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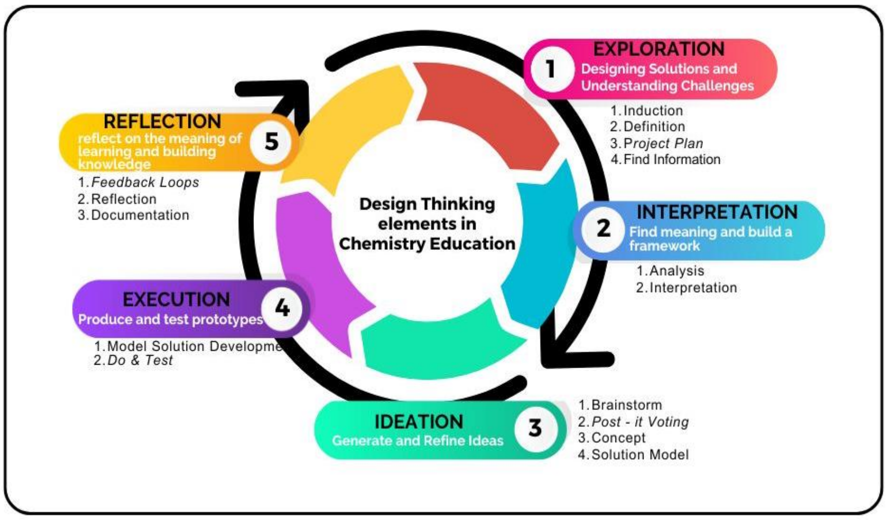
Determining design thinking elements in chemistry education: A Fuzzy Delphi method

Norliyana binti Md. **Aris**[1+], Nor Hasniza binti **Ibrahim**[1], Noor Dayana binti Abd **Halim**[1], Nurul Hanani binti **Rusli**[1], Muhammad Nidzam bin **Yaakob**[2]

Abstract

Creating a high-quality learning environment where students can solve real-world problems and be receptive is essential for fostering students' innovation competencies. Using appropriate pedagogical strategies and classroom activities is a crucial aspect of Malaysian education. This article uses the Fuzzy Delphi Method (FDM) to design chemistry classroom teaching strategies based on the design thinking paradigm. This research involves 12 experts in purposive sampling to form a diverse panel encompassing expertise in Chemistry Education, Curriculum, Module Development, Research, and Innovation. Using the Fuzzy Delphi method (FDM), the data were analyzed. Four elements for exploratory constructs, two elements for construct interpretation, four elements for ideation, two elements for execution, and three elements for construct evolution met the FDM requirements, according to the findings. Its threshold value is less than 0.2, the expert consensus is less than 75%, and the average score of the fuzzy number is over 0.5. Encouraging design thinking in chemistry classes and thereby enhancing students' innovation skills, this research unquestionably induces a paradigm shift in teaching practice.



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Habiddin Habiddin
Natany Dayani de Souza Assai

Highlights

- Designed innovative chemistry teaching strategies using the Fuzzy Delphi method.
- Promoted design thinking to boost students' innovation competencies in chemistry.
- Emphasizes real-world problem-solving and inquisitive learning in chemistry.
- Integration of design thinking to foster student innovation skills.
- Verified expert consensus on the design thinking framework in chemistry education.

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[1]University of Technology Malaysia, Faculty of Educational Sciences and Technology, Johor Bahru, Malaysia. [2]Darulaman Campus Teacher Education Institute, Jitra, Malaysia.
+Corresponding author: Norliyana binti Aris, Phone: +6013-3881723, Email address: liyanaaris23@gmail.com

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1. Introduction

Innovation competency emphasizes the need for an educational strategy promoting active learning and real-world problem-solving (Hero *et al.*, 2017) and highlights the seamless technological integration of teaching and learning transitions (Falloon, 2020). Academic scholars propose the inclusion of innovation competence and its various dimensions in the curriculum to cultivate innovation competence through educational practices (Bascopé *et al.*, 2019; Durall *et al.*, 2022). There is consensus in the research that education positively impacts students' creativity and innovation (Hu *et al.*, 2016; Ovbiagbonhia *et al.*, 2020). In contemporary days, it is imperative for academics and educational authorities to actively promote the development of students' inventive competency (Ojeda *et al.*, 2021). To foster the development of students' innovation competence, educators require clear principles for designing instructional approaches and curricula that effectively enhance expected competence (Franco *et al.*, 2019; Herodotou *et al.*, 2019). Nevertheless, there is a massive gap between the curricular aspirations in facing real-world needs and the actual learning outcomes and competencies of students in chemistry education (Hero, Pitkäjärvi, and Matinheikki-Kokko 2021; OCDE 2018). Additionally, the current educational setting may not offer a conducive environment for fostering students' competency in innovation (Keinänen and Kairisto-Mertanen, 2019). Studies have shown that chemistry students struggle to explain phenomena based on knowledge (Kanapathy et al. 2019) and solve problems in real-world contexts or generate original ideas from learned concepts (Broman *et al.*, 2018).

The importance of innovation skills in addressing global challenges, particularly in chemistry, has been well recognized (Garcia-Martinez, 2021). Chemistry significantly advances many Sustainable Development Goals (SDGs) outlined by the United Nations to foster a more sustainable future by 2030. These goals include nanotechnology, sustainable energy transition, smart cities, innovative industries, and addressing social and environmental concerns (Anastas and Zimmerman, 2018). The emphasis on innovation within the National STEM Action Plan for 2017–2025 underscores the importance of cultivating expertise in innovation. The collaboration between the Federal Ministry of Science, Technology, and Innovation (MOSTI) and the Malaysian Ministries of Education (KPM) and Higher Education (KPT) encompasses various areas such as innovation, cultural research, and the enhancement of teaching and learning quality. The discipline of chemistry education equips students with the necessary skills and knowledge to foster innovation in several domains as the demand for creativity grows across multiple industries (Droescher, 2018; García-Pérez *et al.*, 2021; Gomollón-Bel, 2020). Previous research shows that chemistry educators' instructional techniques and classroom practices have still to cultivate innovation and problem-solving skills (Keinänen and Kairisto-Mertanen, 2019) effectively. Additionally, restricted resources and teachers' heavy workloads pose obstacles to enhancing innovation competence in the classroom (Lo *et al.*, 2019). Given the critical role that chemistry educators must play, this study uses a Fuzzy Delphi approach, which gathers views from a diverse panel of experts, synthesizes their knowledge, and coordinates different perspectives to create a strategic framework. This framework aims to integrate elements of design thinking into the chemistry curriculum, thereby increasing students' innovation efficiency in a dynamic educational environment.

