Mapping Innovation in Chemistry Education: Expert Insights on Innovation Competence and Learning Environments

Norliyana Md. Aris[1*], Nor Hasniza Ibrahim[2], Noor Dayana Abdul Halim[3], Nadhihah Idris[4]

[1,2,3]Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Malaysia

[4]Faculty of Human Development, Sultan Idris Education University, Malaysia

***Corresponding Author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.9010126

Received: 30 December 2024; Accepted: 07 January 2025; Published: 06 February 2025

ABSTRACT

Innovation competence is needed to solve many global problems, especially in chemistry. Along with the Sustainable Development Goals (SDGs) of the United Nations, it is essential to achieve a better and more sustainable future by 2030. This study aims to map the views of experts' chemistry teachers on whether current school curricula and classroom environments foster innovation competence and their views on its necessity for high school chemistry. A semi-structured interview protocol as a research instrument was used with three experts in the field to identify the need for competence development in teaching and learning chemistry and the proposed solutions suitable for teachers to develop students' innovation competence in chemistry class. Findings indicate a strong need to enhance the learning environment to support innovation competence. A supportive setting with clear, structured resources and active learning strategies in chemistry education will significantly improve student engagement and learning outcomes.

Keywords: Iinnovation competence, chemical concepts, reinforcement, supports, self-organization

INTRODUCTION

Enhancing innovation competencies among students encompasses critical thinking, problem-solving, creativity, and applying knowledge in new and innovative ways. The National STEM Action Plan 2017–2025 emphasizes innovation as a critical focus area. According to the World Economic Forum (World Economic Forum, 2022), the demand for analytical thinking and innovation skills will dominate the job market by 2025. Studies show that the need to develop innovation competencies through real-world problem-solving in STEM education is becoming a focus among many educators (Dunnigan et al., 2020; Padmanabhan et al., 2017). Innovation competence is needed to solve many global problems, especially in (SDGs) to achieve a better and more sustainable future by 2030, such as nanotechnology, sustainable energy transition, smart cities, innovative industries, and other social and environmental issues (Chalkiadaki, 2018; Garcia-Vaquero, 2021; Sáez-López et al., 2021).

The thought processes that go into it will help students develop creativity, develop new ideas, solve problems, and discover new opportunities in problem-solving (Kaberman et al., 2009; Norliyana Md Aris et al., 2022). Therefore, whether it is the views of scholars or education policymakers, developing students' innovation competencies is seen as indispensable to remain relevant in society.

LITERITURE REVIEW

Innovation Competencies

Today's global world recognizes innovation competencies, especially considering these factors can help prepare students to solve complex problems and positively impact individual personality qualities (Atamanyuk et al., 2021; OECD, 2019). However, a study by . Keinänen and Kairisto-Mertanen (2019), showed that students have a low level of innovation competence and depend on the given environment. Meanwhile, a study by Ovbiagbonhia (2021), revealed that the level of student competence is still moderate. As a result, developing students' innovation competencies emphasized in many educational policies (Hero et al., 2021; Sáez-López et al., 2021) displays an urgent need for innovation-competent professionals to participate in the innovation process and contribute to the creation of innovations (Hero et al., 2021; Ovbiagbonhia et al., 2019).

According to Wang (2017) and Fisher et al. (2013), innovation is a problem-solving process that begins with a goal, generates an idea, produces a product or prototype, and ends with implementation and reflection. The development process must take an idea from invention to implementation to achieve innovative solutions. The general term competency requires an explanation in this context. Competence is the integration and manifestation of knowledge, skills, and attitudes in performance in a predetermined specific context and a concrete and authentic assignment (Hero et al., 2021; Sáez-López et al., 2021). The competencies required in the innovation process can refer to knowledge, skills, and attitudes (Dzhengiz & Niesten, 2020). Based on these prerequisites, individual innovation competencies are understood in this study as synonymous with personal characteristics, knowledge, skills (or abilities), and attitudes related to creating and implementing new things through collaboration in complex innovation processes. Therefore, students competent in innovation must possess the necessary knowledge, skills, and attitudes related to problem identification, creativity in solution / idea generation, and implementation of solutions or ideas (Becker & Mentzer, 2015; Ramos et al., 2016). In parallel with the challenges of a rapidly changing and unpredictable globalized world, changes need to be made from a culture of testing to a culture of supporting learning, from controlling and teacher-centered to active and student-centered learning of students, and from product evaluation to evaluation of the learning process.

Innovation Competencies in Chemistry Relevance

TInnovation competencies is needed to solve many global problems, especially in chemistry. Chemistry is critical in achieving several United Nations Sustainable Development Goals (SDGs) to achieve a better and more sustainable future by 2030 (Anastas & Zimmerman, 2018), such as nanotechnology, sustainable energy transition, smart cities, innovative industries, and other social and environmental issues (Droescher, 2018; Gomollón-Bel, 2020; Ojeda et al., 2021). The thought processes that go into it will help students develop creativity, develop new ideas, solve problems, and discover new opportunities in problem-solving (Beckman & Barry, 2007; Nainggolan et al., 2020). Chemistry educators hold the responsibility of guiding students to understand the critical role that chemistry plays in ensuring a sustainable future Therefore, whether it is the views of scholars or education policymakers, developing students' innovation competencies is seen as indispensable to remain relevant in society by both parties (Krstikj et al., 2022; Ojeda et al., 2021).

