SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied
Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Design and Development Research (DDR) Approach in Designing Design Thinking Chemistry Module to Empower Students' Innovation Competencies

Norliyana Md. Aris[1,*], Nor Hasniza Ibrahim[1], Noor Dayana Abd Halim[1]

[1] School of Education, Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Article history:
Received 23 June 2023
Received in revised form 23 September 2023
Accepted 15 February 2024
Available online 25 April 2024

ABSTRACT

Design and evaluation processes to provide an empirical basis for producing instructional and non-instructional products, tools, and new or improved development models. This method uses various methods, including qualitative and quantitative techniques, and thoroughly examines the literature. The design and development of this chemistry module using design thinking to empower students' innovation competencies are described in this article. The main challenge for the teaching implementation process that is capable of mastering the skills of generating new ideas and solving problems in the real world is preparing teaching materials, consuming time, and putting pressure on the teacher. Teachers need more support resources to translate the expected teaching practices. This effort aims to generate a new perspective in education, especially chemistry education, in developing student innovation competence in secondary schools in Malaysia. Therefore, this study aims to discuss the design and development research (DDR) approach used to develop a design thinking chemistry module using a DDR approach. The researcher will go through three study phases and use several different research approaches in each phase. In the first phase, the researcher investigated the teachers' needs in their pedagogy used in teaching and students' innovation competencies. The second phase is the design and development phase, involving the consensus of twelve experts in various fields, such as chemistry/science, technology, engineering, and mathematics (STEM), curriculum development, module construction experts, and research and innovation planning experts. Consequently, the final phase is implementation and evaluation, focusing on determining the module's effectiveness in teaching and learning. Expert consensus is the primary input in developing modules in Malaysian chemistry education. Malaysian education needs to bring a different educational paradigm and teaching strategy, which includes the impact of teacher pedagogy through design thinking in the future. The conclusion of this article proposes a conceptual framework for the research to contribute to the advancement of design thinking and chemistry education.

Keywords:
Design thinking; Design and development research (DDR); Innovation competencies; Teachers' pedagogy; Chemistry education

---

[*] *Corresponding author.*
E-mail address: liyanaaris23@gmail.com

https://doi.org/10.37934/araset.44.1.5568

1. Introduction

Fostering students' innovation competencies and equipping them with the skills necessary to navigate real-world challenges are paramount [1,2]. This study, guided by a design and development research (DDR) approach, sets out to address this need by designing and developing a groundbreaking Design thinking chemistry module. The objective is to empower students' innovation competencies through an immersive and experiential learning experience. By integrating design thinking principles into the chemistry curriculum, this module aims to transform traditional pedagogical practices. It provides teachers with valuable support resources, enabling students to master the art of generating new ideas and problem-solving. Furthermore, the main contribution of this study lies in its comprehensive exploration of teachers' needs, the design and development of the module through expert consensus, and its subsequent implementation and evaluation to assess its effectiveness in enhancing students' innovation competencies. Hence, by bridging the gap between theory and practice, this research endeavors to advance the fields of design thinking and chemistry education, paving the way for a new paradigm in teaching and learning.

Innovation competence emphasizes the demand for education that enables the renewal of initiatives, focusing on changes in teaching and learning with technology integration [3,4]. In line with that, scholars have recommended integrating the teaching and training of innovation competence and its various aspects into the curriculum to foster innovation competence through education [5,6]. According to the literature consensus, education can significantly improve students' innovation competencies [7,8]. However, the existing learning environment is still not optimal for supporting the improvement of student innovation competence [9]. In addition, although the importance of developing students' innovation skills is emphasized, developing teaching strategies and specifications on how teachers should plan curricula for innovation competence are not provided [10,11]. Studies have also revealed little discussion of innovation competence, a learning activity teachers must organize [12].

2. Innovation Competencies and Their Relevance to Chemistry Education

Chemistry education has the potential to provide students with critical skills and knowledge that will allow them to contribute to innovation in a variety of fields, including materials science, biotechnology, energy, and environmental sustainability [13-15]. To meet this need, we developed a chemistry module incorporating design thinking principles to strengthen students' innovation competencies. Empathy, experimentation, and collaboration are critical components of design thinking, a problem-solving approach. By combining design thinking into the chemistry classroom environment, we aim to engage students in a more interactive and exploratory learning experience in which they can apply their knowledge to real-world challenges and develop their innovation competencies.

Traditionally, chemistry education has focused on memorizing and applying established concepts and procedures [16]. This method has successfully taught fundamental principles and prepared students for standardized tests. However, it may not fully equip students with the skills required to succeed in today's rapidly changing world. As the demand for innovation grows across all industries, it is becoming increasingly important for chemistry students to develop creative problem-solving, critical thinking, and design thinking competencies [17].

Innovation competence is also needed to solve many global problems, especially in chemistry [18]. Chemistry is vital in achieving some of the sustainable development goals (SDGs) of the United Nations to ensure a brighter and more sustainable future by 2030, such as nanotechnology, sustainable energy transition, smart cities, innovative industries, and other social and environmental issues [19]. Furthermore, the thought process that goes into it will help students develop creativity, develop new ideas, solve problems, and discover new opportunities in solving problems [20]. Therefore, whether it is the view among scholars or educational policymakers, developing students' innovation competence is necessary to remain relevant in both parties [21,22].

Undeniably, the need for students to empower their innovation competence is critical in producing effective problem solvers, critical thinkers, and creative researchers [3]. The importance of developing innovation competence is demonstrated by innovation being one of the national STEM action plan 2017-2025's focus areas. Aside from research culture and improving the quality of teaching and learning, the federal ministry of science, technology, and innovation (MOSTI) collaborates with the Malaysian ministry of education (KPM) and higher education (KPT) on innovation [23]. According to studies, many educators focus on developing innovation competence through real-world problem-solving in STEM education [24,25]. This chemistry module's development has far-reaching implications for chemistry education and beyond. Thus, we need to prepare students for the challenges and opportunities of a rapidly changing world where creativity, critical thinking, and collaboration are increasingly valued by enhancing innovation competencies.