2. 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 (Keinänen *et al.*, 2018). 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 (Hsiao *et al.*, 2017; Koh *et al.*, 2015; Zupan *et al.*, 2018) support this viewpoint, states that when teachers use a design thinking approach to create learning materials and lectures for students, they improve student learning. The quality of the classroom improves. Design thinking should be one of the solution methods to provide students with the ability to solve problems innovatively (Pruneau *et al.*, 2021; Scott *et al.*, 2021). The development of innovation competence can be encouraged by creating a learning environment that promotes student engagement with real-world challenges and encourages curiosity and creativity (IDEO, 2012; Keinänen *et al.*, 2018).

Ultimately, design thinking effectively develops students' innovation competencies (Androutsos and Brinia, 2019; Raber *et al.*, 2018). Design thinking gives students a structured framework for developing innovation skills (Garcia-Vaquero, 2021; Lynch *et al.*, 2021). By embracing design thinking, students are equipped with a structured yet inventive problem-solving methodology, enabling them to approach challenges creatively and systematically. Within this structured guidance, educators play a crucial role, instilling in students the art of methodical problem-solving that fosters innovation (Jan *et al.*, 2017). However, in the context of Malaysia, elements of the design thinking approach are still not disclosed to Science and Mathematics teachers (Adam and Halim, 2019) and teachers are still unclear about the design thinking approach and how it can be applied in the classroom (Noh and Karim, 2021; Noh, 2020) to encourage the development of students' innovation competencies. Therefore, this study aimed to provide concrete solutions to stimulate and enhance student innovation competencies and employ the Fuzzy Delphi Method to determine the elements of Design Thinking in Chemistry Classroom Teaching Strategies. The research questions that need to be answered are:

1. What are the elements of design thinking implementation in chemistry classroom education through expert consensus?
2. What are this item's values and rankings for each element based on an expert consensus?

3. Research design

This research adopts the Fuzzy Delphi technique to gain expert approval. The Fuzzy Delphi technique, or the Fuzzy Delphi method (FDM), is a measurement and tool developed or modified from the Delphi method. As a result, FDM is not a new method because it is based on the classic Delphi method, which has been widely used and accepted in many studies (Cone and Unni, 2020; Jamil and Noh, 2020). The selection of experts is significant in meeting the consensus of experts in this FDM as it involves a process of agreement from a group of experts to verify, evaluate, reject, or add elements to the framework. Thus, selecting experts is critical to meet the context of expert consensus in this FDM method. The FDM can be a more effective measurement tool in placing the strength of element selection for design thinking elements in chemistry classroom teaching strategies based on expert consensus. Studies also prove that this method can solve problems with inaccuracy and uncertainty for a study (Bui *et al.*, 2020; Lim *et al.*, 2021; Zhu *et al.*, 2023).

Berliner (2004) emphasizes the significance of selecting experts with a minimum of five years of consistent expertise to guarantee a comprehensive understanding of the issues under study. This study recruited a purposeful sample of 12 diverse experts (**Table 1**) consistent with the recommendation of Adler and Ziglio (1996), who suggest involving 10 to 15 experts in the Delphi method to obtain a high consensus. The criteria for the experts were as follows: **1.** Experts in chemistry or STEM education; **2.** Expert in curriculum and instruction development; **3.** Experts in module development; **4.** Experts in development, research, and innovation.

Table 1. Fuzzy Delphi method expert demography.

Expert	Institution	Position	Experience	Field Expertise
1	Public University	Senior Lecturer	More than 21 years	- Chemistry education - Chemistry curriculum development
2	Public University	Associates Professor	More than 21 years	- STEM education - STEM culture study center
3	Public University	Associates Professor	More than 21 years	- STEM Education
4	Public University	Senior Lecturer	6–10 years	- Chemistry education - Module development
5	Public University	Senior Lecturer	11–15 years	- Curriculum and instruction development - Module development
6	Public University	Senior Lecturer	More than 20 years	- Module development - Development, research, and innovation
7	Public University	Senior Lecturer/ Professional Chemists	15–20 years	- Chemistry education
8	Public University	Senior Lecturer	11–15 years	- Chemistry education - Module development
9	Institute of Teacher Education	Senior Lecturer	More than 21 years	- Curriculum and instruction development - Development, research, and innovation
10	Institute of Teacher Education	Lecturer	6–10 years	- Development, research, and innovation - Module development
11	Institute of Teacher Education	Senior Lecturer	15–20 years	- Development, research, and innovation
12	Education Resources and Technology Division of the Malaysian Ministry of Education	Assistant director	More than 21 years	- Chemistry education

4. Data collection and analysis

To ensure the empirical nature of this study, the researcher implemented the Fuzzy Delphi method following **Fig. 1**.

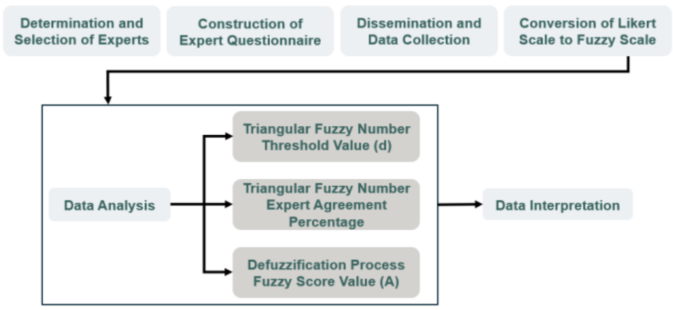

Figure 1. Fuzzy Delphi method (FDM) approach.
Source: Retrieved from Jamil *et al.* (2015).

Step 1: ***Determination and selection of experts***

The researcher sought out specialists who met specific criteria. A letter of appointment and approval as an expert panel was sent to experts willing to participate in the research.

Step 2: ***The construction of the experts' questionnaire***

This study created a questionnaire using a standards-based literature review and expert consultations (Sekaran and Bougi, 2016). The fuzzy questionnaire presented is used to obtain expert agreement on the elements in the required activity design components, as shown in **Table 2**.

The questionnaire employed the seven-point Likert scale to reduce ambiguity and increase expert consensus. Noh, Halili and Siraj (2020) and Jamil *et al.* (2015), revealed that 7-point Likert scales are more accurate than 5-point ones. This scale is transformed into a fuzzy set with unit intervals between 0 and 1. The Triangular Fuzzy Number represents the lowest, reasonable, and maximum m1, m2, and m3 (**Fig. 2**).

Table 2. Number of items for each element in the questionnaire.

