDE), projetar e implementar planos de resolução de problemas (DES) e avaliar, revisar e refinar soluções científicas (EVA). Com base nessa estrutura, o artigo apresenta um conjunto de 16 indicadores comportamentais e uma estrutura de pesquisa preliminar para examinar a adequação inicial, a clareza e a viabilidade do modelo no contexto do ensino de ciências no ensino médio.

Palavras-chave: Competência em Criatividade Científica. Alunos do Ensino Médio. Educação



1 INTRODUCTION

In contemporary education, the development of higher-order competencies has increasingly become a central orientation of curricula and instructional activities (González-Pérez & Ramírez-Montoya, 2022; Herodotou et al., 2019; Kwangmuang et al., 2021). Alongside problem-solving ability, critical thinking, and collaboration, creativity is regarded as a core competence that enables learners to adapt to rapidly changing knowledge environments, interdisciplinary challenges, and the demand for innovation in social life (Chalkiadaki, 2018; Bao & Koenig, 2019; Thornhill-Miller et al., 2023; Zhang et al., 2024; Ye & Xu, 2023). In science education, creativity is not merely the ability to generate new ideas; it also involves identifying problems, formulating hypotheses, designing procedures to test them, selecting evidence, and refining solutions on the basis of scientific reasoning (DeHaan, 2009; Lu et al., 2020; Schaller et al., 2023; Tan et al., 2022).

In international research, scientific creativity has been viewed as a domain-specific form of creativity shaped by disciplinary knowledge, rules of reasoning, and the methodological norms of science (Gómiz-Aragón et al., 2025; Kwangmuang et al., 2021; Tan et al., 2022). This perspective indicates that scientific creativity cannot be equated with creativity in general, nor can it be assessed solely through broad divergent-thinking tests (Thornhill-Miller et al., 2023; Zhang et al., 2024). Conversely, if science education focuses primarily on scientific knowledge while paying insufficient attention to the processes of problem identification, idea generation, experimentation, and solution refinement, the development of scientific creativity in schools is unlikely to be substantively effective (Demircioğlu et al., 2022; Lu et al., 2020; Tan et al., 2022).

In Vietnam, the reform of general education toward the development of students' qualities and competencies has created an important foundation for researching domain-specific competencies in science teaching (Bui & Khuu, 2020; Nguyen et al., 2023; Ministry of Education and Training, 2018; Chau, 2026). However, most domestic studies

have concentrated on related constructs such as ‘creativity competence’, ‘creative thinking’, or ‘problem-solving-and-creativity competence’, whereas studies that directly address the structure of scientific creativity competence among high school students remain relatively limited (Vu et al, 2024; Chau, 2026; Suherman et al., 2025). This gap creates the need to define more clearly the concept, structural dimensions, and system of behavioral indicators of scientific creativity competence as a foundation for both teaching and assessment (Gómez-Aragón et al., 2025; Herodotou et al., 2019; Ye & Xu, 2023).

Against this background, the article pursues two objectives. First, it establishes the theoretical foundations for proposing an MSCC for high school students (Gómez-Aragón et al., 2025; Lu et al., 2020). Second, it develops a system of behavioral indicators and a preliminary survey framework to examine the model’s initial appropriateness in the context of high school science teaching (Calavia et al., 2021; Demircioğlu et al., 2022; Lu et al., 2020).

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Scientific creativity competence as a domain-specific competence

From the perspective of competency-based education, competence is understood as the ability to mobilize knowledge, skills, attitudes, and contextual conditions in an integrated manner in order to accomplish a meaningful task successfully. This approach emphasizes the distinction between accumulated knowledge and the capacity for action; in other words, learners must not only ‘know’ but also be able to ‘do’ in specific situations. On this basis, creativity is regarded as a domain-specific competence expressed in the ability to produce ideas or products that are novel and valuable within a particular context (Ministry of Education and Training, 2018; Lucas, 2016; Kelley & Knowles, 2016).