These competencies enable students to develop sustainable solutions, advance green chemistry initiatives, and contribute to scientific breakthroughs in chemistry (Mahaffy & Elgersma, 2022; Muñoz-Galván & Padilla, 2024). For instance, understanding chemical principles such as reaction mechanisms and molecular interactions can create environmentally friendly materials and processes, addressing significant global challenges like climate change and resource depletion (Gomollón-Bel, 2020; Kanapathy et al., 2019). Incorporating innovation competencies into chemistry education necessitates a shift towards more active learning strategies and practical experiences. Innovation competence is the ability to identify and solve problems creatively, develop and implement new ideas, and be adaptable and flexible in response to change (Aris et al., 2025; Wright et al., 2010). In the context of this research, each of these innovation competencies also refers to elements that can be translated through teaching and learning activities, such as problem-solving skills, how chemical concepts relate and the relevance of concepts in achieving the goal of solving chemical problems, students' ability to create and produce things, work skills in groups and students' ability to find productive references.

Researchers have examined innovation competence from various perspectives, primarily focusing on students at the tertiary education level (M. Keinänen et al., 2018a; Marin-Garcia et al., 2016; Ovbiagbonhia, 2021). Attempts to deconstruct innovation competencies for educational purposes are still few, and most studies only focus on creativity as a personality trait (Halek et al., 2021; Stojcic et al., 2018). Therefore, the research underscores the critical need to improve the learning environment to support the development of innovation competencies in chemistry education. By analyzing global trends, policymakers and educators must prepare students to face future challenges and contribute meaningfully to sustainable development goals.

A bibliometric study conducted by Draman and Mohd (2021), on research trends in chemistry education for the period 2011-2020 shows that chemistry teaching and learning has shifted to integrating pedagogy, e-learning, virtual classrooms, and learning involving technology towards IR 4.0. It shows that the chemistry teaching and learning process is facing significant challenges, and the role of teachers is increasingly challenging in preparing students to become

innovative individuals. However, what happens is chemistry teachers are less involved in the exploration and encouragement of the development of innovation competencies among students (Chou et al., 2022; Schafer & Yezierski, 2021).

A study by Jha and Jacob (2020), also reported that the teaching role is still ineffective. The teaching and learning strategies used by chemistry teachers also do not support active learning and stimulating student competence (Karolčík & Marková, 2023; Nguyen et al., 2021). Therefore, this study aims to map the views of expert chemistry teachers on their perspective on whether current school curricula and classroom environments foster this innovation competence and their views on its necessity for students in chemistry education, well as answering the following study questions:

1. Is there a Need to Develop Innovation Competencies for high school chemistry students?
2. Are there any challenges and suitable environments in developing student?

METHODOLOGY

The data in this study were collected using qualitative methods through analysis of semi-structured interviews. This method was chosen to enable researchers to obtain information about participants' perspectives more deeply and better understand a phenomenon that occurs (Creswell, J. W., & Poth, 2016; Merriam, S. B., & Grenier, 2019) and gives researchers an advantage to control the discussion (Aspers & Corte, 2019). In addition, this method also offers an alternative to study data. Participants are free to submit additional ideas during the interview process (Barnett-Page & Thomas, 2009). The questions are open-ended, allowing participants to provide views creatively and flexibly as well as consider the meaning and 'reality' of the participant's experience in a broader sense (Rubin, Herbert J., 2011). This semi-structured interview-based method can enable researchers to explore the importance of knowledge, skills or other factors needed to motivate chemistry students in developing problem-solving skills, applying knowledge and making decisions in daily life related to the chemistry field that has been studied.

Instruments

One of the most dominant and widely used data collection methods in the social sciences is the qualitative method with a semi-structured interview approach (Dolczewski, 2022). The semi-structured interview protocol was used as a study instrument to identify the need for competence development in teaching and learning chemistry and the proposed solutions suitable for teachers to develop students' innovation competence in chemistry class (Merriam, S. B., & Grenier, 2019).

Sample

In this study, sampling was designed for use by experts in chemistry. The selected samples were intended to provide sufficient qualitative data for understanding the current phenomena in research (John W. Creswell, 2014). The design of a study depends on determining an adequate sample size or selecting a more precise sample (Cornish, 2006). Following John W. Creswell (2014), perspective, which suggests that the ideal number of participants for a qualitative study falls between 3 to 10, the researchers chose three participants from a homogeneous group based on the study's context. This approach aligns with the aim of obtaining in-depth information (Patton, 2014).

Data Analysis

Before the interview, the protocol was validated for language validity, content, and quality. The experts agreed

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

to be interviewed, and the text was transcribed verbatim. All study participants verified the transcripts before the analysis, classification, and coding process (Cohen & Crabtree, 2008). The data analysis involved carefully reading the transcriptions to investigate emerging new issues and possible themes related to the study.

FINDING AND DISCUSSION

Innovation competencies are arranged according to the five-dimensional innovation competency model (M. Keinänen et al., 2018b). This innovation competencies requirement is then empirically supported by findings from interviews with a panel of experts. Thus, the innovation competencies obtained from qualitative analysis are strengthened and refined, especially in secondary school chemistry. At this stage, the focus of the analysis is to see the development needs of the innovation competency dimension required by chemistry students in line with the goals of the Chemistry KSSM.

Theme 1: The Need for Innovation Competencies Development for Chemistry Students

All participants agreed that the dimension of competency in problem-solving innovation from the perspective of students' ability to generate and elaborate ideas in problem-solving activities or issues related to chemistry should be the focus in providing students with an understanding of the chemistry concept. Teachers must be essential in providing a learning environment that stimulates students to engage in problem-solving activities.

