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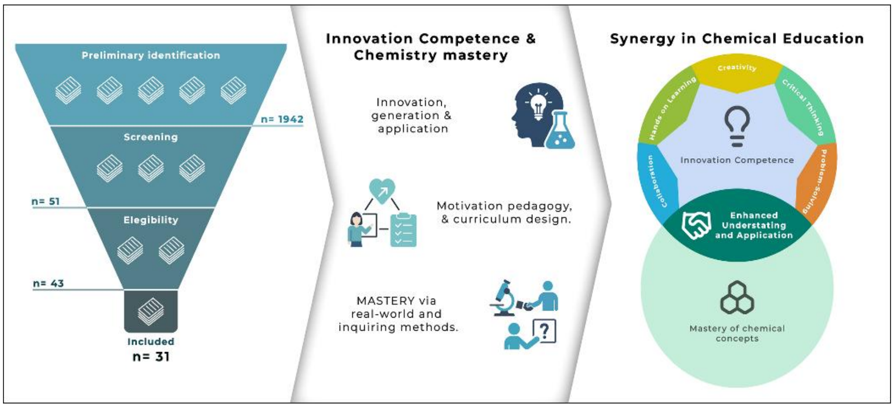
Exploring the interplay of innovation competence and chemistry mastery: insights from educational practices and factors of influence

Norliyana binti Md. **Aris**[1+], Nor Hasniza binti **Ibrahim**[1], Noor Dayana Binti Abd **Halim**[1], Johari bin **Surif**[1]

Abstract

Innovation competence is a critical skill today, enabling individuals to generate and apply innovative ideas. Its influence on students' mastery of chemical concepts and the factors shaping this relationship remain underexplored. This scoping review analyzes 31 studies to address three research questions: (1) How does innovation competence influence students' mastery of chemical concepts? (2) What factors shape this relationship? (3) What strategies can educators implement to foster innovation competence and chemical mastery? Findings reveal a positive correlation between innovation competence and chemical mastery, influenced by motivation, teaching strategies, and curriculum design. Practical strategies include problem-based learning, collaborative projects, and hands-on activities. While these insights provide valuable guidance, further research is needed to fully understand the interplay between innovation competence and chemical learning. This study offers actionable recommendations for enhancing teaching practices and advancing future research in chemistry education.



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Natany Dayani de Souza **Assai**

Highlights

- Fluency, Innovation skills link strongly with chemical concept mastery.
- Motivation and teaching design shape students learning outcomes.
- Review of 31 studies shows chemistry–innovation connections.
- Innovative methods improve skills and concept understanding.
- Educational practices significantly impact chemistry learning.

[1]University of Technology Malaysia, Faculty of Social Sciences and Humanities, Johor Bahru, Malaysia. **+Corresponding author:** Norliyana binti Md. Aris, **Phone:** +60133881723, **Email address:** liyanaaris23@gmail.com

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1. Introduction

Education is essential in fostering the development of a generation of innovators and problem solvers. The National Science, Technology, and Innovation (DSTIN) Policy 2021–2030 (MySTIE) and the Malaysian Science, Technology, Innovation, and Economic Framework 10–10 provide an overview that summarises the significance of science, technology, and innovation's (STI) role in making Malaysia a high-tech nation. By 2030 (DSTIN (2013-2030), the country needs to increase its Gross Domestic Product (GDP) to RM 3.4 trillion and reduce its dependence on foreign labor. Transforming Malaysia into a country that benefits from an ecosystem that fosters innovation is only possible if highly qualified STEM experts who can meet this demand are available. As a result, students must be prepared for professions in STEM fields with the innovative skills needed to compete globally (The United States Department of Education, 2016).