Implementation of the IDEO Design Thinking Model in Chemistry Learning	
Design thinking phase	**Number of item**
Exploration	4
Interpretation	4
Ideation	4
Execution	3
Reflection	4

Source: Elaborated by the authors using the literature review: IDEO (2012); Kalkbrenner and Horton-Parker (2016); Ovbiagbonhia *et al.*, (2023); Auernhammer and Roth (2021); Pande and Bharathi (2020); Abidin (2020).

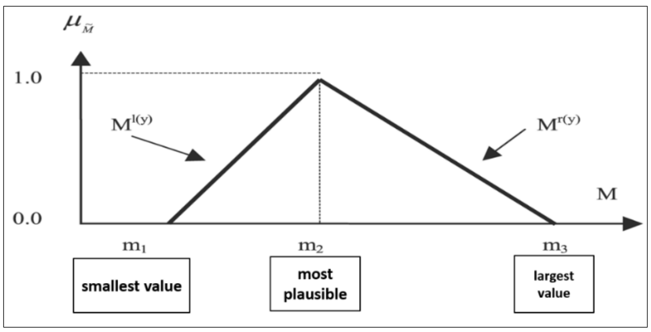

Figure 2. Triangular Fuzzy Number.
Source: Retrieved from (Siraj *et al.*, 2021).

The field experts rated their agreement with the assertions, facilitating content validation through this process. This fuzzy approach allows for a more refined analysis, accommodating the uncertainty inherent in human judgment. For example, when an expert rates "Students cooperate effectively during group assignments" with a score of 5 on a 7-point Likert scale, indicating agreement, the Triangular Fuzzy Number (TFN) translates it into a fuzzy scale range (0.50, 0.70, 0.90) representing a 50% agreement value for m1, 70% for m2 and 90% for m3. This range captures the potential variation in expert opinion, reflecting a single point of agreement and a spectrum that can be slightly skewed toward a percentage of agreement. Ambiguity at this scale improves data accuracy, makes analysis more robust, and reflects the real-world complexity inherent in expert judgment.

Step 3: ***Dissemination and data collection***

This phase involved distributing surveys to recognized experts using one of two methods: There are two main ways to engage experts: Meeting with each expert in person or using email for conversation and information sharing.

Step 4: ***Conversion of Likert scale to fuzzy scale***

The linguistic variables are converted into fuzzy triangular numbers, and each criterion is allocated a fuzzy rij number to indicate the expert's competence. Data Average Value was determined using a Delphi Fuzzy analysis template intended for Microsoft Excel (**Eq. 1**).

$$I = 1 \ldots m, j = 1, \ldots n, \quad K = 1 \ldots., k \\ and \\ rij = 1/K\,(r^1 ij \pm r^2 ij \pm r^K ij) \quad (1)$$

Step 5: ***Data analysis***

To obtain the agreement and consensus of the expert panel, three main conditions must be met, which rely on the triangular fuzzy number and the defuzzification process. The condition for *triangular fuzzy numbers* is to involve *the threshold* value (d) and the percentage of expert agreement. For the defuzzification *process*, there is only one condition: the *fuzzy* score value (A). These three conditions will be analyzed using *Microsoft Excel*. **Table 3** shows the interpretation of the Triangular score values of the Fuzzy Number and Defuzzification Process to measure the consensus of the expert group.

Table 3. Interpretation of score values for acceptance conditions based on expert agreement Fuzzy Delphi method data analysis (FDM).

Condition	Process	Criterion	Value	Interpretation
1	*Triangular fuzzy number*	*Threshold* value (d)	*Threshold* (d) ≤ 0.2 (equal or less than 0.2)	Accepted (Chen, 2000; Cheng and Lin, 2002)
2	*Triangular fuzzy number*	The percentage of expert agreement	Percentage of expert agreement ≥ 75% (equal to or greater than 75%)	Accepted (Chu and Hwang, 2008; Murry and Hammons, 1995)
3	*Defuzzification process*	*The fuzzy* score value (A)	*The fuzzy* score value (A) ≥ 0.5 (α– cut value equal to or greater than 0.5)	Accepted (*Ranking*) (Bodjanova, 2006; Tang and Wu, 2010)

a: Determining Threshold Value (d)

Each item's threshold value (d) must be less than or equal to 0.2 to reflect experts' consensus (Cheng and Lin, 2002). The **Eq. 2** calculated the distances between two fuzzy numbers, m = (m1, m2, m3) and n = (n1, n2, n3).

$$d(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad (2)$$

b: Expert Consensus Percentage

Expert consensus must exceed 75% to indicate agreement. Non-agreement items were eliminated (Garriga *et al.*, 2016).

c: Defuzzification Process

The defuzzification method determined item scores and rankings. The symbol for defuzzification is Amax. The fuzzy score (A) must be greater than the median value (α-cut value) of 0.5 (Tang and Wu, 2010) to indicate expert agreement and item acceptance. If (A) exceeds 0.5, it signifies expert consensus to accept the item in the question (Bodjanova, 2006). This α-cut-based decision-making process is a critical determinant in accepting or rejecting items within the study (**Eq. 3**).

$$Amax = \frac{1}{3} \times (m_1 + m_2 + m_3) \\ Amax = \frac{1}{4} \times (m_1 + 2m_2 + m_3) \\ Amax = \frac{1}{6} \times (m_1 + 4m_2 + m_3) \quad (3)$$

5. Findings and results

5.1. What are the elements of design thinking implementation in chemistry classroom education?

Dewey's Experiential Learning Theory (Roberts, 2003) and IDEO's design thinking model (IDEO, 2012) have been implemented in developing activities based on design thinking in chemistry classes. The activity design is guided by the Curriculum Standard Document and Chemistry Assessment in the Secondary School Standard Curriculum (BPK 2018). Area 6.0 on the topic of acids, bases, and salts is mapped to content standards (SK) with design steps that students will undertake. For activity 1: Design of environmentally friendly washing soap, there are three content standards involved, namely SK 6.1, SK 6.2, and SK 6.3. For activity 2, the smoke filter, Eco involves SK 6.4 and SK 6.7. Based on the findings, there are five elements of design thinking implementation in Chemistry Classroom Teaching Strategies based on the experts' consensus. The elements are exploration, interpretation, ideation, execution, and reflection. These five phases are used as a structured phase framework to improve the quality of the teaching and learning process through the integration of design thinking.

Students learn to approach problems structured and systematically and develop the problem-solving approach required to enhance innovation competencies. Teaching and learning activities are systematically mapped to the design components corresponding with a phase of the IDEO Design Thinking Model (IDEO, 2012): Exploration, Interpretation, Ideation, Execution, and Reflection. The parameters of each phase from the IDEO model are integrated into elements of our activity design, which results in a holistic learning experience. Practice examples in Table 4 adapt the activity design types proposed and refined via expert consensus to show how these phases of design thinking can be applied.