3. The Potential of Design Thinking in Stimulating Innovation Competencies

The key to developing this innovation competency is creating a quality learning environment that allows students to solve real-world problems and be curious and open-minded [26]. The question here is how the development of innovation competence and maximizing digital technology through one method can impact the development of students' innovation competence. Scholars, among them, have proposed several solutions to apply the design thinking approach as a modern learning paradigm in the classroom. For example [27-29] support this viewpoint, stating that when teachers use a design thinking approach to create learning materials and lectures for students, they improve student learning. Note that the quality of the classroom improves. Hence, design thinking should be one of the solution methods to provide students with the ability to solve problems innovatively [30,31].

Ultimately, design thinking can effectively develop students' innovation competencies [32,33]. Design thinking provides students a structured framework for developing innovation skills [34,35]. Empathy, defining, ideating, prototype, and testing are the five stages of design thinking [36]. Furthermore, this structured framework enables students to develop the systematic problem-solving approach required for innovation. Consequently, students learn to approach problems in a structured and systematic manner, which aids in developing their innovation skills. However, in the context of Malaysia, elements of the design approach are still not disclosed to science and mathematics teachers in particular [37]. Besides, teachers are still unclear about the design approach and how it can be applied in the classroom [38,39] to encourage the development of students' innovation competencies.

4. Design and Development of Design Thinking Chemistry Module

The idea of the entire study is described in the conceptual framework [40]. It also forms the basis of research that clarifies how a concept developed will guide the design and execution of this study. This module development is based on Richey and Klein's DDR, a systematic method for developing teaching modules [41]. Other than that, it involves a process that includes needs analysis, determining gaps to be filled, creating educational goals, designing materials to achieve the objectives, and implementing and evaluating the effectiveness of instructional materials.

This DDR research comprises four comprehensive phases [41]. However, Noh and Karim [38] and Saedah *et al.*, [42] divided DDR research into three stages that have been used in the implementation procedure of this study: (1) needs analysis, (2) design and development, and (3) implementation and evaluation of module results that are developed. The illustration Figure 1 below displays the study design used for each stage of the study implementation process.

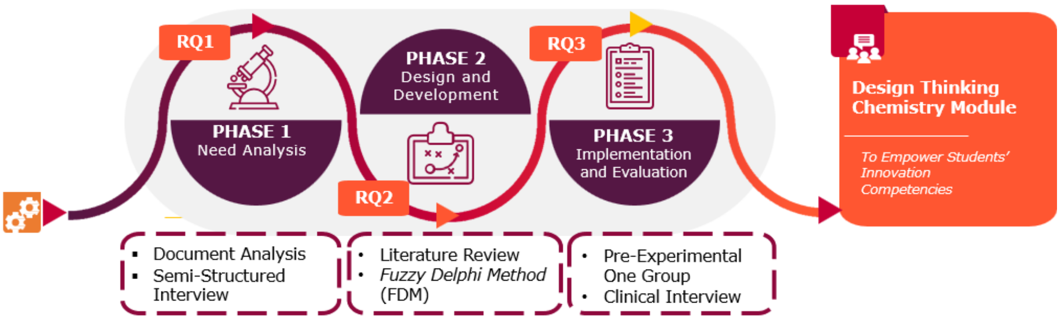

Fig. 1. Research flow chart

4.1 Phase 1- Need Analysis

A needs analysis was the first phase in DDR. A needs analysis was a critical stage in developing a product, in which information could be obtained through the user directly or indirectly [41]. It was intended to look at the problems that arose to predict solutions to future customer needs. Environmental information among the selected population was collected and analyzed to identify the matter's needs. Moreover, this phase focused on what should be done compared to what had been done in a study that identified the need to develop design thinking modules to empower innovation competence in chemistry class [42].

The discrepancy model by McKillip will be used as the model in the needs analysis phase [43] used in the field of educational research. This model emphasized several expectations, namely the process of setting goals, the method of measuring performance that involved identifying what should be done and identifying discrepancies (discrepancy identification) that should have happened (what ought to be), and what exactly a problem was (what was). In the context of this study, needs analysis helped to obtain information about the need to develop design thinking chemistry modules from the perspective of chemistry expert teachers to empower the innovation competencies of high school chemistry students. It is based on the following research questions: 1. Explore the need for applying design thinking for chemistry subjects based on the expert teacher's perspective. 2. Explore teachers' views on the need for chemistry modules to apply design thinking among chemistry students.

A qualitative approach is used in this study, using interview methods and document analysis. The semi-structured interview method is selected as this method allows to obtain information about the participants' perspectives, conduct the study, and better understand a phenomenon [44,45]. Moreover, it provides an advantage in controlling the discussion [46]. Information on opinions, beliefs, attitudes, and experiences could be learned effectively through interviews.

This study also focuses on the needs and applications of technology in teaching and learning in the chemistry classroom. Consequently, this process can identify an initial review of complex information, technical requirements, criteria, appropriate teaching strategies, resource materials, and applications. This explains why semi-structured interviews are considered one of the most valuable techniques for gathering qualitative scientific data. Note that document analysis is utilized in this step to triangulate the study.

4.2 Phase 2- Design and Development

The second phase is the design and development phase of the design thinking module for chemistry subjects in secondary schools based on expert consensus. This design and development phase is crucial for module development in this research. Consequently, McKenny and Reeves [47] argued that this phase is essential and must be emphasized since the product produced, a module, model, or curriculum, is relevant and requires scrutiny to ensure that it benefits users, whether teacher or student. The results obtained in the requirements analysis are used in this phase. Additionally, essential elements in the module, including learning objectives, content modules, activities, and assessment methods, will be designed and evaluated according to an expert consensus before developing the module prototype [48,49]. This phase will determine the appropriate module design and identify important decisions and rational alternatives [42]. This is to meet the needs of the high school chemistry teaching and learning process in improving student innovation competence. Note that the module prototype produced in this phase is based on the inputs obtained [50]. This study developed modules using the IDEO design thinking model [36], and the Sidek module development model as studied by Sidek and Ahmad [56]. The IDEO model contains five phases that are suitable to be used in this development module to increase the efficiency of student innovation as shown in Figure 2.