Innovation efficiency is needed to solve many global problems, especially in chemistry. The field of chemistry is also a focus area. It is linked to achieving some of the Sustainable Development Goals (SDG) of the United Nations to achieve a better and more sustainable future by 2030, such as in the field of nanotechnology, sustainable energy transition, smart cities, innovative industries, and other social and environmental issues (Droescher, 2018; Gomollón-Bel, 2020; Luo, 2018). The global world recognizes the efficiency of innovation, especially when it is considered that this factor can help prepare students to solve complex problems and positively affect individual personality quality (Atamanyuk *et al.*, 2021; OECD, 2019). Therefore, whether it is the view of scholars or educational policymakers, developing students' innovation competence is necessary to remain relevant in society (Krstikj *et al.*, 2022; Ojeda *et al.*, 2021). Cultivating innovation competence enables students to foster creativity, generate new ideas, solve problems, and identify new opportunities for problem-solving (Fredagsvik, 2023).

Chemistry students need to construct knowledge actively, work together in groups, and solve problems related to the real world (Anim-Eduful and Adu-Gyamfi, 2023). Through this method, students can be encouraged to connect the content of chemical concepts with real situations experienced by students. Innovative learning resources will be able to influence students' active learning (Clark *et al.*, 2018; Dunnigan *et al.*, 2020). In addition, carrying out a research project related to students' daily lives can enhance the mastery of analytical skills and a higher level of critical thinking skills (Jaleniauskiene and Kasperiuniene, 2022; Muna, 2021). Simultaneously, effective teaching practices can make learning chemistry more enjoyable, improve performance, and help students meet the required skills, especially in chemistry (Kalkbrenner and Horton-Parker, 2016).

One of the biggest obstacles to solving problems in a real-world context in chemistry is students' need to understand the basic concepts of chemistry (Mahaffy *et al.*, 2018). If students do not have a solid knowledge base, they may be unable to think creatively about how to apply that knowledge to solve problems (Ellah *et al.*, 2019). The study highlights chemistry students' challenges, revealing their difficulties in explaining natural phenomena based on acquired knowledge (Kanapathy *et al.*, 2019). Moreover, students encounter obstacles in problem-solving within the context of the natural world, struggling to generate diverse ideas—whether original concepts from their learned material or elaborations on existing ideas (Handayani *et al.*, 2021). High school chemistry students, despite exposure to relevant concepts, occasionally struggle with analyzing and interpreting chemical data (Lewis, 2020; Salleh *et al.*, 2023). Therefore, it highlights the need to develop innovation competence among chemistry students, which must be implemented immediately and optimally across disciplines, particularly at the secondary school level.

Recognizing the importance of meeting students' innovation competencies in equipping them to solve problems, especially the importance of chemistry in addressing real-life challenges and preparing students for the future, requires changes in the teaching and learning process. However, educational change requires dedication and transformation in the learning process. Hence, this study aims to review the synergistic relationship between innovation competence and chemical concept mastery and how their integration can enhance student learning in chemistry. Exploring this relationship aims to uncover how innovation competence and chemical concept mastery can mutually reinforce and amplify each other, resulting in more comprehensive and effective learning outcomes for students and answer the research questions:

- How does innovation competence influence the mastery of chemical concepts in students?
- What factors influence the relationship between innovation competence and mastering chemical concepts?
- What practical strategies can educators implement to foster innovation competence and mastery of chemical concepts in the classroom?

2. Method

The methodology for this study followed a scoping review framework, a structured approach well-suited for exploring emerging evidence where specific research questions or systematic review criteria are not yet clearly defined. Scoping reviews aim to examine the breadth and depth of available evidence, offering a comprehensive understanding of how research has been conducted in a field and the types of evidence available to inform practice.

This approach systematically identifies, categorizes, and maps existing studies to provide an overview of the current knowledge state while highlighting literature gaps. Framework by Arksey and O'Malley (2005) outlines four key objectives of scoping reviews: clarifying definitions and conceptual boundaries, summarizing research findings, identifying research gaps, and informing future investigations. For this review, a thorough search of relevant databases was conducted using predetermined inclusion criteria. Studies were selected, analyzed, and categorized into themes, which included definitions and measures of innovation competence, its relationship with chemical concepts, influencing factors, gaps in the literature, and implications for practice. By mapping the findings, the review delineated the existing evidence and pinpointed areas lacking rigorous investigation.