Table 4. Design thinking elements in chemistry classroom teaching strategies.

Item	Elements
Exploration Phase	
E1.1	*Project Plan:* Students build structured plans, assign distributions in groups, and outline plans to follow during their design thinking project assignment. Students make strategies, plan action plans to overcome environmental issues and distribute tasks.
E1.2	*Induction*: The teacher raises the issue of the problem and introduces students to the project's objectives, methods, and expectations. Students answer KNOWLEDGE practice questions, and students explore "Acids and Alkalies: How do they affect the Environment".
E1.3	*Definition:* Students actively define problem issues, clearly outlining the problem statements and objectives to be addressed. Students define related issues and list pollutants that affect the quality of the environment (like sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which lead to acid rain, alter the pH of water bodies, and harm aquatic life).
E1.4	*Find Information:* Students search for information from various sources and research and collect relevant data on the problem. Students explore and find information on the concept of pH for acid, base, and salt in (laboratory station activity), test the pH levels of different substances, and analyze how acidic or basic solutions can neutralize to mitigate environmental damage.
Interpretation Phase	
E2.1	*Interpretation:* Students evaluate and interpret information to draw meaningful conclusions. Students connect the concept of pH value and concentration of a solution and suggest possible solutions.
E2.2	*Synthesis:* Students synthesize the information obtained, integrate information, and generate creative solutions to address assigned problems. Combine their understanding of chemical reactions, such as neutralization, with real-world applications to propose methods to reduce the acidity of affected water bodies.
E2.3	*Analysis:* Students analyze the exploration results, breaking down complex information to identify key patterns, trends, or relationships related to a defined problem. Students present ideas, analyze, and make connections about how the pH value of a cleaning solution affects the effectiveness of washing.
E2.4	*Concept mapping:* Students visually organize and connect key concepts and ideas from the information gathered. Map the relationship between different types of acids and bases, their reactions with salts, and their effects on the environment.
Ideation Phase	
E3.1	*Concept:* Students associate the solution idea and the chemical concepts involved. Students link the chemical concepts of acids, bases, and salts with the solution concept. Students state how the properties of acids, bases, and salts allow solutions that are suggested.
E3.2	*Post-it Voting:* A collaborative decision-making process in which students use Post-it notes to vote for the most appropriate ideas. Evaluate ideas based on feasibility, functionality, and alignment with problems foster collaboration.
E3.3	*Brainstorm:* Collaborative and open sessions where students generate ideas for solving defined problems. Students consider the properties and characteristics of acids, bases, and salts during brainstorming.
E3.4	*Solution Model:* Students suggest a solution model for implementing the selected solution. Visualize and sketch a model of their solution for a smoke filter – eco. Label the main components and processes involved in their solution.
Execution Phase	
E4.1	*Solution Model Development*: Students develop prototypes and detail the selected solution model.
E4.2	*Do & Test:* Students test a prototype to solve a pre-defined problem. Students test the functionality and ability of prototypes to solve air or air pollution problems (acid, base, and agar concepts). List the apparatus and materials needed in the testing experiment. Students must propose their investigative activity procedures. List the apparatus and materials needed for the testing experiment. Students are required to propose their investigative activity procedures.
E4.3	*Re-Test:* Revising and re-evaluating the solution model implemented based on feedback and results.
Reflection Phase	
E5.1	*Documentation:* Students make project documentation systematically recording and presenting learning outcomes and modifications made throughout the design process carried out.
E5.2	*Feedback loops:* continuous feedback, allowing for repeated improvements based on input from peers, teachers, or self-reflection.
E5.3	*Sustainability:* Students consider developed solutions' long-term viability and impact on environmental, social, and economic effects.
E5.4	*Reflection:* Students reflect on the entire design process, including challenges, successes, and areas for improvement. Reflect on how design projects in creating environmentally friendly cleaning solutions challenge an understanding of chemical concepts such as pH, chemical reactions, and the properties of acids and bases.

Source: Elaborated by the authors from expert views.

Some elements did not meet the requirements of the acceptance of elements in the FDM analysis, such as elements in the design of the activities of the interpretation phases. These elements meet the first requirement but do not meet the second requirement; the percentage requirement of the expert agreement should be more than or equal to 75%.

The synthesis elements (67%) and *concept mapping* (50%) in the interpretation phase, as well as *Re-test* elements (67%) in the implementation phase, meet the first requirement *of the threshold* value (d) less than 0.2 but have less than 75% of expert agreement. Meanwhile, the sustainability element (d = 0.204) in the reflection phase meets the second requirement but does not meet the first requirement *of the threshold* value (d) less than 0.2.

Therefore, as formulated in Table 5, these four elements have been rejected. The results also show the expert's consensus on the elements in the design thinking component of the activity with the *threshold value* (d) of the exploration phase between (0.098 to 0.126) and the ideation phase (0.057 to 0.092) and has met the first FDM requirement in the *Triangular fuzzy number* which is (d) smaller than 0.2. The testing of the percentage of agreement for the second FDM conditions also showed that the design thinking element of the activity for these two phases received a high rate of agreement of 96% and 94% for the percentage of the entire component.

Table 5 also presents the consensus reached among experts regarding 15 out of 19 elements in design thinking elements. In total, all four elements in the exploration phase and the ideation phase, two of the four elements in the interpretation phase, two of the three elements in the experimental phase as well as three of the four proposed elements were accepted by consensus for the design component of the activity in the design thinking implementation in chemistry classroom education.

Table 5. Expert consensus on design thinking elements.

	Triangular Fuzzy Numbers		*Defuzzification Process*					
Item	Threshold Value (d)	Percentage Expert Consensus (%)	m1	m2	m3	*Fuzzy* Score (A)	Ranking	Results
Exploration Phase								
E1.1	0.098	92%	0.800	0.942	0.992	0.911	3	Accepted
E1.2	0.023	100%	0.883	0.992	1.000	0.958	1	Accepted
E1.3	0.042	100%	0.867	0.983	1.000	0.950	2	Accepted
E1.4	0.126	92%	0.767	0.917	0.975	0.886	4	Accepted
Interpretation Phase								
E2.1	0.097	92%	0.783	0.933	0.992	0.903	2	Accepted
E2.2	0.201	67%	0.617	0.800	0.925	0.781	-	Rejected
E2.3	0.068	100%	0.833	0.967	1.000	0.933	1	Accepted
E2.4	0.147	50%	0.533	0.733	0.900	0.722	-	Rejected
Ideation Phase								
E3.1	0.082	83%	0.700	0.883	0.983	0.856	4	Accepted
E3.2	0.076	100%	0.800	0.950	1.000	0.917	2	Accepted
E3.3	0.057	100%	0.850	0.975	1.000	0.942	1	Accepted
E3.4	0.092	92%	0.767	0.925	0.992	0.894	3	Accepted
Execution Phase								
E4.1	0.068	100%	0.833	0.967	1.000	0.933	1	Accepted
E4.2	0.068	100%	0.767	0.933	1.000	0.900	2	Accepted
E4.3	0.187	67%	0.633	0.808	0.933	0.792	-	Rejected
Reflection Phase								
E5.1	0.091	83%	0.717	0.892	0.983	0.864	3	Accepted
E5.2	0.095	92%	0.817	0.950	0.992	0.919	1	Accepted
E5.3	0.204	83%	0.400	0.600	0.800	0.600	-	Rejected
E5.4	0.102	83%	0.733	0.900	0.983	0.872	2	Accepted