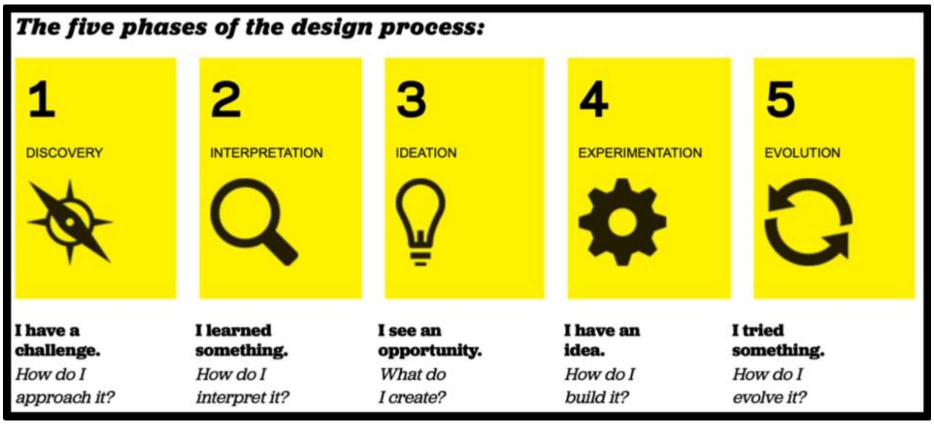

Fig. 2. The five phases of design thinking [36]

IDEO model in Figure 2 is an instructional design model applied to develop student knowledge through experience. Students define problems, identify, and develop potential solutions, and determine how to evaluate real-world work. There are five main phases in the implementation of teaching: exploration, interpretation, idea generation, experimentation, and evolution in the group problem-solving process. A flexible approach through exploring ideas until producing prototypes in solving problems can help students face and solve current challenges.

The theoretical basis of this study is derived from Dewey's experiential learning theory [51]. The roots of pedagogy involving the application of innovation competence can be used in the constructivist approach through collaborative learning and learning from experience [52]. This theory examines reality as constructed, and experience will determine the outcome [53]. Moreover, students develop intuitive thinking skills by engaging in cooperative learning activities that require critical thinking in solving problems by considering various actions [54,55] for a more effective learning process.

Therefore, the selection model in this study is suitable and in line with the primary objective of developing innovation competencies and improving students' mastery of chemical concepts through design thinking in chemistry subjects. Table 1 illustrates the design adaptation of the Sidek module development model in the DDR approach utilized in this study.

Table 1
Applying the Sidek module development model in the design and development of design thinking chemistry module

Phase	Design and development research (DDR)	Sidek module construction model [56]	Description
1	Need analysis	Goal setting, identifying the theory, rationale, philosophy, concept, target, and period, and needs study	Issues and module design on learning based on design thinking to improve innovation efficiency, based on the opinion of the expert chemistry teacher.
2	Design and development	Objective setting, content, strategy, logistics, media selection, and combining draft	Development of module prototype based on expert consensus through the Fuzzy Delphi Method (FDM).
3	Evaluation	Pilot study, validity test, and module evaluation	Conduct the experimental to evaluate the effectiveness

The fuzzy Delphi method (FDM) technique was used in this study to design and develop a design thinking teaching module for high school chemistry students as depicted in Figure 3. FDM is a measurement tool developed or modified from the Delphi method. As a result, FDM is not a new method since it is based on the classic Delphi method, which has been widely employed and accepted in many studies [57-59]. Hence, the researcher chose this FDM approach as this improved FDM can be a more effective measurement tool in placing the strength of element selection in the module based on expert consensus. Studies also prove that this method can solve problems with inaccuracy and uncertainty [60-62]. Furthermore, researchers use the FDM method, which involves a process of agreement or agreement from a group of experts selected to confirm, evaluate, reject, or add elements to the module to be developed [63]. Thus, selecting experts is critical to meet the context of expert consensus in this FDM method.

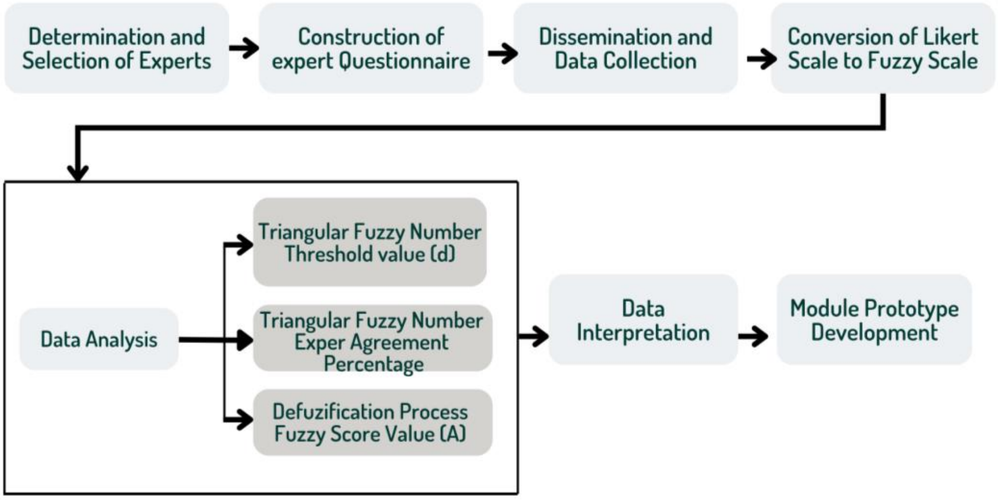

Fig. 3. Fuzzy Delphi method (FDM) approach [64]

To ensure the empirical nature of this study, the researcher followed several steps to implement the fuzzy Delphi method, as illustrated in Figure 3.

Step 1: Determination and selection of experts.

Berliner [65] highlights the importance of selecting experts with a minimum of five years of consistent experience to ensure comprehensive insights into the studied issues. In this study, we purposively sampled 12 experts to form a diverse panel encompassing expertise in Chemistry Education, Curriculum, Module Development, Research, and Innovation. This panel size aligns with the recommendation by Adler and Ziglio [66], who suggest involving 10 to 15 experts in the Delphi technique to achieve a high level of agreement.