2.1. Preliminary identification

During the identification stage, research materials related to the developed research question on the relationship between innovation competence and mastery of chemical concepts were searched for. The identification process was initiated by keyword identification, where "classification of cervical cell" was one of the key phrases. Synonymous phrases were identified from dictionaries, thesauri, encyclopaedias, and previous research. With the help of these phrases, the search strings were constructed for the Web of Science and Scopus databases. Using these, an advanced search retrieved 1,942 from these databases.

Scopus: The following string was used:
TITLE-ABS-KEY (innovation AND competence AND education) AND (LIMIT-TO (SUBJAREA,"CHEM") OR LIMIT-TO (SUBJAREA,"SOCI")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (LANGUAGE,"English"))
Access date: July 2023

Web of Science: The search was done by the following search parameters: Innovation competence (All Fields) AND Article or Review Article (Document Types) AND ((2020 OR 2021 OR 2022 OR 2023) Publication Years) AND Education Educational Research (Web of Science Categories)
Access date: July 2023

2.2. Screening

In the screening phase, the retrieved research items were screened for their content to align with the research questions. The content-related criteria were directed towards the selection of studies that addressed innovation competence in education. Initial screening excluded 1,891 publications, leaving 51 papers for further review based on inclusion and exclusion criteria. The first criterion emphasized literature type, prioritizing journal articles as primary sources of practical recommendations. Reviews, meta-analyses, books, book series, chapters, and conference proceedings were excluded. Additionally, publications were restricted to English and covered a 5-year timeline (2019–2023).

Inclusion criteria: English language, journal articles, final publication stage, and topics related to chemistry education and social sciences.

Exclusion: Non-English, conference papers, reviews, and subjects not from the domain of either chemistry education or social sciences.

2.3. Eligibility

Following the inclusion and exclusion criteria, the sample to be reviewed was filtered further to ensure clarity and transparency. At this stage, 51 articles were screened, and their titles and content were reviewed in detail for confirmation of relevance to the study objectives. This resulted in 12 publications being excluded because they did not fit within the empirical, data-driven scope of the study. This resulted in 31 articles being considered for in-depth evaluation. The strict process of eligibility determination underlines rigorous methodology and therefore assures the integrity and validity of the review findings. On that basis, such a systematic approach achieved appropriate alignment with the research objectives upheld to high-quality standards for selecting the articles.

2.4. Data analysis and abstraction

A detailed data analysis was performed of data from the 31 selected publications to identify the themes of related topics and subtopics, as described by **Fig. 1**. From this analysis, three themes emerged: **(1)** the relationship between innovation competence and mastery of chemical concepts; **(2)** factors influencing that relationship; and **(3)** implications for practice. Each theme was explored for more sub-themes or ideas emerging from the evidence in the context of the research. The data were discussed in collaboration with co-authors to ensure definitive interpretations and alignment with the research objectives. The results were reviewed to address any inconsistencies in the thematic analysis, ensuring the clarity, relevance, and appropriateness of the sub-themes. To avoid redundancy or confusion, the review focused exclusively on studies that directly aligned with the core research themes. This included only studies that explored the relationship between innovation competence and mastery of chemistry, as these were central to the research topic. By narrowing the scope in this way, the review provided a more focused and meaningful exploration of the factors influencing innovation competence and chemistry mastery within educational practices.