Requirement: *Triangular Fuzzy Numbers* (1) *Threshold Value* (d) ≤ 0.2, (2) Percentage of Expert Consensus ≥ 75.0%; *Defuzzification Process* (3) *Fuzzy* Score (A) ≥ α – cut = 0.5.

5.2. What are this item's values and rankings for each element based on an expert consensus?

After successfully addressing the initial two requirements, the analysis proceeds to ascertain the fulfillment of the third FDM requirement through defuzzification analysis. Notably, the highest fuzzy score value secures the top rank within each design thinking element. In the defuzzification analysis, a higher fuzzy score means to be the most likely or agreed upon sub-element within each phase of design thinking. Presenting these higher scores first highlights the most critical items, making the key findings more prominent and impactful. The final resulting value (A) is compared against α-cut values; any score below 0.5 reflects expert consensus to reject the item, while scores exceeding 0.5 indicate sufficient literature support to adopt it (Bodjanova, 2006). The high fuzzy scores (ranging from 0.958 to 0.856) in Table 6 confirm broad consensus (Roldan Lopez *et al.*, 2021), which is crucial for applying the design thinking framework to the chemistry education model.

Overall, the analysis results indicate a logical structure within the Design Thinking process, with specific priorities for each phase. In the Exploration Phase, the Induction element, which introduces the process, holds the highest importance (A=0.958), followed closely by Definition (problem definition) at 0.950. However, Finding Information (gathering information) ranks the lowest at 0.886, suggesting that a clear understanding of the problem is paramount before collecting data. In the Interpretation Phase, the Analysis element (A=0.933) is considered more critical than Interpretation (A=0.903), emphasizing the necessity of thorough data analysis prior to drawing conclusions. Moving to the Ideation Phase, Brainstorming (creative idea generation) is the highest-ranked element (A=0.942), followed by *Post-it Voting* (selection of the best ideas) at 0.917, and Solution Model Development (A=0.894). The Concept (basic concept) element ranks the lowest at 0.856, implying that generating and selecting ideas should precede the development of a solution model. In the Execution Phase, Solution Model Development (A=0.933) is prioritized over Do & Test (A=0.900), underlining the importance of having a well-defined solution model before testing. Lastly, in the Reflection Phase, Feedback Loops (continuous feedback) are deemed the most crucial (A=0.919), followed by Reflection (self-reflection) at 0.872, with Documentation being the least important (A=0.864). This suggests that feedback exchanges should take precedence over mere documentation of reflections. In conclusion, this ranking emphasizes the sequential and structured approach in Design Thinking, where each phase—understanding the problem, conducting analysis, generating and selecting ideas, modeling solutions, implementing them, and reflecting—must follow a clear order of priority to effectively foster innovative and systematic solutions.

Figure 3 displays a visual picture of the ranking formulation of each element of the design of the activity in all phases of design thinking according to the priority position.

Table 6. Ranking of elements in the design thinking phase activity to the value of Fuzzy evaluation.

Item	Design Thinking Activity Components	Fuzzy Score (A)	Ranking
Design Thinking (Exploration) Elements			
E1.1	Project Plan	0.911	3
E1.2	Induction	0.958	1
E1.3	Definition	0.950	2
E1.4	Find Information	0.886	4
Design Thinking (Interpretation) Elements			
E2.1	Interpretation	0.903	2
E2.3	Analysis	0.933	1
Design Thinking (Ideation) Elements			
E3.1	Concept	0.856	4
E3.2	Post-it Voting	0.917	2
E3.3	Brainstorm	0.942	1
E3.4	Solution Model	0.894	3
Design Thinking (Execution) Elements			
E4.1	Solution Model Development	0.933	1
E4.2	Do & Test	0.900	2
Design Thinking (Reflection) Elements			
E5.1	Documentation	0.864	3
E5.2	Feedback loops	0.919	1
E5.4	Reflection	0.872	2

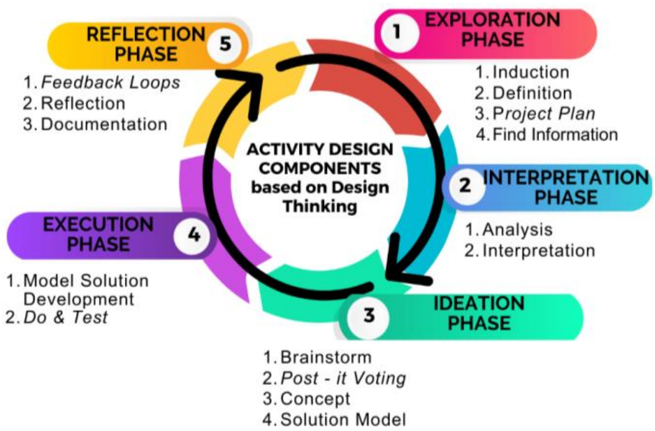

Figure 3. Activity Design Thinking Component through Fuzzy Delphi method approach.

6. Discussion

The results of this study demonstrate the effective utilization of the FDM in developing teaching techniques for chemistry classrooms that align with the design thinking paradigm. The consensus levels among the expert panel, which ranged from 83 to 100%, validate the appropriateness and comprehensiveness of the proposed design thinking principles in the context of chemistry education. The elements classified as exploration, interpretation, ideation, execution, and reflection jointly play a significant role in nurturing students' innovation competencies. The consensus reached, as indicated by the low threshold values ($d \leq 0.2$), demonstrates that experts have agreed on the fundamental elements required for a learning environment to be effective. The value of supporting inquiry-driven learning and problem-solving in the Malaysian school setting is highlighted by this consensus, which is consistent with earlier research that emphasizes the importance of active learning approaches (Halim *et al.*, 2022; Maneeratana *et al.*, 2019).