Step 2: The construction of the experts' questionnaire.

In this study, a researcher developed a questionnaire based on a literature review and expert discussions, following recommended guidelines [67]. The questionnaire utilized a 7-point Likert scale, chosen for its ability to reduce ambiguity and promote higher expert agreement. Moreover, previous research findings [58,64] supported the superior accuracy achieved with a 7-point Likert scale compared to a 5-point Likert scale. Experts requested to indicate their level of agreement with the provided statements, facilitating content validation.

Step 3: Dissemination and data collection.

In this step, we distributed the developed questionnaires to the identified experts through two methods: (i) conducting face-to-face meetings with each expert or (ii) disseminating the questionnaires online, such as via email.

Step 4: Conversion of Likert scale to fuzzy scale.

All linguistic variables are converted into fuzzy triangular numbers, assigning a fuzzy rij number to each criterion representing the K expert.

$$I = 1 \dots m, j = 1, \dots n, \qquad K = 1 \dots., k \ and \ rij = 1/K \ (r^1 ij \pm r^2 ij \pm r^K ij)\text{I= 1} \tag{1}$$

The average data value was calculated using a Delphi Fuzzy Analysis template developed in Microsoft Excel.

Step 5(a): Determining threshold value (*d*).

Subsequently, experts' agreement for each item was indicated by the threshold value d, which must be less than or equal to 0.2—an undeniable consensus achieved [68]. The distances between two fuzzy numbers, m = (*m1*, *m2*, *m3*), and n = (*n1*, *n2*, *n3*), were computed using the following formula.

$$d\ (m, n) = \surd 1/3\ [(m1 - n2)2 + (m2 - n2)2 + (m3 - n3)2] \tag{2}$$

Step 5(b): Percentage expert consensus

The percentage of expert consensus must be more than 75%, indicating that the experts have reached an agreement. Correspondingly, any questionnaire item not reaching an agreement was dropped [69].

Steps 5(c): Defuzzification process

If the group consensus percentage exceeded 75%, the researcher proceeded with the Defuzzification Process to determine the fuzzy score value (A). The fuzzy score (A) had to be equal to or greater than the median value (α-cut value) of 0.5 [70], indicating agreement among the experts and acceptance of the item. The formula used is as follows:

$$Amax = 1/3 * (m1 + m2 + m3) \tag{3}$$

Based on the consensus obtained from the experts, we developed prototypes of the chemistry design thinking module. This phase involved restructuring the content program, organizational chart, storyboard, flowchart program, screen design, evaluation process, and repetition. Before the module's actual implementation by the group, we conducted a pilot study with a student group to identify any issues that arose during module development.

4.3 Phase 3- Evaluation

The module's impact on enhancing innovation competence and mastery of concepts is thoroughly evaluated in the final phase of this innovative design research. Sidek and Ahmad [56] emphasize that the evaluation module encompasses various activities and questions. To comprehensively assess the module, three types of assessments, formative, summative, and confirmatory [71], are conducted throughout the teaching process and after completion. This study also evaluates the module's effectiveness in improving students' innovation competence, encompassing individual, interpersonal, and network dimensions. The assessment process involves administering a pre-test (O_1) to gauge students' baseline abilities, followed by implementing the design thinking module (X) as a treatment, and finally conducting a post-test (O_2) as depicted in Figure 4. To evaluate creative problem-solving and thinking skills development, structured problem-based learning questions and pre-post multiple-choice questions are utilized. Meanwhile, increased scores on both tests indicate progress.

Furthermore, dimensions such as goal orientation, group work, and networking are evaluated through assigned design projects. Throughout the group intervention, an observation list of innovation competencies, encompassing 25 items across five primary domains, offers a comprehensive snapshot of student innovation competence during each classroom session. This meticulous evaluation process enables a thorough understanding of students' growth and development in innovation competence.

Controlling all types of threats related to procedures and participants' experiences is essential to guard against threats to internal validity [67,72]. Therefore, during the implementation of the experimental study, we will ensure the control of threats to internal and external validity. According to Creswell [72], a study involving one group may face a significant threat from history and maturity when extending the study period. To mitigate this threat, the researcher conducted a four-week interval study. Other than that, previous studies by Omar [73] support the appropriateness of a four-week interval, as it effectively addresses the threat and achieves the study's objectives. The researcher utilized the same rubric and scoring scheme for pre- and post-tests to maintain consistency in testing and measurement.

This impactful study collects quantitative data through pre-test and post-test scores while gathering qualitative data through clinical interviews with teachers and students. The data collection is seamlessly integrated into the student's learning environment to ensure validity and trustworthiness [72,73]. Moreover, the study explores improvements in innovation competence and student conceptual changes by evaluating intervention effects and classroom observations. This comprehensive approach provides valuable insights to enhance students' development.

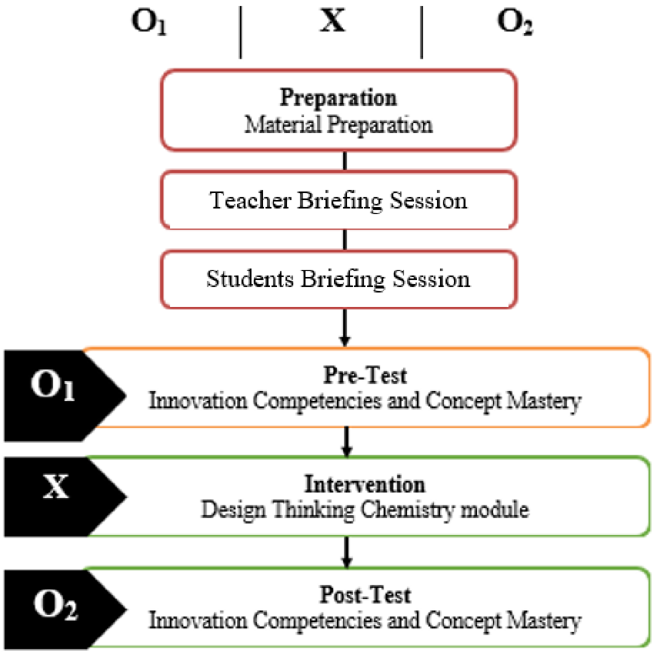

Fig. 4. Evaluation phase procedures

5. Research Conceptual Framework

DDR's systematic and evidence-based nature enables a comprehensive understanding of design and development processes [42,59]. DDR's iterative and evaluative nature allows for the refinement and improvement of instructional interventions [41]. Furthermore, the involvement of expert consensus enhances the quality and relevance of the design thinking chemistry module. By aligning with previous research on the benefits of DDR in educational design and development, this study contributes to advancing the field. It ensures a robust and practical approach to instructional design in chemistry education. The study aims to create a comprehensive reference tool for enhancing student innovation competence by incorporating STEM teaching strategies. Figure 5 illustrates the conceptual framework employed in this study. To initiate the teaching process, the teacher will catalyze organizing knowledge by integrating students' existing knowledge.