In the domain of science, creativity must be linked to the methodological characteristics of scientific research and learning. Hu and Adey (2002) argued that scientific creativity should be approached as a domain-specific competence manifested through tasks such as problem finding, scientific imagination, proposing experiments, improving products, and solving scientific problems. Subsequent studies have continued

to affirm that scientific creativity depends not only on divergent thinking but also on convergent thinking, metacognition, domain knowledge, the ability to evaluate evidence, and cognitive control (De Vries & Lubart, 2019; Sternberg et al., 2020; Lebuda & Benedek, 2023).

From the perspective of cognitive psychology, scientific creativity results from the coordination of multiple higher-order cognitive processes such as controlled attention, memory, imagination, remote association, divergent thinking, convergent thinking, and metacognition. This coordination helps learners identify anomalies in phenomena or data, generate multiple solution paths, select appropriate solutions, and continuously monitor and regulate their own thinking processes (Benedek & Fink, 2019; Jia et al., 2019; Gu et al., 2025). Therefore, the structure of scientific creativity competence cannot be described by a single overall index; it needs to be interpreted in terms of logically related dimensions.

2.2 Research gap and the need to build a structural model

A growing body of international research has shown that learning environments rich in problems, experimentation, and feedback exert a positive influence on students' scientific creativity. Studies on CASE, problem-based learning, project-based learning, and STEM education all converge in suggesting that students develop scientific creativity more clearly when they participate in cycles of problem identification, idea generation, experimentation, and solution improvement (Lin et al., 2003; Aguilera & Ortiz-Revilla, 2021; Tran, 2024; Pinar et al., 2025). However, to organize instruction intentionally in this direction, it is first necessary to have a sufficiently clear structural model of competence to orient objectives, content, learning activities, and assessment.

Drawing on the synthesis of theory and in congruence with the Vietnamese general education context, this article conceptualizes scientific creativity competence among high school students as the ability to mobilize, coordinate, and effectively regulate higher-order cognitive processes while solving specialized scientific tasks in order to generate ideas, solutions, or products that are both novel and consistent with scientific standards at a level appropriate to students' age. This concept highlights the domain-

specific nature of scientific creativity while remaining consistent with competency-based orientations in the general education curriculum.

3 METHODOLOGY

3.1 Research design

The study combines literature analysis and synthesis with the design of a preliminary survey instrument. First, literature related to scientific creativity, competency assessment, STEM education, science teaching, and competency development in schools was selected, analyzed, and systematized. This synthesis was intended to establish the scientific basis for defining scientific creativity competence, identifying its structural dimensions, and constructing a corresponding system of behavioral indicators.

On that basis, the study proposes MSCC for high school students as a second-order construct in which PRB, IDE, DES, and EVA function as first-order constructs. Each dimension is expressed through a set of behavioral indicators that can be observed, described, or transformed into survey items.

3.2 Preliminary survey framework

To examine the initial appropriateness of the proposed structural model of scientific creativity competence, a preliminary survey was conducted with 32 participants, including 24 high school teachers of physics, chemistry, and biology and 8 lecturers/experts in science education or STEM education. Participants were selected through purposive convenience sampling based on criteria related to experience in teaching, research, or professional activities associated with science education and the development of student competencies. The survey was carried out from February to March 2026 in several high schools and teacher education institutions in Ho Chi Minh City and surrounding areas. Data were collected through both paper-based questionnaires and online forms. A total of 34 questionnaires were returned; after screening and removing 2 questionnaires with incomplete or inconsistent responses, 32 valid questionnaires were retained for analysis. The survey instrument was a five-point Likert-

scale questionnaire ranging from 1 = completely inappropriate to 5 = highly appropriate. The data were analyzed using descriptive statistics, including frequency, percentage, mean, and standard deviation.