In addition, the examination of defuzzification provides valuable insights into the relative importance of each part of design thinking. The Fuzzy score values, which regularly range from 0.856 to 0.958, emphasize the importance of each element in effectively implementing design thinking ideas in chemistry teaching. The prominence of the exploration element in the exploration portion is particularly noteworthy, as it emphasizes the importance of enabling students to engage with real-world situations to frame challenges appropriately. Likewise, prioritizing analysis and interpretation components highlights the significance of employing critical thinking during the ideation process. The above findings align with prior research that underscores the crucial significance of design thinking in cultivating innovation skills and aptitude for resolving problems (Buhl *et al.*, 2019; Ellah, *et al.*, 2019)

7. Conclusions

In conclusion, this research makes a valuable contribution to the advancement of pedagogical approaches in the field of chemistry education in Malaysia. It achieves this by offering empirically supported design thinking components that align with the requirements for fostering students' innovation competencies. The efficacy of employing the Fuzzy Delphi method to establish consensus among experts serves to enhance the validity of the offered plans. The results emphasize the necessity for educational establishments to integrate design thinking principles, thereby fostering an environment that motivates students to engage in exploration, ideation, and implementation to address authentic challenges. By emphasizing these components, educators can cultivate a dynamic educational setting that encourages creativity, critical thinking, and innovation within the student body. The findings derived from this research can provide a basis for educators, curriculum creators, and policymakers to formulate and execute efficacious approaches for fostering student innovation competencies.

Authors' contribution

Conceptualization: Norliyana Binti Md. Aris; Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; **Data curation:** Norliyana Binti Md. Aris; Muhammad Nidzam bin Yaakob; **Formal Analysis:** Norliyana Binti Md. Aris; Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; **Funding acquisition:** Norliyana Binti Md. Aris; **Investigation:** Norliyana Binti Md. Aris; **Methodology:** Norliyana Binti Md. Aris; Muhammad Nidzam bin Yaakob; **Project administration:** Norliyana Binti Md. Aris; Nurul Hanani Binti Rusli; **Resources:** Norliyana Binti Md. Aris; Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; **Software:** Not applicable. **Supervision:** Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; **Validation:** Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; **Visualization:** Norliyana Binti Md. Aris; Nurul Hanani Binti Rusli; **Writing – original draft:** Norliyana Binti Md. Aris; Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim; Nurul Hanani Binti Rusli; **Writing – review & editing:** Norliyana Binti Md. Aris; Nor Hasniza Binti Ibrahim; Noor Dayana Binti Abd Halim.

Data availability statement

All data sets were generated or analyzed in the current study.

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Conflict of interest

The authors declare that there is no conflict of interest.

References

Abidin, M. D. S. Z. *Panduan Asas Pemikiran Reka Bentuk Produk (UiTM Press)*. UiTM Press. 2020.

Adam, N. A.; Halim, L. Cabaran Pengintegrasian Pendidikan STEM Dalam Kurikulum Malaysia. In: *Seminar Wacana Pendidikan (SWAPEN 2.0)*. **2019**.

Adler, M.; Ziglio, E. *Gazing into the Oracle*: The Delphi Method and Its Application to Social Policy and Public Health. Jessica Kingsley Publishers. 1996.

Anastas, P. T.; Zimmerman, J. B. The United Nations Sustainability Goals: How Can Sustainable Chemistry Contribute? *Current Opinion in Green and Sustainable Chemistry*. **2018**, *13*, 150–153. https://doi.org/10.1016/j.cogsc.2018.04.017

Androutsos, A.; Brinia, V. 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*. **2019**, *9* (2), 113. https://doi.org/10.3390/educsci9020113

Auernhammer, J.; Roth, B. The origin and evolution of Stanford University's design thinking: From product design to design thinking in innovation management. *Journal of Product Innovation Management*. **2021**, *38* (6), 623–644.

Bascopé, M.; Perasso, P.; Reiss, K. Systematic Review of Education for Sustainable Development at an Early Stage: Cornerstones and Pedagogical Approaches for Teacher Professional Development. *Sustainability*. **2019**, *11* (3), 719. https://doi.org/10.3390/su11030719

Berliner, D. C. Describing the behavior and documenting the accomplishments of expert teachers. *Bulletin of Science, Technology & Society*. **2004**, *24* (3), 200–212. https://doi.org/10.1177/0270467604265535

Bodjanova, S. Median alpha-levels of a fuzzy number. *Fuzzy sets and Systems*. **2006**, *157* (7), 879–891. https://doi.org/10.1016/j.fss.2005.10.015

BPK Dokumen Standard Kurikulum dan Pentaksiran (DSKP) Kimia Tingkatan 4 dan 5. *Kementerian Pendidikan Malaysia*. **2018**, 71. http://www.moe.gov.my/bpk (accessed 2025-01-31).

Broman, K.; Bernholt, S.; Parchmann, I. Using model-based scaffolds to support students solving context-based chemistry problems. *International Journal of Science Education*. **2018**, *40* (10), 1176–1197. https://doi.org/10.1080/09500693.2018.1470350

Buhl, A.; Schmidt-Keilich, M.; Muster, V.; Blazejewski, S.; Schrader, U.; Harrach, C.; Schäfer, M.; Süßbauer, E. Design thinking for sustainability: Why and how design thinking can foster sustainability-oriented innovation development. *Journal of Cleaner Production*, **2019**, *231*, 1248–1257. https://doi.org/10.1016/j.jclepro.2019.05.259

Bui, T. D.; Tsai, F. M.; Tseng, M. L.; Helmi Ali, M. D. Identifying Sustainable Solid Waste Management Barriers in Practice Using the Fuzzy Delphi Method. *Resources, Conservation and Recycling*. **2020**, *154*, 104625. https://doi.org/10.1016/j.resconrec.2019.104625

Chen, C. T. Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy sets and systems*, **2000**, *114* (1), 1–9. https://doi.org/10.1016/S0165-0114(97)00377-1

Cheng, C.-H.; Lin, Y. Evaluating the Best Main Battle Tank Using Fuzzy Decision Theory with Linguistic Criteria Evaluation. *European J. Operational Research*. **2002**, *142*, 174–186. https://doi.org/10.1016/S0377-2217(01)00280-6

Chu, H. C.; Hwang, G. J. A Delphi-based approach to developing expert systems with the cooperation of multiple experts. *Expert systems with applications*. **2008**, *34* (4), 2826–2840. https://doi.org/10.1016/j.eswa.2007.05.034

Cone, C.; Unni, E. 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*. **2020**, *16* (12), 1711–1717. https://doi.org/10.1016/j.sapharm.2020.02.007

Droescher, M. Chemistry: The Driving Force for Emerging Technologies. *Chemistry International*. **2018**, 14–17. https://doi.org/10.1515/ci-2018-0405

Durall, E.; Carter, C.; Burns, K. Transdisciplinary Education and Innovation through STEAM. In: *Proceedings of the Mini-Conference on Transdisciplinary Research and Design*. **2022**, 26–33. https://oulurepo.oulu.fi/bitstream/handle/10024/34183/nbnfi-fe2022092860365.pdf?sequence=1&isAllowed=y (accessed 2025-01-31).