Consequently, the experience phase, where the implementation of teaching based on the design thinking model of IDEO [36], is conducted. The IDEO design thinking model application allows students to solve creative problems in group work systematically according to the five phases in this model. Next, evaluate the impact of learning strategies on the dimension of innovation competence while looking at the impact on students' mastery of concepts.

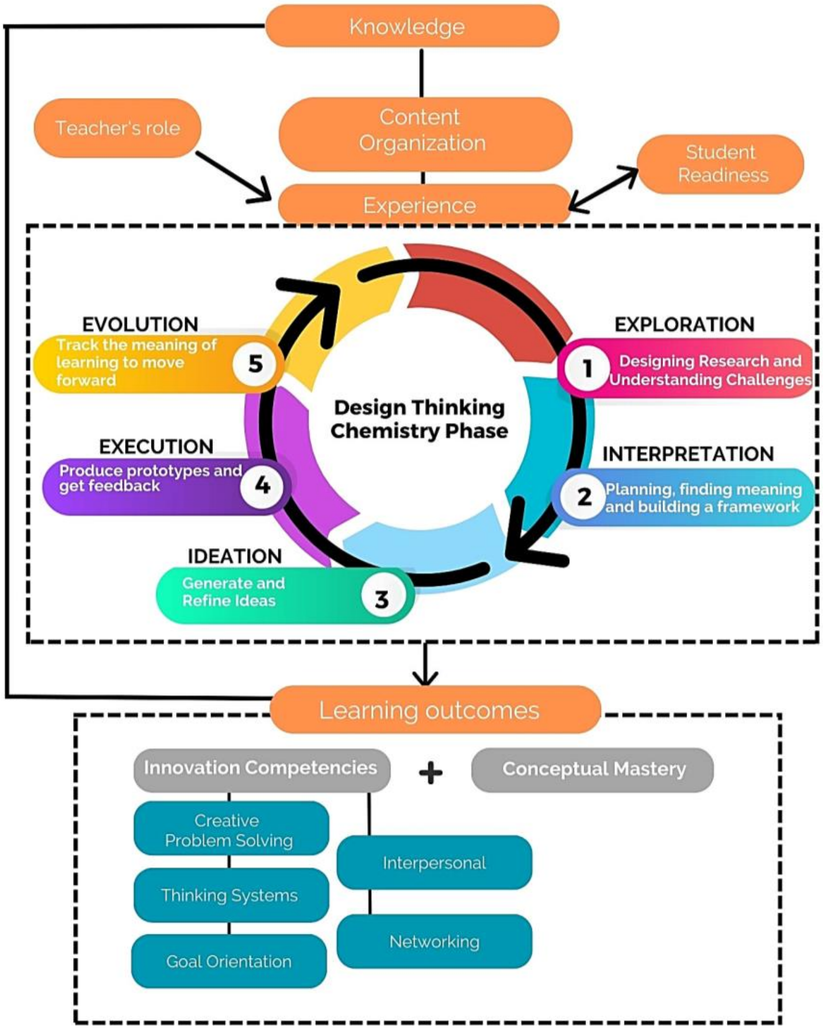

Fig. 5. Research conceptual framework

6. Conclusion and Recommendation

This research provides an empirical basis for producing instructional materials that empower students' innovation competencies by systematically studying the design, development, and evaluation processes. Through the DDR approach, which incorporates qualitative and quantitative techniques and thorough literature examination, the study phases and research approaches contribute to the comprehensive development of the module. The expert consensus from diverse fields ensures the quality and relevance of the module in Malaysian chemistry education. This study contributes valuable insights into design thinking and chemistry education. Hence, it is crucial to consider certain limitations. The study's findings may have limited generalizability due to its exclusive focus on Malaysian secondary schools. It would be beneficial to conduct the study in various educational contexts to acquire a thorough knowledge of the effectiveness of the design thinking chemistry module.

In conclusion, this study has significantly contributed to the field of design thinking and chemistry education. The design thinking chemistry module has successfully addressed the challenge of creating effective teaching materials and has provided teachers with invaluable support resources. Moreover, the module has bridged the gap between theoretical understanding and practical problem-solving abilities by strengthening students' innovation competencies. The proposed conceptual framework advances design thinking principles in the context of chemistry education and ensures the module's quality and relevance through expert consensus. Furthermore, the implementation and evaluation phases can prove the module's effectiveness in teaching and learning. This research offers a new perspective on education and emphasizes the significance of teacher pedagogy and the necessity for a different educational paradigm. This study highlights the potential to transform chemistry education practices and promote student innovation by integrating design thinking principles. Therefore, the findings of this study can guide the development of instructional materials and strategies that foster innovation competencies and advance the field of design thinking and chemistry education, informing future research and educational initiatives in Malaysia and beyond.

