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Innovate to Educate: The Development and Validation of the Design Thinking Chemistry Module

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Abstract
This study aims to develop an innovative approach to chemistry instruction in light of the changing education landscape. The objective is to cultivate innovation competencies among chemistry students in secondary school by integrating the principles of Science, Technology, Engineering, and Mathematics (STEM) within a design thinking framework. The primary objective of this undertaking is to create a Design Thinking Chemistry Module (Chem_PRO) specifically designed to instruct the fundamental principles of "acid, base, and salt." The module is developed using the Design and Development Research (DDR) approach based on the Sidek Module Development Model. It exhibits the potential to address the disparity between theoretical comprehension and the application of problem-solving abilities in practical contexts. The primary objective of this research is to create the Chem_PRO module, utilizing a Design and Development Research (DDR) methodology inside the Sidek Module Development Model. The purpose of this module is to instruct Form Four students on the fundamental principles of "acid, base, and salt." The module fosters innovation competencies by incorporating STEM ideas and employing a design thinking methodology. The validation process involved assessing the content by a panel of nine experts from diverse domains. This evaluation resulted in a Content Validity Index (CVI) of 0.975. The module's validity and reliability were confirmed through subsequent pilot testing with Form Four chemistry students, as evidenced by a strong Cronbach's alpha reliability coefficient of 0.924. The Chem_PRO module is anticipated to function as an essential pedagogical instrument, augmenting theoretical comprehension and practical problem-solving abilities in chemistry education.
Keywords: Design Thinking, Innovation Competencies, Module Development, Stem Integration, Chemistry Education.

Introduction

Knowledge change, empowering innovation competencies, and fostering resilient educational infrastructure are the agenda of the United Nations Education Science and Culture Organization (UNESCO) 2030 as the key to sustainable development (UNESCO, 2018).

The innovation competency dimension is where the attention is most noticeable on new skill sets, focusing on the significant changes brought about by the growth of the digital economy. As highlighted in the World Economic Forum's 2018 report, fostering students' innovation skills and equipping them with the skills to solve problems are critical and needed at the top of the skills list by 2025. This innovative skill is necessary to solve global issues, especially in chemistry, which is crucial in achieving several Sustainable Development Goals (SDGs) by 2030. However, there is a considerable gap between curriculum desirability in the face of real-world needs with learning outcomes and the fundamental competencies of students in the current education system (Li et al., 2021; OCDE, 2018).

From the context of the Malaysian state itself, both the Malaysian 10-10 Science, Technology, Innovation, and Economy Framework (MySTIE) and the National Science, Technology, and Innovation Policy (DSTIN) 2021–2030 highlight the significance of science, technology, and innovation (STI) towards a high-tech nation (DSTIN (2013-2030). The country needs to increase its Gross Domestic Product (GDP) to RM 3.4 trillion by 2030 and reduce its dependence on external labor. This goal is laid to make Malaysia a country that can take advantage of human capital that is technological and innovative. However, this goal cannot be achieved because the number of highly skilled STEM professionals, especially in chemistry, cannot be provided. Therefore, developing students' innovation skills through real-world problem-solving in STEM is indispensable.

Additionally, the role of education is not only to educate students for future work but also to provide competent students with innovative skills for society. Unfortunately, research indicates that chemistry students need help explaining knowledge-based phenomena (Kanapathy et al., 2019). Most chemistry students face challenges in using their understanding of chemical concepts or theories to solve problems in real-world contexts. They also need help explaining ideas from the concepts studied (Siti Najihah et al., 2020). Studies have also shown that the field of education, in general, is still insufficient to assume the responsibility of developing innovation competencies among students (Situmorang et al., 2020; Soledad Ramírez-Montoya et al., 2022), and teaching methods and techniques are also still unable to meet these demands (M. et al., 2019; Rahman, 2021). The comprehensive framework developed in the context of education, explaining the teaching and learning activities involved in developing student innovation competencies, is also still relatively limited (M. Keinänen et al., 2018a). Hence, there is a need to develop a design thinking chemistry module by integrating design thinking principles into the subject of chemistry to help teachers with step-by-step, hands-on design thinking project activities to empower students' innovation competencies in their classrooms.

Literature Review

Why Design Thinking?