Table 1

Preliminary Survey Framework

Content	Illustrative description
Survey participants	High school teachers of physics, chemistry, and biology; lecturers and experts in science education/STEM education
Sample size	32 participants
Sample composition	24 high school teachers; 8 lecturers/experts
Survey period	February-March 2026
Sites/institutions	Several high schools and teacher education institutions in Ho Chi Minh City and surrounding areas
Survey mode	Online and face-to-face
Sampling method	Purposive convenience sampling
Questionnaires returned	34
Valid questionnaires	32
Valid response rate	94.1%
Instrument	Five-point Likert questionnaire; may include open-ended items
Analytical indices	Frequency, percentage, mean, standard deviation

Source: Author's research results.

4 RESULTS AND DISCUSSION

4.1 Structural model of scientific creativity competence

The primary outcome of the study is a structural model of scientific creativity competence (MSCC), which consists of four dimensions systematically coordinated with the progression of scientific activity. The first dimension, identifying and detecting scientific problems (PRB), initiates the creative cycle because it concerns the ability to recognize anomalies, contradictions, or knowledge gaps in scientific phenomena, data, or

arguments. This dimension provides the basis for formulating questions and determining possible directions for problem solving.

The second dimension, generating and proposing ideas for solving scientific problems (IDE), reflects the ability to mobilize prior knowledge in combination with scientific imagination and divergent thinking in order to propose multiple alternatives for the same problem. Within this dimension, novelty, flexibility, fluency, and the capacity to connect interdisciplinary knowledge are especially important. Unlike artistic creativity, however, scientific ideas must not only be new but also logical, explainable, and testable.

The third dimension, designing and implementing problem-solving plans (DES), translates ideas into concrete action. At this stage, students are expected to construct plans, select tools and means, organize experiments or models, collect and process data, and adjust their approach when encountering obstacles. This dimension clarifies that scientific creativity does not end with coming up with ideas; it must be realized through an organized course of action.

The fourth dimension, evaluating, revising, and refining scientific solutions (EVA), completes the cycle while simultaneously opening new loops of scientific creativity. Here, students need to compare results with objectives, identify the strengths and limitations of a solution, propose directions for improvement, and derive lessons that can be applied to other situations. The EVA dimension clearly highlights the role of metacognition, critical thinking, and executive functions in scientific creative activity.

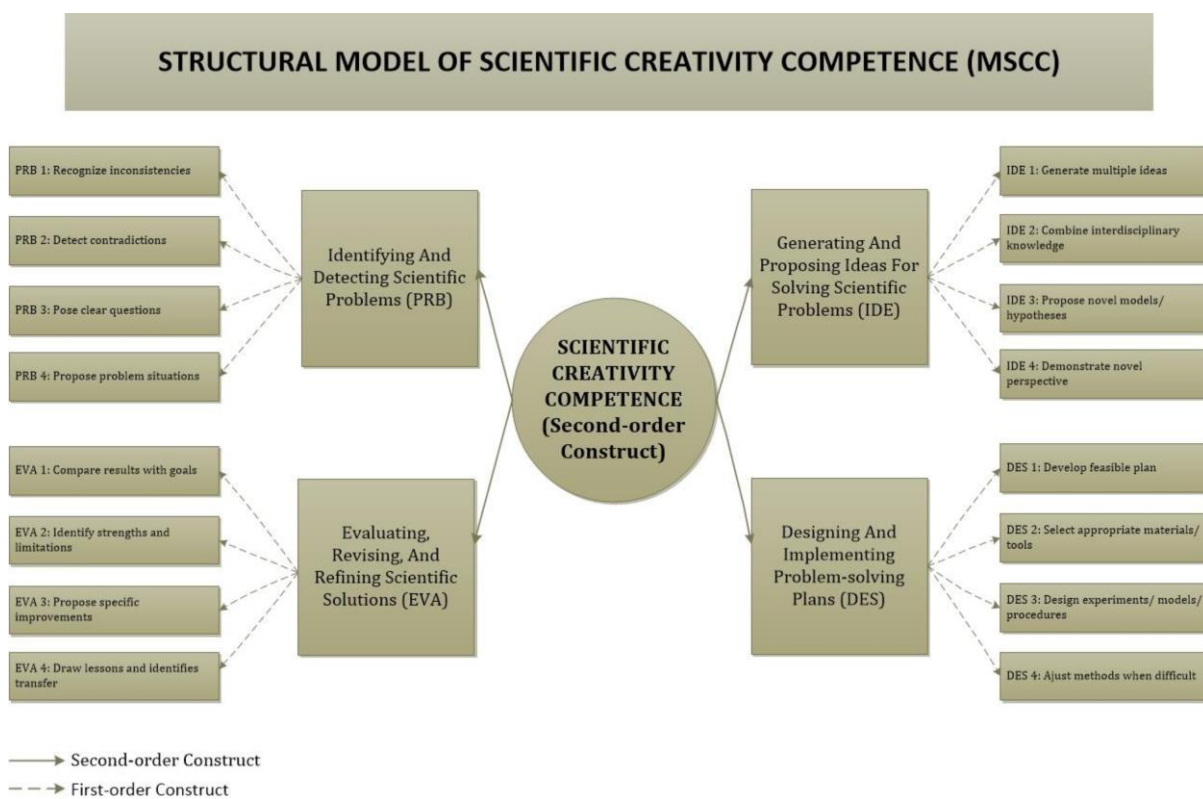
These four dimensions do not exist in isolation; they are linked within a dynamic system. In process terms, PRB begins with problem identification, IDE generates solution possibilities, DES realizes the selected alternative, and EVA provides a feedback mechanism for adjusting or restructuring the entire process. In educational terms, this model suggests that the development of scientific creativity competence should be designed as a chain of learning activities involving problems, experimentation, critique, and solution refinement, rather than being limited to tasks that merely require the reproduction of knowledge.