Ellah, B. O.; Achor, E. E.; Enemarie, V. 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*. **2019**, *6* (3), 135–141. https://doi.org/10.20448/journal.509.2019.63.135.141

Falloon, G. From Digital Literacy to Digital Competence: The Teacher Digital Competency (TDC) Framework. *Educational Technology Research and Development*. **2020**, *68* (5), 2449–2472. https://doi.org/10.1007/s11423-020-09767-4.

Franco, I.; Saito, O.; Vaughter, P.; Whereat, J.; Kaine, N.; Takemoto, K. Higher Education for Sustainable Development: Actioning the Global Goals in Policy, Curriculum and Practice. *Sustainability Science*. **2019**, *14* (6), 1621–1642. https://doi.org/10.1007/s11625-018-0628-4

Garcia-Martinez, J. Chemistry 2030: A Roadmap for a New Decade. *Angewandte Chemie*. **2021**, *133* (10), 5008–5012. https://doi.org/10.1002/ange.202014779

García-Pérez, L.; García-Garnica, M.; Olmedo-Moreno, E. M. Skills for a Working Future: How to Bring about Professional Success from the Educational Setting. *Education Sciences*. **2021**, *11* (1), 27. https://doi.org/10.3390/educsci11010027

Garcia-Vaquero, M. Design Thinking Online: Approaching Constructive Learning In Food Science. In: *18th International Conference on Cognition and Exploratory Learning in Digital Age*. **2021**, 339–344. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124069878&partnerID=40&md5=89c87c5d1d0c70fb5d10cbefc146c774 (accessed 2025-01-31).

Garriga, M.; Pacchiarotti, I.; Hidalgo, D.; Bernardo, M.; Vieta, E. Detection and management of agitation in psychiatry: A Delphi expert consensus study. *European Psychiatry*. **2016**, *33* (S1), S170–S170. https://doi.org/10.1016/j.eurpsy.2016.01.350

Gomollón-Bel, F. Ten Chemical Innovations That Will Change Our World. *Chemistry International.* **2020**, *42* (4), 3–9. https://doi.org/10.1515/ci-2020-0402

Halim, L.; Ramli, M.; Mohamad Nasri, N. The cultural dimensions of inquiry-based practices: towards a comprehensive understanding. *Asia Pacific Journal of Education.* **2022**, *43* (4), 1328–1342. https://doi.org/10.1080/02188791.2022.2106941

Hero, L. M.; Eila Lindfors, E.; Taatila, V. Individual Innovation Competence: A Systematic Review and Future Research Agenda. *International Journal of Higher Education.* **2017**, *6* (5), 103–121.

Hero, L. M.; Pitkäjärvi, M.; Matinheikki-Kokko, K. Validating an individual innovation competence assessment tool for university–industry collaboration. *Industry and Higher Education.* **2021**, *35* (4), 485–496. https://doi.org/10.1177/09504222211017447

Herodotou, C.; Sharples, M.; Gaved, M.; Kukulska-Hulme, A.; Rienties, B.; Scanlon, E.; Whitelock, D. Innovative Pedagogies of the Future: An Evidence-Based Selection. *Frontiers in Education*. **2019**, *4*, 1–14. https://doi.org/10.3389/feduc.2019.00113

Hsiao, H.-S.; Yu, K. C.; Chang, Y. S.; Chien, Y. H.; Lin, K. Y.; Lin, C. Y.; Chen, J. C.; Chen, J. H.; Lin, Y. W. 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).* **2017**, 383–390. https://doi.org/10.1109/WEEF.2017.8467111

Hu, M.-L. I.-C. M.; Horng, J. S.; Teng, C. C. Developing a Model for an Innovative Culinary Competency Curriculum and Examining Its Effects on Students' Performance. *Journal of Creative Behavior.* **2016**, *50* (3), 193–202. https://doi.org/10.1002/jocb.139

IDEO. *Design Thinking for Educators Toolkit*. IDEO, 2012.

Jamil, M. R. M.; Siraj, S.; Yusof, F.; Noh, N. M.; Hussin, Z.; Sapar, A. A. Aplikasi Teknik Fuzzy Delphi Terhadap Keperluan Elemen Keusahawanan Bagi Pensyarah Kejuruteraan Politeknik Malaysia. *Int. J. Bus. Technopreneursh.* **2015**, *5* (1), 135–150.

Jamil, M. R. M.; Noh, N. M. *Kepelbagaian metodologi dalam penyelidikan reka bentuk dan pembangunan*. Qaisar Prestige Resources, 2020.

Jan, M.; Yang, W. L.; Thomas, M. Exploring teachers' pedagogical design thinking in game-based learning. In: *Proceedings of the 25th International Conference on Computers in Education.* **2017**, 832–834. https://researchoutput.ncku.edu.tw/en/publications/exploring-teachers-pedagogical-design-thinking-in-game-based-lear (accessed 2025-01-31).

Kalkbrenner, M.; Horton-Parker, R. Applying John Dewey's Theory of Education to Infuse Experiential Learning in an Introduction to Human Services Course. *Journal of Human Services*. **2016**, *36* (1), 65–68.

Kanapathy, S.; Lee, K. E.; Sivapalan, S.; Mokhtar, M.; Syed Zakaria, S. Z.; Mohd Zahidi, A. Sustainable development concept in the chemistry curriculum: An exploration of foundation students' perspective. *International Journal of Sustainability in Higher Education*. **2019**, *20* (1), 2–22. https://doi.org/10.1108/IJSHE-04-2018-0069

Keinänen, M.; Ursin, J.; Nissinen, K. How to Measure Students' Innovation Competences in Higher Education: Evaluation of an Assessment Tool in Authentic Learning Environments. *Studies in Educational Evaluation.* **2018**, *58*, 30–36. https://doi.org/10.1016/j.stueduc.2018.05.007

Keinänen, M. M.; Kairisto-Mertanen, L. Researching Learning Environments and Students' Innovation Competences. *Education and Training.* **2019**, *61* (1), 17–30. https://doi.org/10.1108/ET-03-2018-0064

Koh, J. H. L.; Chai, C. S.; Wong, B.; Hong, H.-Y. *Design Thinking for Education*: Conceptions and Applications in Teaching and Learnin. Springer, 2015. https://doi.org/10.1007/978-981-287-444-3