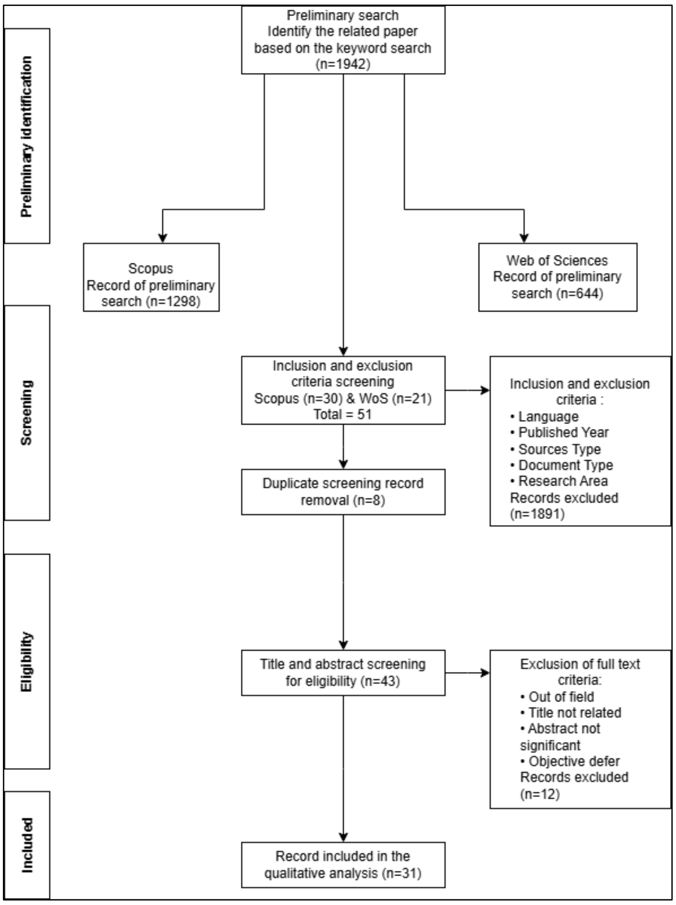

Figure 1. Flowchart of study selection adapted from PRISMA Statement.
Source: Guidance for Conducting Systematic Scoping Reviews (Peters *et al.*, 2015).

3. Result and discussion

3.1. How does innovation competence influence the mastery of chemical concepts in students?

Innovation competence contributes much to the students' mastering of chemical concepts, deepens their theoretical knowledge and practical skills, and develops their innovative thinking and active learning (Laliyo *et al.*, 2023; Rusmansyah *et al.*, 2019). It gives students the power to effectively present their ideas and solve problems that deepen their knowledge of chemical concepts (Margallo *et al.*, 2019). In these innovative activities of hands-on experiments, design challenges, and problem-based learning, the connection of theory with real situations is made (A. Solodikhina and M. Solodikhina, 2023); chemistry becomes more relevant and meaningful. These approaches not only enhance their mastery of chemical concepts but also encourage creativity in applying the same knowledge in new contexts.

Besides, innovation competence is a basis for acquiring essential critical skills: concentration planning, project management, social collaboration, and networking (Keinänen and Kairisto-Mertanen, 2019; Ong *et al.*, 2023). It has been revealed that a profound understanding of chemistry principles and their practical applications is an important prerequisite for developing innovative problem-solving skills. Active problem solvers build a holistic view to approach chemical phenomena, allowing them to explore, experiment, and apply chemical concepts innovatively (Margallo *et al.*, 2019). Such an interactive relationship of innovation competence to mastery in chemistry provides students with academic knowledge and practical skills.

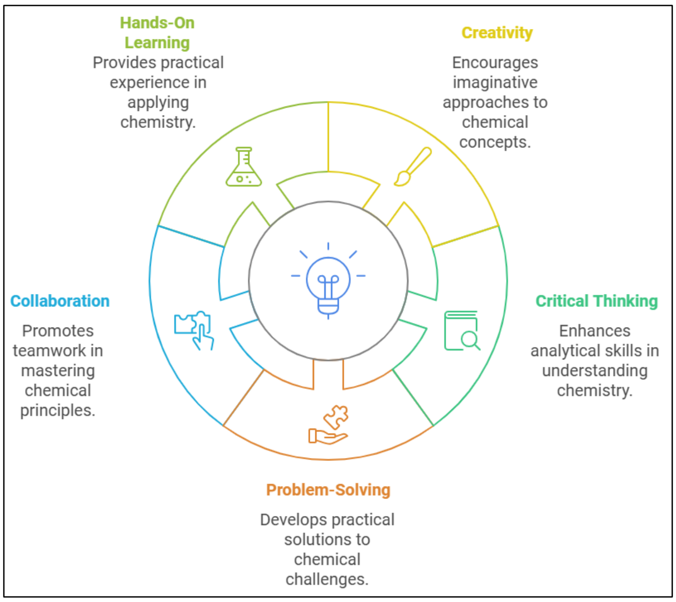

Figure 2. Innovation competence and its influence on students' mastery of chemical concepts.
Source: Elaborated by the authors.