"*When students have experience learning through problem-solving, they can see real-world applications. As teachers, we must also encourage them to use methods suitable for today's challenges."* (P02T1 – 14/1/2023)

The experts also emphasized that chemistry students need to be able to generate and elaborate various ideas to solve problems or issues related to chemistry through hands-on activities to understand chemical concepts. Experts also support the need for competency development through practical activities or active learning that can positively impact the understanding of chemical concepts.

"*Students will usually understand a concept better when they can do something. They also tend to be active in activities they enjoy, especially when it comes to technology and the practical application of concepts*" (P03T1-10/2/2023)

In chemistry, students have the opportunity to enhance their practical learning experience by exercising their creativity and perseverance in solving real-world problems and completing assignments. This approach fosters the development of problem-solving skills within a real-world context.

"*The impact of chemicals in everyday life can give students space to develop the ability to consider and devise creative and innovative solutions*" (P03T1- 10/2/2023)

The experts stressed the importance of empowering chemistry students with the practical skills to apply their knowledge of chemical concepts in problem-solving scenarios, emphasizing the value of making connections between these concepts for enhanced learning and application.

"*With appropriate chemistry project activities, students can use their knowledge to solve real-world problems. If they don't apply what they've learned, they'll lose it... Chemistry isn't just a theory; it's about how students apply their knowledge. That's what makes it valuable*." (P03T1- 10/2/2023)

"*Topics related to rusting also provide opportunities for design exploration. For example, they can design and manufacture products such as electrochemical cell models*" (P02T1– 14/1/2023)

In addition, the results highlight the importance of developing competence and interpersonal networks through collaborative activities and discussions in chemistry classes. Students' ability to collaborate and communicate effectively in problem-solving activities can significantly enhance their understanding of chemistry concepts. They are further proving that the collaborative effect and discussion on learning is better not only in the subject of Biology (Mahanal et al., 2022) but also in chemistry. Students' ability to collaborate and communicate effectively in problem-solving activities can significantly enhance their understanding of chemical concepts.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

These findings show that it is essential for students to actively search for information through various sources, including digital sources such as the Internet. Students are also encouraged to evaluate their learning based on the information they search for and use in problem-solving activities. Students are more engaged in learning when it provides challenges and provides practical experience rather than mere theory (Redmond et al., 2023).

The visual overview in Figure 1 demonstrates the summary of the views of experts on how innovation competencies are needed and can be developed in the context of chemistry education using draw.io. application. The innovation competencies must be developed so chemistry students can convey chemical ideas in relevant contexts and improve their ability to think logically and critically through understanding and applying chemistry in decision making and problem-solving (Md. Aris et al., 2024). To ensure the achievement of the intended goals of KSSM Chemistry (BPK, 2018), it is crucial to focus on developing innovation competencies in chemistry students.

It is evident from the findings that there is a strong consensus among all participants in the study about the importance of enhancing innovation competencies for secondary school chemistry students. By establishing a supportive environment and providing well-structured resources and active learning strategies in chemistry education, we can notably enhance student engagement and improve learning outcomes.

Theme 2: The Need for the Implementation of a Design Thinking-Based Approach

The experts acknowledged that the design thinking-based teaching approach could positively impact students' learning development, especially in improving students' innovation competence, providing experience in building knowledge, and creating an enjoyable real-world context learning environment.