STEM education in chemistry has the potential to provide students with critical skills and knowledge that will enable them to contribute to innovation in a variety of fields, including materials science, biotechnology, energy, and environmental sustainability (The United States Department of Education, 2016). Exploration, interpretation, idea generation, experimentation, and group collaboration in problem-solving are essential components of design thinking (Docherty, 2017). By incorporating design thinking into STEM classroom environments, the study aims to engage students in more interactive and exploratory learning experiences where they can apply their knowledge to real-world challenges and develop their innovation competencies (Nguyen et al., 2020).

Traditionally, chemical education has focused on memorizing and using established concepts and procedures (Herranen et al., 2021). Although this method has successfully taught basic principles and prepared students for standardized tests, it may not fully equip students with the skills needed to succeed in today's rapidly changing world. As the demand for innovation grows across all industries, it is becoming increasingly crucial for STEM students to develop creative problem-solving, critical thinking, and design thinking competencies (Mahaffy et al., 2019).

Research in bibliometric analysis by Norliyana et al., (2022) from 2000 to 2021 shows that researchers increasingly widely accept the design thinking approach as a paradigm of modern learning in the classroom. This approach is seen as capable of developing innovation competencies and creating a quality learning environment. Design thinking is also among the solution methods to prepare students to solve real-world problems. Nevertheless, in the Malaysian context, the elements of the design thinking approach are still lacking (Nur Amelia Adam & Lilia Halim, 2019) and educators are still unclear about the design approach and how it can be applied in the classroom (Noh & Karim, 2021; Nurulrabihah Mat Noh, 2020).

The Five Phases of Design Thinking

A more authentic learning experience, thus fostering student engagement (Lande, 2016), is an essential element of the design thought process. According to the findings of past studies (Aguilar Moreno, 2022; Zhang & Chen, 2021), it has been integrated into broader borderline learning, especially in education (Lyche et al., 2018; Micheli et al., 2019). The growing interest in integrating design thinking into STEM education (Science et al.) is capable of impacting the physical environment of classrooms (Balakrishnan et al., 2021; Benita et al., 2021). In today's rapidly changing technology and globally competitive environment, success requires developing and using a unique set of competencies. Design thinking is one of these qualities.

The design thinking approach is carried out in the classroom based on the IDEO design model. IDEO 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, ideation, 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.

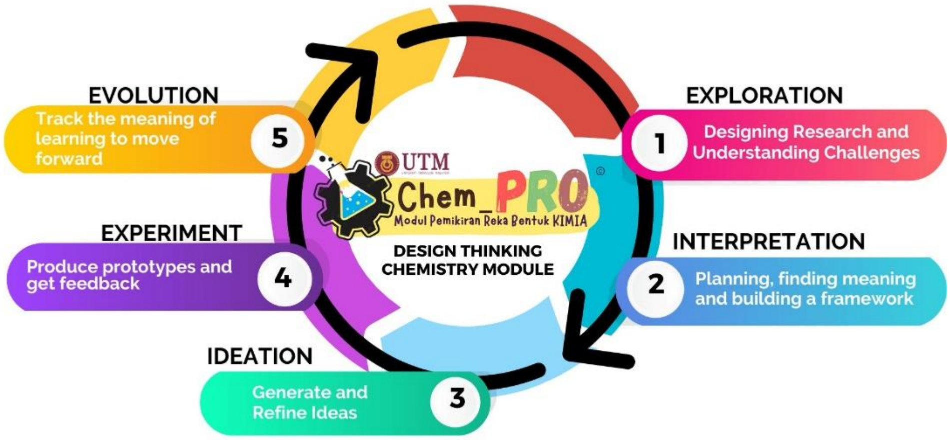

Figure 1. Five Phases of Design Thinking in Chem_PRO Module (IDEO, 2012).

The main strengths seen from the IDEO Model (2012) in Figure 1 are the five components found in the process and capacity building through learning experiences, group collaborative training, and creative problem-solving. The learning process through the design phase is appropriate for integrating many activities in learning, such as observation, collaboration, fast learning, visualization of ideas, and prototype construction (Raber et al., 2018). Focus on the design process, not just results. Failures in projects can lead to positive outcomes, highlighting the value of embracing the iterative nature of design. In the design process, prioritize the journey over the outcome. Failures in design projects can yield positive results, as (Noh, 2020) emphasized since the engagement and learning lie within the students' involvement.