References

[1] Ovbiagbonhia, A. R., Bas Kollöffel, and Perry den Brok. "Educating for innovation: Students' perceptions of the learning environment and of their own innovation competence." *Learning environments research* 22 (2019): 387-407. https://doi.org/10.1007/s10984-019-09280-3

[2] Hero, Laura-Maija, Marianne Pitkäjärvi, and Kaija Matinheikki-Kokko. "Validating an individual innovation competence assessment tool for university–industry collaboration." *Industry and Higher Education* 35, no. 4 (2021): 485-496. https://doi.org/10.1177/09504222211017447

[3] Hero, Laura-Maija, Eila Lindfors, and Vesa Taatila. "Individual Innovation Competence: A Systematic Review and Future Research Agenda." *International Journal of Higher Education* 6, no. 5 (2017): 103-121. https://doi.org/10.5430/ijhe.v6n5p103

[4] Falloon, Garry. "From digital literacy to digital competence: the teacher digital competency (TDC) framework." *Educational Technology Research and Development* 68 (2020): 2449-2472. https://doi.org/10.1007/s11423-020-09767-4

[5] Bascopé, Martín, Paolo Perasso, and Kristina Reiss. "Systematic review of education for sustainable development at an early stage: Cornerstones and pedagogical approaches for teacher professional development." *Sustainability* 11, no. 3 (2019): 719. https://doi.org/10.3390/su11030719

[6] Durall, Eva, Claudia Carter, and Kathryn Burns. "Transdisciplinary education and innovation through STEAM." In *Proceedings of the Mini-Conference on Transdisciplinary Research and Design (TRaD 2022): 14th February 2022, University of Oulu (online)*. Oulun yliopisto, 2022.

[7] Hu, Meng-Lei I-Chen Monica, Jeou-Shyan Horng, and Chih-Ching Teng. "Developing A model for an innovative culinary competency curriculum and examining its effects on students' performance." *The Journal of Creative Behavior* 50, no. 3 (2016): 193-202. https://doi.org/10.1002/jocb.139

[8] Ovbiagbonhia, A. R., Bas Kollöffel, and Perry Den Brok. "Teaching for innovation competence in higher education Built Environment engineering classrooms: teachers' beliefs and perceptions of the learning environment." *European Journal of Engineering Education* 45, no. 6 (2020): 917-936. https://doi.org/10.1080/03043797.2020.1784097

[9] Keinänen, Meiju Marika, and Liisa Kairisto-Mertanen. "Researching learning environments and students' innovation competences." *Education+ Training* 61, no. 1 (2019): 17-30. https://doi.org/10.1108/ET-03-2018-0064

[10] Herodotou, Christothea, Mike Sharples, Mark Gaved, Agnes Kukulska-Hulme, Bart Rienties, Eileen Scanlon, and Denise Whitelock. "Innovative pedagogies of the future: An evidence-based selection." In *Frontiers in Education*, vol. 4, p. 113. Frontiers Media SA, 2019. https://doi.org/10.3389/feduc.2019.00113

[11] Franco, Isabel, Osamu Saito, Philip Vaughter, Josh Whereat, Norichika Kanie, and Kazuhiko Takemoto. "Higher education for sustainable development: Actioning the global goals in policy, curriculum and practice." *Sustainability Science* 14 (2019): 1621-1642. https://doi.org/10.1007/s11625-018-0628-4

[12] Redman, Aaron, Arnim Wiek, and Matthias Barth. "Current practice of assessing students' sustainability competencies: A review of tools." *Sustainability Science* 16 (2021): 117-135. https://doi.org/10.1007/s11625-020-00855-1

[13] Droescher, Michael. "Chemistry: The driving force for emerging technologies." *Chemistry International* 40, no. 4 (2018): 14-17. https://doi.org/10.1515/ci-2018-0405

[14] Gomollón-Bel, Fernando. "Ten Chemical innovations that will change our world: The developing science that will fight the pandemic and reshape the chemical landscape." *Chemistry International* 42, no. 4 (2020): 3-9. https://doi.org/10.1515/ci-2020-0402

[15] Ferreras-Garcia, Raquel, Jordi Sales-Zaguirre, and Enric Serradell-López. "Sustainable innovation in higher