4.2 System of behavioral indicators in the model

Based on the four dimensions, the article proposes a system of 16 behavioral indicators to operationalize the model. This system both reflects the conceptual content of each dimension and can be transformed into observational criteria or survey items. This is a crucial step because, without clear behavioral indicators, scientific creativity competence can easily remain at a highly general level and become difficult to use in instructional design and assessment.

Figure 1

Structural Model of Scientific Creativity Competence



From an applied perspective, the preliminary survey framework serves as an intermediate step between theoretical research and more in-depth quantitative research. The preliminary survey is not intended to fully validate the structure of the model; rather, it mainly examines teachers' and experts' initial acceptance of the proposed dimensions and indicators. On that basis, the indicators can be refined in terms of content, wording,

and feasibility before being further developed into a comprehensive measurement scale or assessment rubric for experimental research.

Table 2

Behavioral Indicators of Scientific Creativity Competence

Dimension	Code	Behavioral indicator
PRB	PRB1	Recognize inconsistencies between observed phenomena and previously learned scientific knowledge.
PRB	PRB2	Detect contradictions or unreasonable points in scientific data or arguments.
PRB	PRB3	Pose clear scientific questions linked to learning content or real-life contexts.
PRB	PRB4	Propose problem situations derived from lessons, experiments, or natural phenomena.
IDE	IDE1	Generate multiple ideas or alternative solutions for the same problem.
IDE	IDE2	Combine knowledge from different topics or subjects to form new ideas.
IDE	IDE3	Propose explanations, models, or hypotheses that differ from conventional approaches.
IDE	IDE4	Demonstrate a novel perspective on a scientific problem or situation.
DES	DES1	Develop a feasible implementation plan with appropriate steps, time allocation, and required resources.
DES	DES2	Select and use materials, tools, equipment, and information resources appropriately.
DES	DES3	Design suitable experiments, models, or procedures; collect and process data systematically.
DES	DES4	Actively adjust methods and test alternative options when difficulties arise.
EVA	EVA1	Compare results with predefined goals and criteria to evaluate solution effectiveness.
EVA	EVA2	Identify strengths and limitations of the solution and compare it with alternative options.
EVA	EVA3	Propose specific adjustments or improvements to enhance solution quality.
EVA	EVA4	Draw lessons learned and identify possibilities for transfer to new situations.

Source: Author's research results.