Lim, Y. R.; Ariffin, A. S.; Ali, M.; Chang, K. L. A Hybrid Mcdm Model for Live-Streamer Selection via the Fuzzy Delphi Method, Ahp, and Topsis. *Applied Sciences.* **2021**, *11* (19), 9322. https://doi.org/10.3390/app11199322

Lo, J.-S.; Lo, C.-H.; Huang, S.-C.; Wang, W.-C. Application of User Experience and Design Thinking to the Construction of a Class Assistance System for Hearing-and Speech-Impaired People. *Sustainability.* **2019**, *11* (24) 7191. https://doi.org/10.3390/su11247191

Lynch, M.; Kamovich, U.; Longva, K. K.; Steinert, M. Combining Technology and Entrepreneurial Education through Design Thinking: Students' Reflections on the Learning Process. *Technological Forecasting and Social Change.* **2021**, *164*, 119689. https://doi.org/10.1016/j.techfore.2019.06.015

Maneeratana, K.; Chancharoen, R.; Thongnuek, P.; Sukmuen, P.; Inkaew, C.; Suwannatthachote, P. A reflection on teaching design thinking to first-year engineering students. In: *2019 IEEE International Conference on Engineering, Technology and Education (TALE).* **2019**, 1–8. https://doi.org/10.1109/TALE48000.2019.9225890

Murry Junior, J. W.; Hammons, J. O. Delphi: A versatile methodology for conducting qualitative research. *The review of Higher Education*. **1995**, *18* (4), 423–436. https://doi.org/10.1353/rhe.1995.0008

Noh, N. M.; Halili, S. H.; Siraj, S. 'Analisis faktor kekangan pembelajaran berasaskan reka bentuk dalam kalangan guru berdasarkan Fuzzy Delphi Method', *Jurnal Kurikulum & Pengajaran Asia Pasifik*. **2020**, *8* (1), pp. 33–42.

Noh, S. C.; Karim, A. M. A. Design Thinking Mindset to Enhance Education 4.0 Competitiveness in Malaysia. *International Journal of Evaluation and Research in Education.* **2021**, *10* (2), 494–501. https://doi.org/10.11591/ijere.v10i2.20988

Ojeda, M. D.; Queiruga-Dios, M. A.; Velasco-Pérez, N.; López-Iñesta, E.; Vázquez-Dorrío, J. B. Inquiry through Industrial Chemistry in Compulsory Secondary Education for the Achievement of the Development of the 21st Century Skills. *Education Sciences.* **2021**, *11*, 475. https://doi.org/10.3390/educsci11090475

Organização para a Cooperação e Desenvolvimento Econômico (OCDE). *The Future of Education and Skills*: Education 2030. OECD, 2018. https://www.oecd.org/content/dam/oecd/en/publications/reports/2018/06/the-future-of-education-and-skills_5424dd26/54ac7020-en.pdf (accessed 2025-01-31).

Ovbiagbonhia, A. R.; Kollöffel, B.; Brok, P. D. Teaching for Innovation Competence in Higher Education Built Environment Engineering Classrooms: Teachers' Beliefs and Perceptions of the Learning Environment. *European Journal of Engineering Education.* **2020**, *45* (6), 917–936. https://doi.org/10.1080/03043797.2020.1784097

Ovbiagbonhia, A. R.; Kollöffel, B.; Brok, P. D. Investigating the impact of innovation competence instruction in higher engineering education. *European Journal of Engineering Education*. **2023**, *48* (6), 1068–1101. https://doi.org/10.1080/03043797.2023.2219216

Pande, M.; Bharathi, S. V. Theoretical Foundations of Design Thinking – A Constructivism Learning Approach to Design Thinking. *Think. Ski. Creat.* **2020**, *36*, 100637. https://doi.org/10.1016/j.tsc.2020.100637

Pruneau, D; Freiman, V.; Léger, M. T.; Dionne, L.; Richard, V.; Laroche, A-M. Design Thinking and Collaborative Digital Platforms: Innovative Tools for Co-creating Sustainability Solutions. In: Leal Filho, W.; Krasnov, E. V.; Gaeva, D. V. (Eds.). *Innovations and Traditions for Sustainable Development*: World Sustainability Series. Springer, **2021**, 207–226. https://doi.org/10.1007/978-3-030-78825-4_13

Raber, M; Fraley, M.; Kemppainen, A. Incorporating Design Thinking into the First-Year Engineering Curriculum. In: *ASEE Annual Conference and Exposition, Conference Proceedings*. **2018**, *2018*, 138114. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051203739&partnerID=40&md5=c5eba99ca32f932084f75c3ce7fb212d (accessed 2025-01-31).

Roldan Lopez de Hierro, A. F.; Sánchez, M.; Puente-Fernández, D.; Montoya-Juárez, R.; Roldán, C. A fuzzy delphi consensus methodology based on a fuzzy ranking. *Mathematics*. **2021**, *9* (18), 2323. https://doi.org/10.3390/math9182323

Scott, J. A.; Bouzos, E.; Hendricks, M. P.; Asuri, P. Cultivating Student Adoption of Design Thinking and Entrepreneurial Skills by Addressing Complex Challenges in Healthcare Through Industry Partnerships. In: ASEE Annual Conference and Exposition. **2021**, 176961. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124527217&partnerID=40&md5=b66c32275b2b88b868072fcaa88c29bf (accessed 2025-01-31).

Sekaran, U.; Bougi, R. *Research Methods for Business*: A Skill Building Approach. John Wiley & Sons, 2016.

Siraj, S.; Lim, M. R. T.; Rozkee, R. *Pendekatan Penyelidikan Reka Bentuk Dan Pembangunan*: Aplikasi Kepada Penyelidikan Pendidikan; Penerbit Universiti Pendidikan Sultan Idris, 2021.

Tang, C.-W.; Wu, C.-T. Obtaining a Picture of Undergraduate Education Quality: A Voice from inside the University. *Higher Education*. **2010**, *60* (3), 269–286. https://doi.org/10.1007/s10734-009-9299-5

Zhu, M.; 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*. **2023**, *15* (4), 3769. https://doi.org/10.3390/su15043769

Zupan, B.; Nabergoj, A. S.; Cankar, F. Design Thinking as a Methodology for Teaching Entrepreneurial Mindset in Primary Education. In: *13th European Conference on Innovation and Entrepreneurship, Proceedings of the European Conference on Innovation and Entrepreneurship, ECIE*. **2018**, *2018*, 893–899. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85055438651&partnerID=40&md5=68285fb50f9fc67e00854b052df6c8be (accessed 2025-01-31).