education: the impact of gender on innovation competences." *Sustainability* 13, no. 9 (2021): 5004. https://doi.org/10.3390/su13095004
[16] Dood, Amber J., and Field M. Watts. "Students' strategies, struggles, and successes with mechanism problem solving in organic chemistry: a scoping review of the research literature." *Journal of Chemical Education* 100, no. 1 (2022): 53-68. https://doi.org/10.1021/acs.jchemed.2c00572
[17] Mahaffy, Peter G., Stephen A. Matlin, Thomas A. Holme, and Jennifer MacKellar. "Systems thinking for education about the molecular basis of sustainability." *Nature Sustainability* 2, no. 5 (2019): 362-370. https://doi.org/10.1021/acs.jchemed.9b00991
[18] Garcia-Martinez, Javier. "Chemistry 2030: a roadmap for a new decade." *Angewandte Chemie* 133, no. 10 (2021): 5008-5012. https://doi.org/10.1002/ange.202014779
[19] Anastas, Paul T., and Julie B. Zimmerman. "The United Nations sustainability goals: How can sustainable chemistry contribute?." *Current Opinion in Green and Sustainable Chemistry* 13 (2018): 150-153. https://doi.org/10.1016/j.cogsc.2018.04.017
[20] Chen, Li, Koichi Inoue, Yoshiko Goda, Fumiya Okubo, Yuta Taniguchi, Misato Oi, Shin'ichi Konomi, Hiroaki Ogata, and Masanori Yamada. "Exploring factors that influence collaborative problem solving awareness in science education." *Technology, Knowledge and Learning* 25 (2020): 337-366. https://doi.org/10.1007/s10758-020-09436-8
[21] International Technology and Engineering Educators Association. "Standards for technological and engineering literacy: The role of technology and engineering in STEM education." *(No Title)* (2020).
[22] Diez-Ojeda, María, Miguel Ángel Queiruga-Dios, Noelia Velasco-Pérez, Emilia López-Iñesta, and José Benito Vázquez-Dorrío. "Inquiry through industrial chemistry in compulsory Secondary Education for the achievement of the development of the 21st Century skills." *Education Sciences* 11, no. 9 (2021): 475. https://doi.org/10.3390/educsci11090475
[23] DSTIN (2021-2030), "Pengenalan kepada Dasar Sains, Teknologi dan Inovasi Negara (DSTIN)." *Portal Rasmi Kementerian Sains, Teknologi Dan Inovasi* (2024).
[24] Nguyen, Thi Phuoc Lai, Thi Huy Nguyen, and Thanh Khiet Tran. "STEM education in secondary schools: Teachers' perspective towards sustainable development." *Sustainability* 12, no. 21 (2020): 8865. https://doi.org/10.3390/su12218865
[25] Chalkiadaki, Areti. "A systematic literature review of 21st century skills and competencies in primary education." *International Journal of Instruction* 11, no. 3 (2018): 1-16. https://doi.org/10.12973/iji.2018.1131a
[26] Keinänen, Meiju, Jani Ursin, and Kari Nissinen. "How to measure students' innovation competences in higher education: Evaluation of an assessment tool in authentic learning environments." *Studies in Educational Evaluation* 58 (2018): 30-36. https://doi.org/10.1016/j.stueduc.2018.05.007
[27] J. H. L. Koh, C. S. Chai, B. Wong, and H.-Y. Hong, *Design thinking for education: Conceptions and applications in teaching and learning*. Springer Singapore, 2015.
[28] Zupan, Blaž, Anja Svetina Nabergoj, and Franc Cankar. "Design thinking as a methodology for teaching entrepreneurial mindset in primary education." In *International Conference on Innovation and Entrepreneurship*, pp. 893-XXII. Academic Conferences International Limited, 2018.
[29] Hsiao, Hsien-Sheng, Kuang-Chao Yu, Yu-Shan Chang, Yu-Hung Chien, Kuen-Yi Lin, Chien-Yu Lin, Jyun-Chen Chen, Jheng-Han Chen, and Yi-Wei Lin. "The study on integrating the design thinking model and STEM activity unit for senior high school living technology course." In *2017 7th World Engineering Education Forum (WEEF)*, pp. 383-390. IEEE, 2017. https://doi.org/10.1109/WEEF.2017.8467111
[30] Pruneau, Diane, Viktor Freiman, Michel T. Léger, Liliane Dionne, Vincent Richard, and Anne-Marie Laroche. "Design Thinking and Collaborative Digital Platforms: Innovative Tools for Co-creating Sustainability Solutions." *Innovations and Traditions for Sustainable Development* (2021): 207-226. https://doi.org/10.1007/978-3-030-78825-4_13
[31] Scott, Julia A., Evangelia Bouzos, Matthew Philip Hendricks, and Prashanth Asuri. "Cultivating Student Adoption of Design Thinking and Entrepreneurial Skills by Addressing Complex Challenges in Healthcare Through Industry Partnerships." In *2021 ASEE Virtual Annual Conference Content Access*. 2021.
[32] Androutsos, Athanassios, and Vasiliki Brinia. "Developing and piloting a pedagogy for teaching innovation, collaboration, and co-creation in secondary education based on design thinking, digital transformation, and entrepreneurship." *Education Sciences* 9, no. 2 (2019): 113. https://doi.org/10.3390/educsci9020113
[33] Raber, Mary, Mary Fraley, and Amber Kemppainen. "Incorporating design thinking into the first-year engineering curriculum." In *2018 ASEE Annual Conference & Exposition*. 2018.
[34] Lynch, Matthew, Uladzimir Kamovich, Kjersti K. Longva, and Martin Steinert. "Combining technology and entrepreneurial education through design thinking: Students' reflections on the learning process." *Technological Forecasting and Social Change* 164 (2021): 119689. https://doi.org/10.1016/j.techfore.2019.06.015
[35] Garcia-Vaquero, Marco. "Design thinking online: approaching constructive learning in food science." *COGNITION*