Such research identified a strong positive association between innovation competence and chemistry concept mastery. Hence, an emphasis on skills in problem-solving, collaboration, critical thinking, and hands-on learning is underscored to facilitate a more profound understanding and application of chemistry (**Fig. 2**). Innovation competence will enable students to approach problems more creatively, solve complex problems, and work effectively in teams. These competencies are not only essential for solving real-world problems but also critical to improving both the theoretical and practical aspects of chemistry education.

Critical examination shows that while innovation competence supports creativity and problem-solving, it is not a panacea that assures deep conceptual understanding in chemistry. It may simply be that incorporating innovative capacity in learning automatically gives rise to improved understanding of chemistry concepts, disregarding challenges such as the differing degrees of learner engagement with innovative methodologies and the requirement for tailored interventions in keeping with individual learning styles. For instance, if students lack a solid foundation in chemistry, innovation-oriented activities will be challenging.

However, while collaboration and hands-on learning are essential for developing innovation competence, their effectiveness strongly depends on the quality of the collaborative processes and the nature of the learning activities. If not guided in an organized way, students might not be able to benefit fully from these strategies and might end up with a superficial understanding instead of deep conceptual mastery. For the latter, even though innovation competence pushes towards diversification of approaches, students will not apply their creative solutions if they do not have the critical thinking skills and scaffolding that connect abstract chemical principles to real-life scenarios.

3.2. What factors influence the relationship between innovation competence and mastering chemical concepts?

The relationship between innovation competence and understanding of chemical concepts is complex and influenced by various factors that interact across the educational, environmental, and individual levels (Hero *et al.*, 2021). Innovation competencies, such as creativity, problem-solving, critical thinking, and collaboration, would provide the necessary competencies to let students grasp chemistry concepts thoroughly and apply them in authentic real-life situations (Rampersad, 2020). However, the development of this competency does not solely depend on the learner; rather, it depends upon the educational methods used, the contextual variables surrounding the learner, and the inherent attributes that the students bring to the learning process. Understanding the way these determinants influence the chemical concept proficiency is vital for developing appropriate pedagogical strategies that foster innovation and prepare students with skills suitable for excelling in chemistry as a discipline (Ramírez-Montoya, 2021). In this context, a comprehensive exploration of these influencing factors is necessary to fully appreciate the dynamics in achieving innovation competence and chemical concept mastery.

The data provided in **Table 1** outlines that the relationship between innovation competence and mastering chemical concepts is influenced by several factors, which can be categorized into educational strategies, environmental conditions, and individual attributes. Furthermore, individual factors such as personality traits, flexibility, motivation, and personal characteristics play an essential role in students' competence and skills in mastering chemical concepts (Keinänen and Kairisto-Mertanen, 2019). Empirical evidence supporting the effect of these factors emphasizes their importance in shaping students' ability to build innovation competencies in their learning (Krstikj *et al.*, 2022).

By understanding the factors listed in the **Table 1**, educators and academic institutions can create a learning environment to foster innovation competence and an integrated holistic understanding of chemical principles. Each identified factor innovative models, blended learning, active learning, ecological environment, organizational support, learning strategies, personal characteristics, and motivation is synergistic in augmenting students' capabilities in thinking critically, solving problems creatively, and collaborating effectively. Taken together, these components create a dynamic learning environment that can significantly boost creativity and understanding of chemical principles, provided they are appropriately absorbed and adapted to the needs of the student (Charosky *et al.*, 2022; Ovbiagbonhia, 2021). These skills will be very important for the student to learn, not just the abstract concepts of chemistry, but also to apply these creatively to arrive at a deeper and more practical understanding of the subject (States *et al.*, 2023).

Moreover, by integrating these factors into chemistry education, educators can foster students' innovation competencies, empowering them to drive meaningful progress and contributions in chemistry while embracing lifelong learning and professional development opportunities.

Table 1. Summary of Findings: Influence Factors between Innovation Competence and The Mastery of The Concept.