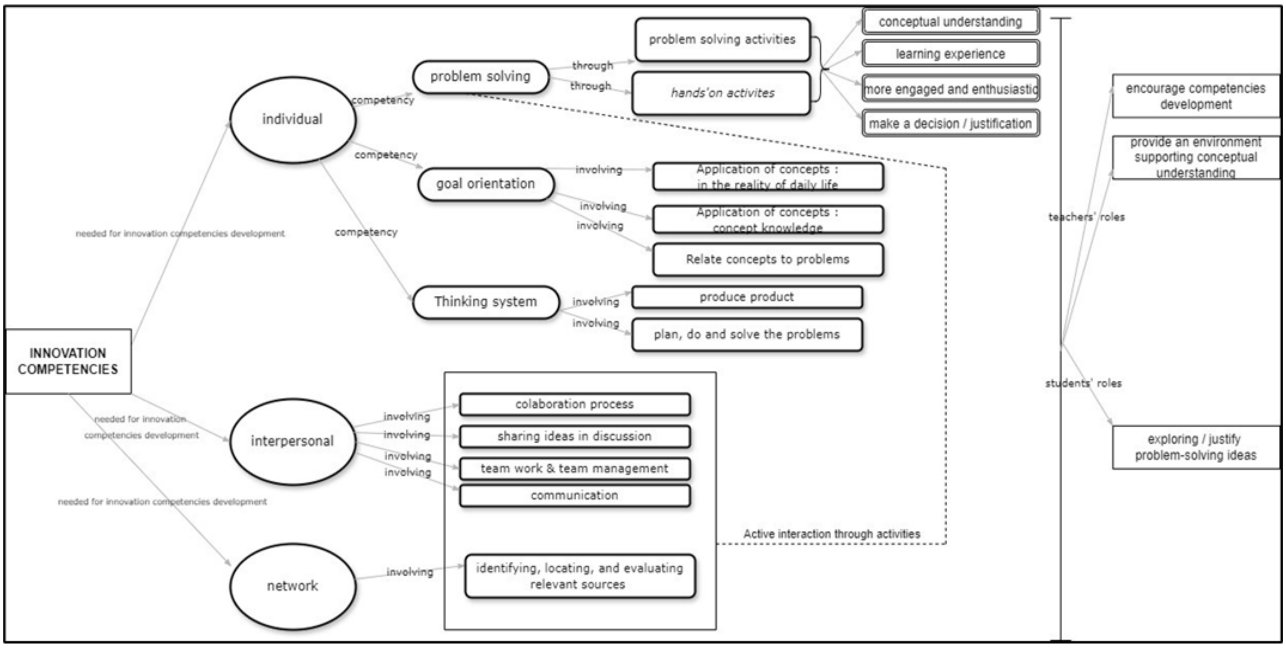

Fig. 1 Graphical Summary for The Need and How Innovation Competencies Can Be Develop in Chemistry Education

The findings of the interviews also show the implementation of a design thinking-based approach in chemistry education involving practical projects beyond theory-based learning.

"Design Thinking can enhance students' competence to ***explore ideas****... When he* ***collaborates or*** *has a new discussion, he knows that he understands the concept or does it. Another thing, if we can do it until students can* ***produce something****, it is perfect for our students" (P01T2– 5/1/2023)*

"I believe using the Design Thinking approach allows students to ***approach problem-solving*** *more creatively and collaboratively. In chemistry, this approach can* ***encourage students to think outside of formulas*** *and equations" (P02T2– 14/1/2023)*

*"From this design project activity, **students solve problems** and **experience themselves**." (P02T2- 14/1/2023)*

This is in line with KSSM Chemistry's goal to provide a learning environment that can provide experience in the process of understanding chemical concepts. The formulation of the findings for theme 2 is as depicted in Figure 2. This teaching strategy can be developed effectively if chemistry teachers have comprehensive solutions and reference resources that can help teachers and students.

Theme 3: Challenges of Implementing a Design Thinking-Based Approach

The results of the interviews further revealed consistent findings among the study participants on the challenges of integrating a design thinking-based teaching approach in the teaching of chemistry. Although the study participants acknowledged the potential of this approach, chemistry teachers faced significant challenges, mainly due to time, material preparation, student control, and planning (Figure 3).

*" This is why **fewer children are interested in learning chemistry**... They often question, 'Why do we need to memorize so much? Can't we just look things up later?" (P03T3- 10/2/2023)*

*"We could spark their interest **by incorporating a design project** like this one. Chemistry has many fascinating aspects, but it is important to find the right time to present them" (*P01T3– 5/1/2023)

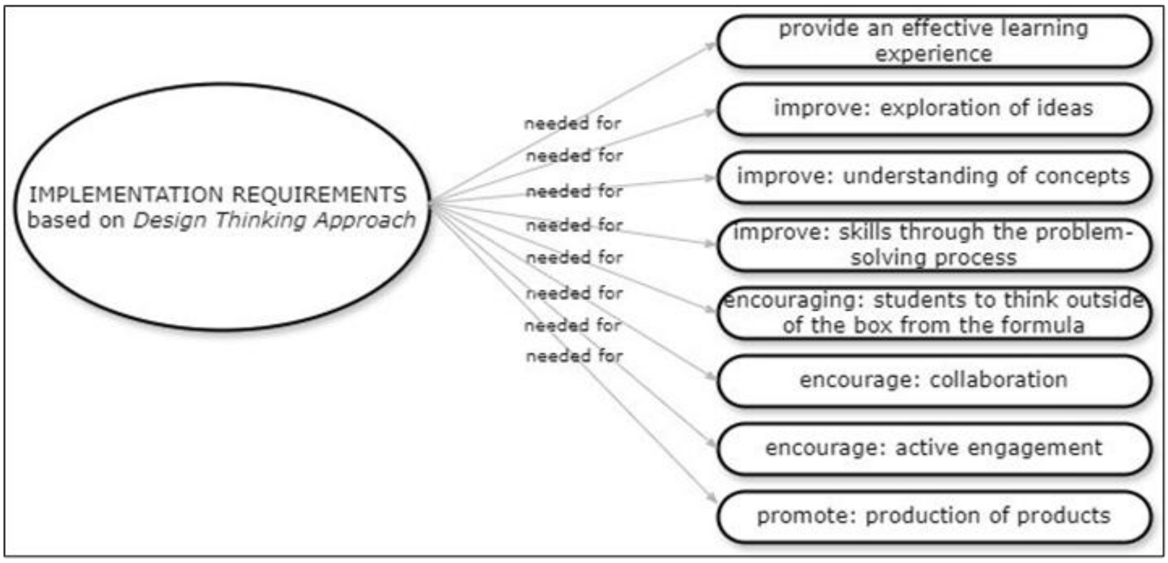

Fig. 2 Graphical Summary of The Need for Design Thinking Strategies for The Development of Innovation Competencies