Table 3*Appropriateness of the Dimensions in the Proposed Model*

Dimension	Number of indicators	Mean	Standard deviation	Interpretation
PRB	4	4.32	0.51	Highly appropriate
IDE	4	4.41	0.47	Highly appropriate
DES	4	4.18	0.56	Appropriate
EVA	4	4.27	0.49	Highly appropriate
Whole model	16	4.30	0.43	Highly appropriate

Source: Author's research results.

4.3 Implications for instructional design and assessment

The preliminary survey results show that IDE obtained the highest mean score ($M = 4.41$), indicating that respondents tended to rate highly the indicators related to generating and proposing ideas for solving scientific problems. DES received a relatively lower mean score ($M = 4.18$), suggesting that in subsequent research the group of indicators related to designing and implementing plans should be reviewed more carefully in terms of wording, clarity, and compatibility with real teaching conditions. Overall, the model's mean score of 4.30 indicates that the proposed model can be regarded as having a high level of appropriateness.

The MSCC framework suggests that the development of scientific creativity competence should be organized as a sequence of interconnected learning experiences. In science teaching, teachers need to create sufficiently open problem situations so that students can identify contradictions, formulate questions, and propose hypotheses, while also providing space for them to design, test, compare, and refine solutions. This orientation is especially compatible with approaches such as STEM education, project-based learning, problem-based learning, and inquiry-based learning, in which learning extends beyond receiving knowledge toward constructing and validating knowledge in real contexts.

From the perspective of assessment, the system of behavioral indicators can be used flexibly in three ways: (i) to build preliminary survey questionnaires for collecting

feedback from experts and teachers; (ii) to develop observation rubrics for classroom learning tasks; and (iii) to be refined into quantitative measurement scales in subsequent studies. Moving from preliminary survey instruments to fully developed assessment tools can help reduce the risk of describing competence only at a general level and generate clearer evidence regarding the quality of the model.

5 CONCLUSION

This article has clarified the theoretical basis for approaching scientific creativity competence as a domain-specific competence in school science education. Based on a synthesis of relevant studies, scientific creativity competence among high school students is proposed as a structure comprising four dimensions: identifying and detecting scientific problems (PRB), generating and proposing ideas for solving scientific problems (IDE), designing and implementing problem-solving plans (DES), and evaluating, revising, and refining scientific solutions (EVA). This model reflects, with reasonable completeness, the course of scientific creative activity, from problem identification to idea generation, plan implementation, and solution evaluation and refinement.

An important contribution of the article is the systematization of 16 behavioral indicators corresponding to the four structural dimensions, thereby creating a foundation for identifying, describing, and surveying scientific creativity competence in the context of school teaching. On this basis, the study developed and implemented a preliminary survey framework to examine the model's initial appropriateness. The survey results show that all dimensions of the model were rated as appropriate, with IDE obtaining the highest mean score, DES obtaining a relatively lower yet still appropriate mean score, and the model as a whole being rated highly appropriate. These findings provide preliminary evidence that the proposed model has acceptable content validity and has potential for use in both research and the practice of science teaching in high schools.

Nevertheless, the study still has several limitations. First, the survey remains preliminary and mainly serves to examine the initial appropriateness, clarity, and feasibility of the dimensions and indicators in the model; therefore, it does not yet provide sufficient evidence to confirm the measurement structure of scientific creativity competence with certainty. In addition, the present data analysis relies primarily on

descriptive statistics and has not yet incorporated more advanced quantitative analyses such as reliability testing, factor analysis, or measurement-model testing on a larger sample. Moreover, the applicability of the behavioral indicators across different teaching contexts still needs to be examined through experimental studies.

Accordingly, future research should continue refining the indicator system, expanding the scope of the survey, and conducting empirical validation on larger and more diverse samples and contexts. At the same time, MSCC needs to be developed into concrete assessment tools such as questionnaires, observation rubrics, or sets of criteria for evaluating scientific and STEM learning tasks. Further refinement of the model would not only strengthen the theoretical foundations of scientific creativity competence but also offer practical value for instructional design and assessment in line with competency-based education in schools today.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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