Design Thinking Module Development Requirements

Studies conducted by (Keinänen et al., 2018b) show that students have low innovation competencies and depend on the given environment. At the same time, a study reveals that the student's competency level is still moderate by (Ovbiagbonhia, 2021). However, the importance of developing student innovation competencies is emphasized, yet developing teaching strategies and specifications on how teachers should design the curriculum for innovation competencies are still not provided (Ovbiagbonhia et al., 2019; Redman et al., 2021). Insufficient attention has been dedicated to exploring innovation competencies and the corresponding learning activities that necessitate organizational efforts by teachers (Kivunja, 2014; Keinänen et al., 2018). Therefore, further research is needed to identify relevant ways to foster student innovation competencies (Cavalcante et al., 2021).

In addition, a study of 1187 teachers conducted Haug & Mork (2021) answered that 57% of teachers agreed that the main challenge for the teaching implementation process is to cultivate students' skills is the provision of time-consuming and stressful teaching materials preparation for teachers (Monnot et al., 2020). Teachers need more support resources to translate expected teaching practices (Marko-Holguin et al., 2019; Saat et al., 2021). Next, the results of the analysis from a descriptive survey of 212 randomly selected chemistry teachers from 185 schools also showed that the methodology and effects of textual materials used by chemistry teachers became the main factors hindering students' ability to develop problem-solving skills (Mahmud & Arifin, 2021).

The above highlights clearly show a need to apply design thinking-based learning and how this approach can help stimulate the innovation competence of chemistry students in Malaysia. Efforts to develop design thinking modules must be implemented so that chemistry students in Malaysia can fill the needs explicitly and move along with the changes in the Industrial Revolution 5.0. Therefore, this study is very timely to fill the diversity of student learning, help the development of innovation competence, and increase mastery of student chemistry concepts.

Research Objectives

The objectives of this study are to:
1. Develop a Design Thinking Chemistry Module
2. Determine the validity and reliability of the Design Thinking Chemistry module.

Methods

Research Design

This study used the DDR (Design & Development Research) approach with three comprehensive phases, as shown in Table 1, according to (Saedah Siraj et al., 2021).

Table 1
Research Design

Phase	Design And Development Research (DDR)	**Sidek Module Construction Model** (Sidek Mohd Noah & Jamaludin Ahmad, 2005)	Description
1	Need Analysis	Goal setting, identify 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, logistic, media selection, and combining draft	Development of module prototype based on expert consensus through *Fuzzy Delphi Method* (FDM).
3	Evaluation	Pilot study, validity test and module evaluation	Conduct the experimental to evaluate the effectiveness

Phase one involves the study of needs analysis through interview protocols as an instrument to review the needs of module development and explore the need to apply design thinking in chemistry subjects based on the expert teacher's perspective.

Phase two is a module design and development phase based on the Fuzzy Delphi method involving twelve heterogeneous expert panels. Expert chemistry or STEM education, curriculum development, module development research, and innovation exist. The data is analyzed to get expert consensus on the elements that must be included in the module. The final phase is implementing and evaluating the design thinking chemistry module's effectiveness.

Sample

Before teachers and students tested this design thinking module, it was given to nine experts, as shown in **Table 2**, to evaluate the content and quality of the module produced and refined through correction and improvement.

Table 2
The Experts Involved in The Evaluation Process

Expert	Designation	Discipline of expertise
1	Associates Professor Public University	Chemistry and STEM education
2	Senior Lecturer Public University	Chemistry, STEM education & Design Thinking Approach
3	Assistant Director, Education Resources and Technology Division of The Malaysian Ministry of Education (KPM)	Chemistry, STEM Education & Module development
4	Senior Lecturer Institute of Teacher Education (IPG)	STEM Education & Module development
5	Assistant Director, Science & Mathematics State Education Department (JPN)	STEM Education & Development, Research, and Innovation
6	School Improvement Specialist Coaches SISC+ (Science & Mathematics)	STEM Education & Module development
7	Lecturer Matriculation Centre	Chemistry Education Research, and Innovation
8	Chemistry Teacher (PhD)	Chemistry Education & Module development
9	STEM Teacher (PhD)	STEM Education & Development, Research, and Innovation

The panel of experts selected is from chemistry and STEM subject specialist lecturers from public universities and senior lecturers from teaching and matriculation institutes who have more than 20 years of teaching experience and have expertise in terms of syllabus, teaching delivery, question formulation, and examination of exam papers as well as module development.