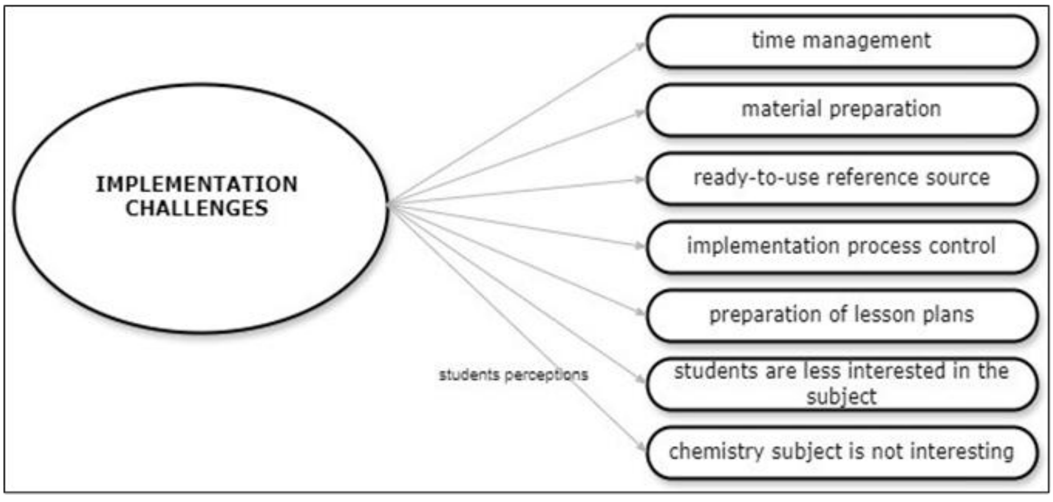

Fig.3. Graphical Summary of a Challenge in Implementing Design Thinking in The Classroom for The Development of Innovation Competencies

Providing adequate and comprehensive resources and training programs for chemistry teachers is an initiative to encourage and foster an environment of a design thinking-based approach so that the chemistry teaching and learning conducted is more attractive and practical. By addressing these challenges head-on, teachers can create an environment that recognizes the potential of innovative teaching approaches and actively facilitates their implementation in enhancing students' innovation competencies.

Innovation competencies in the context of this study are arranged according to the innovation competency model (M. Keinänen et al., 2018a). As mentioned in the study highlights, there is evidence that the development of students' innovation competencies needs attention because learning practices are still mostly not supportive of the development of these competencies. This need analysis phase highlights the critical need to develop innovation competencies in Chemistry education, especially in the dimension of problem-solving, particularly the ability of students to generate and elaborate ideas.

The findings clearly show that chemistry students need to be guided in generating and elaborating ideas, enabling them to integrate theoretical knowledge with practical application in the problem-solving process. This statement is in line with a study by Tran (2024), which emphasizes the importance of problem-solving skills in helping students to make effective decisions in the future.

In addition, the ability to consider ideas in decision-making is not only an important aspect of the problem-solving process, but this process can form a more holistic and in-depth understanding of students' chemistry concepts. Tsaparlis et al. (2021) also opined that when students are involved in the problem-solving process, it can help them develop a deeper understanding of chemistry's basic concepts and principles. The findings of the interviews in this phase also underline the need to develop goal-oriented innovation competencies in Chemistry classes to help students make meaningful connections between different concepts and use their knowledge more effectively.

The study participants unanimously acknowledged that adequate support in refining and critically evaluating students' ideas is also critical. Knowing the concepts of Chemistry alone is not enough (Surif et al., 2014), students need to be trained to use these concepts by making relevance to Chemistry concepts and using Chemistry knowledge in problem-solving scenarios. In parallel with the views of Ellah et al. (2019) and Hancock (2024), Chemistry problem-solving relies on conceptual knowledge and how concepts are applied in the problem-solving process. The study's findings in this phase also show the need for student competence in producing a material, solution, or product by applying Chemistry concept knowledge. This idea is also consistent with a study by Li et al. (2019), which states that producing a product such as a prototype is an important step in applying knowledge in practice. Developing this competency is necessary to provide space for students to explore and apply the concept of Chemistry in translating theoretical knowledge into practical applications.

CONCLUSIONS

The findings of this study underscore the critical need for enhancing innovation competencies among secondary school chemistry students. Expert interviews reveal a strong consensus on providing a supportive learning environment that integrates clear, structured resources and active learning strategies. Integrating practical application and theoretical understanding within the curriculum fosters student engagement and improves learning outcomes by encouraging hands-on activities and real-world problem-solving. These strategies enhance students' understanding of chemical concepts and stimulate their ability to generate and elaborate ideas, significantly contributing to developing innovation competencies. It supports the broader educational goals of equipping students with the necessary skills to tackle global challenges and contribute meaningfully to sustainable development goals.

Moreover, the study highlights the potential of implementing a design thinking-based approach in chemistry education. Students involved in design thinking projects develop their innovation competencies and display enhanced creativity and collaborative skills. These findings align with the goals of the KSSM Chemistry curriculum, emphasizing the importance of a supportive learning environment that encourages active participation and practical application of knowledge.

The study reinforces the need for educational strategies that move beyond rote memorization to engage students in meaningful, real-world problem-solving, preparing them for future challenges in chemistry and beyond. However, the study also identifies several challenges, such as time constraints, material preparation, and adequate student management. Addressing these challenges through comprehensive resource provision and targeted teacher training programs can significantly enhance the feasibility and effectiveness of innovative teaching methods. By adopting these strategies, chemistry educators can better prepare students for future challenges, ensuring they possess the critical thinking, problem-solving, and creativity skills necessary for success in a rapidly changing world.

ACKNOWLEDGMENT

This research was funded by a scholarship from Ministry of Education Malaysia (Hadiah Latihan Persekutuan, HLP) and Universiti Teknologi Malaysia.