Category	Factor Influenced	Impact on Innovation Competence and Chemical Concepts
Educational Strategies	Active Learning	Enhances fundamental understanding, collaboration, and problem-solving skills (Liliasari *et al.*, 2021; Zubair *et al.*, 2023)
	Innovative Models	Improves creative and critical thinking, practical application of knowledge (Krab-Hüsken *et al.*, 2023)
	Blended Learning	Makes abstract concepts tangible, improves subject-specific knowledge (Krab-Hüsken *et al.*, 2023; Obada *et al.*, 2023)
Environmental Conditions	Ecological Environment	Enhances innovation intention and effectiveness (Jenniffer *et al.*, 2022)
	Organizational Support	Provides resources and expertise for innovation (Sinaga *et al.*, 2019)
Individual Attributes	Learning Strategies	Enhances idea generation and promotion (Kirchhoff *et al.*, 2023)
	Personal Characteristics	Influences idea generation, networking, and decision-making (Brändle *et al.*, 2023; Kirchhoff *et al.*, 2023)
	Motivation and Attitudes	Affects competence development, requires diverse teaching methods (Anwar *et al.*, 2022; Brändle *et al.*, 2023)

Source: Elaborated by the authors using data from Scopus AI.

3.3. What practical strategies can educators implement to foster innovation competence and mastery of chemical concepts in the classroom?

To effectively foster innovation, competence, and mastery of chemical concepts, educators must implement practical strategies that engage students in both critical thinking and hands-on learning. Innovation competence includes skills relevant to mastering both the theoretical and practical aspects of chemistry: the ability to think creatively, solve complex problems and work collaboratively. Combining active learning, technology integration, real-world applications, and collaborative exercises in the learning environment fosters an environment where students not only gain a deeper understanding of chemistry concepts but also develop the skills necessary for innovation. These types of strategies help learners connect abstract chemical concepts to real-world problems, promoting deeper learning and development of critical innovation competencies.

Table 2 shows studies emphasizing the importance of implementing various practical strategies to produce innovation and creativity in different contexts. Techniques and methods are crucial factors in moulding creativity and fostering innovation (Hernández-Torrano and Ibrayeva, 2020), underscoring the significance of adaptability in thinking and comprehension of thinking processes. In education, universities are urged to prioritize teaching and evaluating innovation efficiency. They should deliberately design the learning environment to foster innovative competence among students (Ovbiagbonhia *et al.*, 2019). There is a call for developing and implementing an innovation competency framework in the national curriculum that aims to integrate education to build innovation competency systematically. Design learning approaches stimulate practical higher-order thinking skills, providing students with opportunities to develop the innovative mindset and skills needed to succeed in various domains (Cai and Tang, 2022). The practical implications of this study offer educators valuable rewards and collaborative educational practices that empower students to face future challenges and opportunities.

Table 2. Summary of findings: practical strategies for enhancing innovation competence and mastery of chemical concepts.

Practical Strategies	Impact on Understanding Chemical Principles
Design Thinking	Empowers innovation competencies and problem-solving skills (Nasir *et al.*, 2023; Obolewicz *et al.*, 2023)
Hands-on Pedagogy	Increases curiosity, engagement, peer learning, and collaboration (Spaan *et al.*, 2023)
Gamification and Experiential Learning	Enhances retention of key concepts and deep understanding of chemical processes (Czok *et al.*, 2023; Peeters *et al.*, 2023)
Innovative Learning Materials	Facilitates independent learning and better performance (Nagpal *et al.*, 2023)
Project-Based Learning (PBL)	Improves conceptual understanding and crucial learning skills (Chiu, 2021; He *et al.*, 2023)
STEM Integration	Enhances critical thinking and student engagement (Brunnert and Tausch, 2023)
Active Learning Strategies	Promotes higher-order cognitive skills and practical application of knowledge (Shidiq *et al.*, 2022)
Student-Centred Instruction	Improves understanding of concepts and increases interest in subject (Lenihan *et al.*, 2020)

Source: Elaborated by the authors using data from Scopus AI.