The Development of the Module

The Design Thinking Chemistry Module aspires to be a comprehensive resource by incorporating design thinking into chemistry instruction. This module consists of two design project activities for the topic of acid, base, and salt based on findings from a needs analysis with experts in the field who agreed to choose this topic because it is a complex topic to learn and the chemical concepts in this topic are compatible with the design thinking approach.

The module's primary constructs and components of design thinking have been developed based on the consensus of experts from the results of the fuzzy Delphi method analysis in phase two. The objectives and activities arranged in the module are also guided by the Chemistry Curriculum and Assessment Standard Document in the KSSM Secondary School Standard Curriculum (BPK, 2018). This design thinking module also emphasizes learning through experience and strengthening concepts. In this dynamic five-phase design process, students collaborate to generate innovative solutions and tackle real-world challenges, enhancing their collective innovation competencies.

Result and Discussion

Good and quality modules require an accurate validity and reliability approach and good validity and reliability values (Sidek Mohd Noah & Jamaludin Ahmad, 2005). The Polit, Beck, and Owen (2007) I-CVI and S-CVI were converted from category forms to numerical indexes of 0 and 1 to permit objective content evidence evaluation. Each item's mean relevant (agreed) score is divided by the number of experts to calculate the I-CVI value. One may calculate the S-CVI value by dividing the average I-CVI by the total number of items or by dividing the total value for each expert by the number of experts.

The module builder's defined criteria are used to determine both values. If the value based on the number of experts participating exceeds the boundary value (take-off value), the developed module has a high validity value.
Table **3** shows the I-CVI and S-CVI/average to measure experts' consensus on the Design Thinking Chemistry module.

Table 3
Expert Consensus on Design Thinking Chemistry Module

Num	Item	Expert in Agreement	I-CVIs Value (n= 9)	Interpretation
1	Meets the target population	9	1.00V	Excellent
2	Accordance with the DSKP KSSM Chemistry Form 4 syllabus	9	1.00	Excellent
3	Contains appropriate goals and objectives	9	1.00	Excellent
4	Correspond to the allocated time	8	0.88	Excellent
5	Content of module organization is clear, consistent and appropriate	9	1.00	Excellent
6	Can assist teachers in conveying chemical concepts through the application of design thinking	8	0.88	Excellent
7	Able to enhance students' innovation competencies	9	1.00	Excellent
8	The order of activities by phase in this of module is suitable for implementation	9	1.00	Excellent
9	Activities based have implementation opportunities for other topics or subjects	9	1.00	Excellent
		S-CVI/ Ave=	**0.975**	

Validating the Design Thinking Chemistry Module is essential in crafting innovative and quality education products. Nine experts' high I-CVI ratings and S-CVI of 0.975 demonstrate the module's content validity. Expert agreement on fundamental aspects, such as alignment with the syllabus and clear content organization, affirms the module's excellence in meeting essential criteria. Notably, surpassing Lynn's (1986) recommended threshold for I-CVI further validates the module's efficacy.

The module's reliability was assessed using Cronbach's alpha coefficient. As shown by Sidek and Jamaludin (2005), the study's Cronbach's alpha coefficient of.924 is considered very high. The coefficient of reliability that may be employed in research is 0.85. Expert consensus on design thinking in teaching and increasing students' innovative competencies is varied but valuable for improvement and continual development. These insights are critical for adapting the module to evolving educational needs and ensuring its sustained impact. After receiving feedback, significant modifications were made to the module before it was tested in phase three for its effectiveness.

Conclusion

In conclusion, the experts' consensus shows that the Design Thinking Chemistry Module has good validity. Thus, this module may help chemistry teachers to integrate design thinking instruction to enhance students' innovation competencies. However, the module developed only focused on acid, base, and salt topics. Further research is encouraged to develop design thinking with STEM-integrated teaching modules covering more chemistry topics and interesting design thinking projects. This study also provides a fresh viewpoint on education and emphasizes the ability of design thinking to transform chemistry instruction and enhance student innovation competencies.

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