REFERENCES

1. Anastas, P. T., & Zimmerman, J. B. (2018). The United Nations sustainability goals: How can sustainable chemistry contribute? Current Opinion in Green and Sustainable Chemistry, 13, 150–153. https://doi.org/10.1016/j.cogsc.2018.04.017
2. Aris, N. M., Ibrahim, N. H., & Halim, N. D. A. (2025). Design and Development Research (DDR) Approach in Designing Design Thinking Chemistry Module to Empower Students' Innovation Competencies. Journal of Advanced Research in Applied Sciences and Engineering Technology, 44(1), 55–68. https://doi.org/10.37934/araset.44.1.5568
3. Aspers, P., & Corte, U. (2019). What is Qualitative in Qualitative Research. Qualitative Sociology, 42(2), 139–160. https://doi.org/10.1007/s11133-019-9413-7
4. Atamanyuk, S., Semenikhina, O., & Shyshenko, I. (2021). 2021 Pedagogy and Education Management Review (PEMR). Issue, 2(4), 30–36.
5. Barnett-Page, E., & Thomas, J. (2009). Methods for the synthesis of qualitative research: A critical review. BMC Medical Research Methodology, 9(1). https://doi.org/10.1186/1471-2288-9-59
6. Becker, K., & Mentzer, N. (2015). Engineering design thinking: High school students' performance and knowledge. In International Conference on Interactive Collaborative Learning, ICL 2015 (pp. 5–12). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICL.2015.7318218
7. Beckman, S. L., & Barry, M. (2007). Innovation as a learning process: Embedding design thinking. In California Management Review (Vol. 50, Issue 1, pp. 25–56). University of California Press. https://doi.org/10.2307/41166415
8. (2018). Dokumen Standard Kurikulum dan Pentaksiran (DSKP) Kimia Tingkatan 4 dan 5. Kementerian Pendidikan Malaysia, 71. http://www.moe.gov.my/bpk
9. Chalkiadaki, A. (2018). A systematic literature review of 21st century skills and competencies in primary education. International Journal of Instruction, 11(3), 1–16. https://doi.org/10.12973/iji.2018.1131a
10. Chou, P.-N., Lin, K.-Y., Bolick, M. M., Mikhailova, E. A., & Post, C. J. (2022). Teaching Innovation in STEM Education Using an Unmanned Aerial Vehicle (UAV). https://doi.org/10.3390/educsci12030224
11. Cohen, D. J., & Crabtree, B. F. (2008). Evaluative criteria for qualitative research in health care: Controversies and recommendations. Annals of Family Medicine, 6(4), 331–339. https://doi.org/10.1370/afm.818
12. Cornish, R. (2006). Statistics: An introduction to sample size calculations. [Internnet Note], 2, 1–5. http://www.statstutor.ac.uk/resources/uploaded/sample-size.pdf
13. Creswell, J. W., & Poth, C. N. (2016). Qualitative inquiry and research design: Choosing among five approaches. Sage publications.
14. Dolczewski, M. (2022). Semi-structured interview for self-esteem regulation research. Acta Psychologica, 228(March). https://doi.org/10.1016/j.actpsy.2022.103642
15. Draman, S. F. S., & Mohd, N. (2021). A Bibliometric Review on Chemistry Education: Bodies of Research, 1980-2020. Asian Journal of University Education, 17(4), 432–441. https://doi.org/10.24191/ajue.v17i4.16195
16. Droescher, M. (2018). Chemistry : The Driving Force. June 2017, 14–17.