Each strategy is designed to encourage active and creative participation by students, with the goal of not merely increasing their understanding of the chemical concepts but inspiring them to apply these ideas in practical and imaginative ways. The **Table 2** provides a comprehensive set of strategies for educators looking to integrate these useful strategies to enhance student learning outcomes in chemistry.

4. Conclusions

In conclusion, the comprehensive literature review of 31 articles shows a conclusive and consistent association between innovation competence and students' understanding of chemical concepts. The results underline the critical role of developing innovation competencies, especially creativity, problem-solving, and collaboration, in the domain of chemistry education. There is a strong positive relationship in that when students have these competencies, their ability to learn and apply complex chemical concepts is significantly enhanced. **Figure 3** illustrates the interplay between innovation competence and the mastery of chemistry concepts among students. The insights presented here show that fostering innovation competence can lead to better academic performance and a deeper understanding of complex chemical principles.

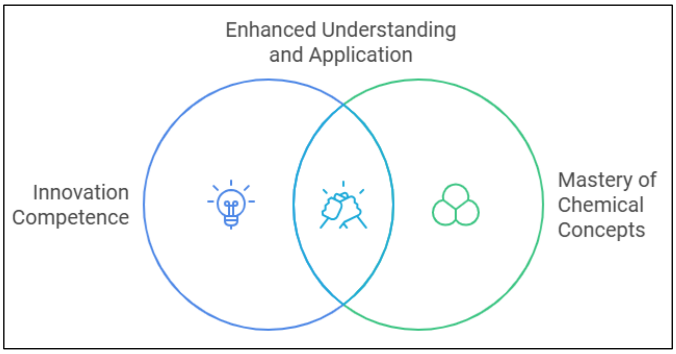

Figure 3. Interplay between innovation competence and the mastery of chemical concepts.
Source: Elaborated by the authors.

The main factors influencing this relationship include active learning, innovative models, blended learning environments, and organizational support, which together create an ecosystem that supports conceptual understanding and innovation skills development. Instructional methods such as Design Thinking, Hands-on Pedagogy, and Project-Based Learning (PBL) are particularly effective in driving this integration because they engage students in hands-on problem-solving and real-world application of chemistry concepts. The review suggests that future research should examine the enduring effects of these instructional strategies, especially within varied educational contexts, and their implications for students' creativity and critical thinking abilities over time. Additionally, it is advisable to conduct further research into the impact of personalized learning methods and the significance of technology in fostering innovative capabilities.

However, the review also highlights several limitations, such as the small scope of some of the studies regarding sample size and geographical context. In addition, the lack of standardized metrics for assessing innovation competence in chemistry education makes cross-study comparisons difficult. This should be addressed in future research by using much larger samples that are diverse in terms of backgrounds and by developing strong measures of innovation competencies applicable to all. This will yield more generalizable insights and help to hone in on the strategies necessary for creating more profound and meaningful learning experiences within chemistry education.

Authors' contribution

Conceptualization: Norliyana binti Md. Aris; Nor Hasniza binti Ibrahim; **Data curation:** Norliyana binti Md. Aris; **Formal Analysis:** Norliyana binti Md. Aris; Noor Dayana binti Abd Halim; **Funding acquisition:** Not applicable; **Investigation:** Norliyana binti Md. Aris; Noor Dayana binti Abd Halim; **Methodology:** Norliyana binti Md. Aris; Nor Hasniza binti Ibrahim; **Project administration:** Norliyana binti Md. Aris; **Resources:** Not applicable; **Software:** Not applicable; **Supervision:** Nor Hasniza binti Ibrahim; Johari Surif; **Validation:** Noor Dayana binti Abd Halim; Johari Surif; **Visualization:** Norliyana binti Md. Aris; **Writing – original draft:** Norliyana binti Md. Aris; **Writing – review & editing:** Nor Hasniza binti Ibrahim; Noor Dayana binti Abd Halim; Johari Surif.

Data availability statement

Data from Scopus and Scopus AI were analyzed by the authors and are included in the article.

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Conflict of interest

The authors declare that there is no conflict of interest.

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