AND EXPLORATORY LEARNING IN THE DIGITAL AGE (CELDA 2021) (2021): 339.
[36] IDEO. *Design thinking for educators*. 2012.
[37] Adam, Nur Amelia, and Lilia bt Halim. "Cabaran pengintegrasian pendidikan STEM dalam kurikulum Malaysia." *Seuntai Kata* (2019): 252.
[38] Noh, Suhaila Che, and Abdul Malek Abdul Karim. "Design thinking mindset to enhance education 4.0 competitiveness in Malaysia." *International journal of evaluation and research in education* 10, no. 2 (2021): 494-501. https://doi.org/10.11591/ijere.v10i2.20988
[39] Nurulrabihah, Mat Noh. "Pembangunan model pengajaran pemikiran reka bentuk sekolah rendah/Nurulrabihah Mat Noh." PhD diss., Universiti Malaya, 2020.
[40] Nieveen, Nienke, Susan McKenney, and Jan van den Akker. "Educational design research: the value of variety." In *Educational design research*, pp. 163-170. Routledge, 2006. https://doi.org/10.4324/9780203088364
[41] Richey, Rita C., and James D. Klein. "Design and development research." *Handbook of research on educational communications and technology* (2014): 141-150. https://doi.org/10.1007/978-1-4614-3185-5_12
[42] Saedah, S., T. L. A. Muhammad Ridhuan, and M. R. Rozaini. "Pendekatan Penyelidikan Rekabentuk dan Pembangunan (PRP): Aplikasi kepada Penyelidikan Pendidikan." *Tanjong Malim, Perak: Universiti Pendidikan Sultan Idris (UPSI)* (2020).
[43] Jack McKillip, *Identifying Needs In: Nedd Analysis*. SAGE Publications, Inc., 2011. https://doi.org/10.4135/9781412985260
[44] Creswell, John W., and Cheryl N. Poth. *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications, 2016.
[45] Merriam, Sharan B., and Robin S. Grenier, eds. *Qualitative research in practice: Examples for discussion and analysis*. John Wiley & Sons, 2019.
[46] Choak, Clare. "Asking questions: Interviews and evaluations." In *Research and research methods for youth practitioners*, pp. 90-112. Routledge, 2013.
[47] McKenney, Susan, and Thomas C. Reeves. "Educational design research." *Handbook of research on educational communications and technology* (2014): 131-140. https://doi.org/10.1007/978-1-4614-3185-5_11
[48] Ahmad, Zanariah. "Pembangunan modul pedagogi kelas berbalik berasaskan pembelajaran reflektif untuk politeknik premier." PhD diss., University of Malaya (Malaysia), 2017.
[49] Dahaman, Amani. "Pembangunan modul m-pembelajaran bahasa Arab di institut pendidikan guru." PhD diss., University of Malaya, 2014.
[50] Padzil, Mohd Ridzuan, Aidah Abd Karim, and Hazrati Husnin. "Employing DDR to design and develop a flipped classroom and project based learning module to applying design thinking in design and technology." *International Journal of Advanced Computer Science and Applications* 12, no. 9 (2021). https://doi.org/10.14569/IJACSA.2021.0120988
[51] Roberts, T. Grady. "An Interpretation of Dewey's Experiential Learning Theory." (2003).
[52] Scheer, Andrea, Christine Noweski, and Christoph Meinel. "Transforming constructivist learning into action: Design thinking in education." *Design and Technology Education* 17, no. 3 (2012): 8-19.
[53] Norlidah, Alias. "Pembangunan modul pedagogi berasaskan teknologi dan gaya pembelajaran Felder-Silverman Kurikulum Fizik Sekolah Menengah/Norlidah Alias." PhD diss., University of Malaya, 2010.
[54] Cho, Youngwoo, and Renee M. Clary. "Challenges and opportunities for virtual learning in college geology." *Active Learning in College Science: The Case for Evidence-Based Practice* (2020): 713-728. https://doi.org/10.1007/978-3-030-33600-4_44
[55] Spitzman, Emily, and Alexandra Balconi. "Social justice in action: A document analysis of the integration of social justice principles into teaching." *Journal of the Scholarship of Teaching and Learning* 19, no. 5 (2019). https://doi.org/10.14434/josotl.v19i5.25071
[56] Mohd, Sidek, and Jamaludin Ahmad. *Pembinaan modul: Bagaimana membina modul latihan dan modul akademik*. Penerbit Universiti Putra Malaysia, 2005.
[57] Cone, Catherine, and Elizabeth Unni. "Achieving consensus using a modified Delphi Technique embedded in Lewin's change management model designed to improve faculty satisfaction in a pharmacy school." *Research in Social and Administrative Pharmacy* 16, no. 12 (2020): 1711-1717. https://doi.org/10.1016/j.sapharm.2020.02.007
[58] Yaakob, Muhammad Nidzam. "Pembangunan model kurikulum m-pembelajaran kursus teknologi dalam pengajaran dan pembelajaran di institut pendidikan guru." *Unpublished doctoral dissertation, Universiti Utara Malaysia* (2017).
[59] Jamil, Mohd Ridhuan Mohd, and Nurulrabihah Mat Noh. "Kepelbagaian metodologi dalam penyelidikan reka bentuk dan pembangunan." *Shah Alam: Qaisar Prestige Resources* (2020).
[60] Zhu, Min, Wenbo Zhou, Min Hu, Juan Du, and Tengfei Yuan. "Evaluating the Renewal Degree for Expressway Regeneration Projects Based on a Model Integrating the Fuzzy Delphi Method, the Fuzzy AHP Method, and the

TOPSIS Method." *Sustainability* 15, no. 4 (2023): 3769. https://doi.org/10.3390/su15043769

[61] Bui, Tat Dat, Feng Ming Tsai, Ming-Lang Tseng, and MohD Helmi Ali. "Identifying sustainable solid waste management barriers in practice using the fuzzy Delphi method." *Resources, conservation and recycling* 154 (2020): 104625. https://doi.org/10.1016/j.resconrec.2019.104625

[62] Lim, You Rang, Aini Suzana Ariffin, Mazlan Ali, and Kuei-Lun Chang. "A hybrid MCDM model for live-streamer selection via the fuzzy delphi method, AHP, and TOPSIS." *Applied Sciences* 11, no. 19 (2021): 9322. https://doi.org/10.3390/app11199322

[63] Siraj, Saedah, Muhammad Ridhuan, and Rozami Muhamad Rozkee. "Pendekatan penyelidikan rekabentuk dan pembangunan. Aplikasi kepada pendidikan." *Penerbit Universiti Pendidikan Sultan Idris* (2021).

[64] Jamil, Mohd Ridhuan Mohd. "Pembangunan model kurikulum latihan SkiVes bagi program pengajian kejuruteraan pembelajaran berasaskan kerja." PhD diss., University of Malaya (Malaysia), 2016.

[65] Berliner, David C. "Describing the behavior and documenting the accomplishments of expert teachers." *Bulletin of Science, Technology & Society* 24, no. 3 (2004): 200-212. https://doi.org/10.1177/0270467604265535

[66] Adler, Michael, and Erio Ziglio. *Gazing into the oracle: The Delphi method and its application to social policy and public health*. Jessica Kingsley Publishers, 1996.

[67] Sekaran, Uma, and Roger Bougie. *Research methods for business: A skill building approach*. john wiley & sons, 2016.

[68] Cheng, Ching-Hsue, and Yin Lin. "Evaluating the best main battle tank using fuzzy decision theory with linguistic criteria evaluation." *European journal of operational research* 142, no. 1 (2002): 174-186. https://doi.org/10.1016/S0377-2217(01)00280-6

[69] Mohd Ridhuan, M. J., S. Saedah, H. Zaharah, M. N. Nurulrabihah, and S. Arifin. "Pengenalan asas kaedah Fuzzy Delphi dalam penyelidikan rekabentuk pembangunan." *Minda Intelek Agency* (2014).

[70] Tang, Chia-Wei, and Cheng-Ta Wu. "Obtaining a picture of undergraduate education quality: a voice from inside the university." *Higher Education* 60 (2010): 269-286. https://doi.org/10.1007/s10734-009-9299-5

[71] Richey, Rita C., and James D. Klein. *Design and development research: Methods, strategies, and issues*. Routledge, 2014. https://doi.org/10.4324/9780203826034

[72] Creswell, John W. "Research design: qualitative, quantitative, and mixed methods approaches." (2014).

[73] Omar, Siti Salbiah. "Model Kreativiti Terarah, Kemahiran Proses Sains Dan Soalan Terbuka Bagi Menggalakkan Kreativiti Dalam Pembelajaran Kimia." *Fakulti Sains Sosial dan Kemanusiaan Universiti Teknologi Malaysia* (2019).