17. Dunnigan, K. A., Dunford, A., & Bringardner, J. (2020). From cornerstone to capstone: Students' design thinking and problem solving. In 2020 ASEE Virtual Annual Conference, ASEE 2020 (Vol. 2020). American Society for Engineering Education. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85095788084&partnerID=40&md5=74bae7db939e4bd829ab2047715d0a55
18. Dzhengiz, T., & Niesten, · Eva. (2020). Competences for Environmental Sustainability: A Systematic Review on the Impact of Absorptive Capacity and Capabilities. Journal of Business Ethics, 162, 881–906. https://doi.org/10.1007/s10551-019-04360-z
19. Ellah, B. O., Achor, E. E., & Enemarie, V. (2019). Problem-solving skills as correlates of attention span and working memory of low ability level students in senior secondary schools. Journal of Education and E-Learning Research, 6(3), 135–141. https://doi.org/10.20448/journal.509.2019.63.135.141
20. Fisher, K. E., Bishop, A. P., Fawcett, P., & Magassa, L. (2013). InfoMe @ Teen Design Days: A multi-disciplinary, design thinking approach to community development. In 6th International Conference on Information and Communications Technologies and Development, ICTD 2013 (Vol. 2, pp. 25–28). https://doi.org/10.1145/2517899.2517914
21. Garcia-Vaquero, M. (2021). Design Thinking Online: Approaching Constructive Learning In Food Science. In 18th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA 2021 (pp. 339–344). IADIS Press. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124069878&partnerID=40&md5=89c87c5d1d0c70fb5d10cbefc146c774
22. Gomollón-Bel, F. (2020). Ten Chemical Innovations That Will Change Our World. Chemistry International, 42(4), 3–9. https://doi.org/10.1515/ci-2020-0402
23. Halek, D. H., Sumarmi, Budijanto, & Utomo, D. H. (2021). Examination Improving Character towards Environment Care Through Their Creativity and Innovation at School (A Case Study at the Senior High School 3 Ternate City)*. Eurasian Journal of Educational Research, 96(96), 82–101. https://doi.org/10.14689/ejer.2021.96.6
24. Hancock, L. M. (2024). Student Perceptions of Team-Based Learning in an Advanced Inorganic Chemistry Course. Journal of Chemical Education, 101(3), 910–920. https://doi.org/10.1021/acs.jchemed.3c00655
25. Hero, L. M., Pitkäjärvi, M., & Matinheikki-Kokko, K. (2021). Validating an individual innovation competence assessment tool for university–industry collaboration. Industry and Higher Education, 35(4), 485–496. https://doi.org/10.1177/09504222211017447
26. Jha, H. K., & Jacob, D. (2020). Legitimizing a practice across fields: Microprocesses of theorization of Design Thinking. Journal of Professions and Organization, 7(2), 156–187. https://doi.org/10.1093/jpo/joaa007
27. John W. Creswell. (2014). Research design : qualitative, quantitative, and mixed methods approaches. SAGE Publications Ltd. https://doi.org/10.5005/jp/books/12716
28. Kaberman, Z., Yehudit, A. E., Dori, J., Kaberman, Z., & Dori, Y. J. (2009). Metacognition in chemical education: question posing in the case-based computerized learning environment. 37, 403–436. https://doi.org/10.1007/s11251-008-9054-9
29. Kanapathy, S., Lee, K. E., Sivapalan, S., Mokhtar, M., Syed Zakaria, S. Z., & Mohd Zahidi, A. (2019). Sustainable development concept in the chemistry curriculum: An exploration of foundation students' perspective. International Journal of Sustainability in Higher Education, 20(1), 2–22. https://doi.org/10.1108/IJSHE-04-2018-0069
30. Karolčík, Š., & Marková, M. (2023). How teachers perceive innovations in education. Journal of Research in Innovative Teaching and Learning. https://doi.org/10.1108/JRIT-04-2023-0039
31. Keinänen, M. M., & Kairisto-Mertanen, L. (2019). Researching learning environments and students' innovation competences. Education and Training, 61(1), 17–30. https://doi.org/10.1108/ET-03-2018-0064
32. Keinänen, M., Ursin, J., & Nissinen, K. (2018a). How to measure students' innovation competences in higher education: Evaluation of an assessment tool in authentic learning environments. Studies in Educational Evaluation, 58(October 2017), 30–36. https://doi.org/10.1016/j.stueduc.2018.05.007
33. Keinänen, M., Ursin, J., & Nissinen, K. (2018b). How to measure students' innovation competences in higher education: Evaluation of an assessment tool in authentic learning environments. https://doi.org/10.1016/j.stueduc.2018.05.007
34. Krstikj, A., Sosa Godina, J., García Bañuelos, L., González Peña, O. I., Quintero Milián, H. N., Urbina

Coronado, P. D., & Vanoye García, A. Y. (2022). Analysis of Competency Assessment of Educational Innovation in Upper Secondary School and Higher Education: A Mapping Review. Sustainability (Switzerland), 14(13). https://doi.org/10.3390/su14138089

35. Li, W.-T., Ho, M.-C., & Yang, C. (2019). A design thinking-based study of the prospect of the sustainable development of traditional handicrafts. Sustainability (Switzerland), 11(18). https://doi.org/10.3390/su11184823
36. Mahaffy, P. G., & Elgersma, A. K. (2022). Systems thinking, the molecular basis of sustainability and the planetary boundaries framework: Complementary core competencies for chemistry education. Current Opinion in Green and Sustainable Chemistry, 37, 100663. https://doi.org/10.1016/J.COGSC.2022.100663
37. Mahanal, S., Zubaidah, S., Setiawan, D., Maghfiroh, H., & Muhaimin, F. G. (2022). Empowering College Students' Problem-Solving Skills through RICOSRE. Education Sciences, 12(3). https://doi.org/10.3390/educsci12030196
38. Marin-Garcia, J. A., Andreu Andres, M. A., Atares-Huerta, L., Aznar-Mas, L. E., Garcia-Carbonell, A., González-Ladrón-de-Guevara, F., Montero Fleta, B., Perez-Peñalver, M. J., & Watts, F. (2016). Proposal of a Framework for Innovation Competencies Development and Assessment (FINCODA). WPOM-Working Papers on Operations Management, 7(2), 119. https://doi.org/10.4995/wpom.v7i2.6472
39. Aris, N., Ibrahim, N. H., & Abd. Halim, N. D. (2024). Innovate to Educate: The Development and Validation of the Design Thinking Chemistry Module. International Journal of Academic Research in Progressive Education and Development, 13(1), 2379–2389. https://doi.org/10.6007/ijarped/v13-i1/21103
40. Merriam, S. B., & Grenier, R. S. (Eds.). (2019). Qualitative research in practice: Examples for discussion and analysis. John Wiley & Sons.
41. Muñoz-Galván, M., & Padilla, K. (2024). Pedagogical content knowledge about the sustainability of high school chemistry and biology teachers. Journal of Environmental Studies and Sciences, Bybee 1991. https://doi.org/10.1007/s13412-024-00919-z
42. Nainggolan, B., Hutabarat, W., Situmorang, M., & Sitorus, M. (2020). Developing innovative chemistry laboratory workbook integrated with project-based learning and character-based chemistry. International Journal of Instruction, 13(3). https://doi.org/10.29333/iji.2020.13359a
43. Nguyen, K. A., Borrego, M., Finelli, C. J., DeMonbrun, M., Crockett, C., Tharayil, S., Shekhar, P., Waters, C., & Rosenberg, R. (2021). Instructor strategies to aid implementation of active learning: a systematic literature review. International Journal of STEM Education, 8(1). https://doi.org/10.1186/s40594-021-00270-7
44. Norliyana Md Aris, Ibrahim, N. H., Noor Dayana Abd Halim, Sariah Ali, Nurul Hanani Rusli, Maizatul Nabila Mohd Suratin, & Firdaus Che Hassan. (2022). Evaluating The Academic Trends On Design Thinking Research: A Bibliometric Analysis From 2000 to 2021. Journal of Positive School Psychology, 6(4), 1022–1038. http://journalppw.com
45. (2019). PISA 2021 creative thinking framework. Oecd, 53(9), 1689–1699. https://www.oecd.org/pisa/publications/PISA-2021-creative-thinking-framework.pdf
46. Ojeda, M. D., Queiruga-Dios, M. Á., Velasco-Pérez, N., López-Iñesta, E., & Vázquez-Dorrío, J. B. (2021). Inquiry through industrial chemistry in compulsory secondary education for the achievement of the development of the 21st century skills. Education Sciences, 11(9). https://doi.org/10.3390/educsci11090475
47. Ovbiagbonhia, A. R. (2021). Learning to innovate: How to foster innovation competence in students of Built Environment at universities of applied sciences. Wageningen University and Research.
48. Ovbiagbonhia, A. R., Kollöffel, B., & Perry Den Brok, ·. (2019). Educating for innovation: students' perceptions of the learning environment and of their own innovation competence. Learning Environments Research, 22, 387–407. https://doi.org/10.1007/s10984-019-09280-3
49. Padmanabhan, P., Baez, A., Caiseda, C., McLane, K., Ellanki, N., Seshaiyer, P., Kwon, B., & Massawe, E. (2017). Design Thinking and computational modeling to stop illegal poaching. In 7th IEEE Integrated STEM Education Conference, ISEC 2017 (pp. 175–181). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ISECon.2017.7910238
50. Patton, M. Q. (2014). Qualitative research & evaluation methods: Integrating theory and practice 4th Edition. Sage publications.

51. Ramos, A. K., Trinidad, N., Correa, A., & Rivera, R. (2016). Partnering for health with Nebraskaâ€™s latina immigrant community using design thinking process. Progress in Community Health Partnerships: Research, Education, and Action, 10(2), 311–318. https://doi.org/10.1353/cpr.2016.0022
52. Redmond, P., Alexsen, M., Maloney, S., Turner, J., Brown, A., Basson, M., Galligan, L., Lawrence, J., & Henderson, R. (2023). Student Perceptions of Online Engagement. Online Learning Journal, 27(1), 383–403. https://doi.org/10.24059/olj.v27i1.3320
53. Rubin, Herbert J., and I. S. R. (2011). Qualitative interviewing: The art of hearing data. SAGE Publications Inc.
54. Sáez-López, J. M., Domínguez-Garrido, M. C., Medina-Domínguez, M. D. C., Monroy, F., & González-Fernández, R. (2021). The competences from the perception and practice of university students. Social Sciences, 10(2), 1–12. https://doi.org/10.3390/socsci10020034
55. Schafer, A. G. L., & Yezierski, E. J. (2021). Investigating high school chemistry teachers' assessment item generation processes for a solubility lab. Chemistry Education Research and Practice, 22(1). https://doi.org/10.1039/d0rp00121j
56. Stojcic, N., Hashi, I., & Orlic, E. (2018). Creativity, innovation effectiveness and productive efficiency in the UK. European Journal of Innovation Management, 21(4), 564–580. https://doi.org/10.1108/EJIM-11-2017-0166
57. Surif, J., Ibrahim, N. H., & Dalim, S. F. (2014). Problem Solving: Algorithms and Conceptual and Open-ended Problems in Chemistry. Procedia - Social and Behavioral Sciences, 116, 4955–4963. https://doi.org/10.1016/j.sbspro.2014.01.1055
58. Tran, M. T. (2024). Fostering sustainable mindsets: A critical exploration of educational psychology in business education. International Journal of Management Education, 22(3), 101054. https://doi.org/10.1016/j.ijme.2024.101054
59. Tsaparlis, G., Pantazi, G., Pappa, E. T., & Byers, B. (2021). Using electrostatic potential maps as visual representations to promote better understanding of chemical bonding. Chemistry Teacher International, 3(4), 391–411. https://doi.org/10.1515/cti-2021-0012
60. Wang, X. (2017). Constructing cognitive pattern in design thinking based on complementary perspective. In 6th International Conference on Design, User Experience, and Usability, DUXU 2017, held as part of the 19th International Conference on Human-Computer Interaction, HCI 2017 (Vol. 10288, pp. 198–215). Springer Verlag. https://doi.org/10.1007/978-3-319-58634-2_16
61. World Economic Forum. (2022). The future of jobs report 2020 | world economic forum. The Future of Jobs Report, October, 1163. https://www.weforum.org/reports/the-future-of-jobs-report-2020/digest
62. Wright, G., Skaggs, P., Fry, R., Howell, B., & West, R. (2010). Increasing student innovation by immersing students in an intensive design thinking workshop. In 2010 ASEE Annual Conference and Exposition. American Society for Engineering Education. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029095950&partnerID=40&md5=2d90ec352dbc73329cb6bfe2a0966ed4