DEVELOPMENT OF MECHANISTIC ORGANIC MODULE IN ENHANCING PRE-UNIVERSITY CHEMISTRY STUDENTS' PROBLEM-SOLVING SKILLS AND SELF-REGULATED LEARNING

By

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Organic chemistry serves as the foundation for understanding the intricacies of chemical reactions and the synthesis of complex molecules. Despite its fundamental importance, students often struggle with problem-solving skills pertaining to the complex mechanisms of organic reactions. Identifying and resolving the complex mechanisms of organic reactions requires not only a strong understanding of organic chemistry principles but also the ability to apply problem-solving skills effectively. Hence, this study aims to develop a module namely Mechanistic of Organic Module (MOM) in enhancing students' problem-solving skills and Self-Regulated Learning (SRL) in organic chemistry. This study integrates the mechanistic problem-solving skills that is combined with SRL to implicit the meaningful learning of Organic Reaction Mechanisms (ORM) among students. Adopting a design and developmental research approach, the study comprises three phases: (1) Needs Analysis, (2) Design and Development, and (3) Evaluation. During Phase 1, a needs analysis was conducted through Systematic Literature Review (SLR) and semi-structured interviews with five chemistry teachers and matriculation lecturers. Based on the findings, an organic module focusing on ORM and integrating technological aspects with problem-solving and SRL was deemed necessary. In Phase 2, the elements appropriate for the MOM were determined using Fuzzy Delphi Method (FDM). The design phase involved document analysis of STPM and matriculation syllabi and a Focus Group Discussion (FGD) to design FDM questionnaire. Based on the findings in needs analysis, document analysis, and the themes from FGD, the draft module was produced. A panel of 15 experts evaluated the module's elements based on a Fuzzy Linguistic Likert Scale, with consensus determined by the threshold d value and suitability of items. After considering the accepted elements that achieved consensus with the threshold d value ≤0.2 and exceeded 75% on the suitability of items in FDM, the development phase involved developing the prototype module (website and booklet), refining lesson plans and assessment sheets with validation by three experts were carried out. The improvements were implemented based on the experts' recommendations. In Phase 3, the evaluation assessed the module's usability, incorporating students' opinion gathered through open-ended questions. The System Usability Scale (SUS) questionnaire was utilized, yielding a SUS score of 76 (B), indicating excellent user acceptance of the MOM. Additionally, the module was evaluated through a triangulation approach, including observations and document analysis of student assessments. This process, conducted with 25 students, aimed to evaluate their problem-solving skills after engaging with MOM. Thematic analysis indicated that MOM effectively engaged students in problem-solving activities. To evaluate students' SRL practices following the use of MOM, data were collected through semi-structured interviews with the top five high-performing students and 25 reflective field notes. The interviews revealed that MOM could motivate students, support personalized learning, encourage social interaction, help students adapt to challenges, and respond to their learning needs for success. Overall, the module was found to enhance problem-solving skills and SRL practices, supporting students' lifelong learning. The implications of this study include the enhancement of problem-solving skills in organic chemistry, enabling students to apply critical thinking and analytical abilities to solve complex problems. These skills are also transferable to other scientific disciplines and real-world contexts. By equipping students with problem-solving and SRL practices, they are prepared to tackle scientific challenges, engage in independent research, and pursue continuous professional development.

Keywords: Organic Chemistry, Mechanistic Organic Module, Organic Reaction Mechanisms, Problem-Solving Skills, Self-Regulated Learning

SDG: GOAL 4: Quality Education

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN *MECHANISTIC ORGANIC MODULE* DALAM MENINGKATKAN KEMAHIRAN PENYELESAIAN MASALAH DAN PEMBELAJARAN REGULASI KENDIRI PELAJAR KIMIA PRA-UNIVERSITI

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Kimia organik berfungsi sebagai asas untuk memahami selok-belok tindak balas kimia dan sintesis molekul kompleks. Walaupun kepentingan asasnya, pelajar sering bergelut dengan kemahiran menyelesaikan masalah mekanisme kompleks tindak balas organik. Mengenal pasti dan menyelesaikan mekanisme kompleks tindak balas organik memerlukan bukan sahaja pemahaman yang kukuh tentang prinsip kimia organik tetapi juga keupayaan untuk menggunakan kemahiran menyelesaikan masalah dengan berkesan. Oleh hal yang demikian, kajian ini bertujuan untuk membangunkan modul iaitu *Mechanistic of Organic Module* (MOM) dalam meningkatkan kemahiran menyelesaikan masalah pelajar dan Pembelajaran Regulasi Kendiri (SRL) dalam kimia organik. Kajian ini mengintegrasikan kemahiran penyelesaian masalah mekanistik yang digabungkan dengan SRL untuk mengimplisit pembelajaran bermakna bagi tajuk Mekanisme Tindak balas Organik (ORM) dalam kalangan pelajar. Mengguna pakai pendekatan

penyelidikan reka bentuk dan pembangunan, kajian ini terdiri daripada tiga fasa: (1) Analisis Keperluan, (2) Reka Bentuk dan Pembangunan, dan (3) Penilaian. Semasa Fasa 1, analisis keperluan telah dijalankan melalui Kajian Literatur Sistematik (SLR) dan temu bual separa berstruktur dengan lima orang guru kimia dan pensyarah matrikulasi. Berdasarkan dapatan kajian, modul organik yang berfokus kepada ORM dan menyepadukan aspek teknologi dengan penyelesaian masalah dan SRL adalah sangat diperlukan. Dalam Fasa 2, elemen yang sesuai untuk MOM ditentukan menggunakan Kaedah Fuzzy Delphi (FDM). Fasa reka bentuk melibatkan analisis dokumen Sukatan Pelajaran Sijil Tinggi Pelajaran Malaysia (STPM) dan sukatan pelajaran matrikulasi serta kaedah Perbincangan Kumpulan Berfokus (FGD) untuk mereka bentuk soal selidik FDM. Berdasarkan dapatan dalam analisis keperluan, analisis dokumen, dan tema daripada FGD, draf modul telah dihasilkan. Panel yang terdiri daripada 15 pakar menilai elemen modul berdasarkan Skala Likert Linguistik Fuzzy, dengan konsensus ditentukan oleh nilai ambang d dan kesesuaian item. Selepas mempertimbangkan elemen yang diterima yang mencapai kata sepakat sebulat suara dengan nilai ambang $d \leq 0.2$ dan melebihi 75% pada kesesuaian item dalam FDM, fasa pembangunan melibatkan pembangunan modul prototaip (laman web dan buku), rancangan pengajaran dan lembaran soalan-soalan penilaian dengan pengesahan oleh tiga orang pakar telah dijalankan. Penambahbaikan telah dilaksanakan berdasarkan cadangan pakar. Dalam Fasa 3, menilai kebolehgunaan modul serta menggabungkan maklum balas pelajar yang dikumpul melalui soalan terbuka. Soal selidik *System Usability Scale* (SUS) telah digunakan, menghasilkan skor SUS sebanyak 76 (B), menunjukkan penerimaan pengguna yang sangat baik terhadap MOM. Selain itu, modul ini dinilai melalui pendekatan triangulasi, termasuk pemerhatian dan analisis dokumen penilaian pelajar. Proses ini, yang dijalankan oleh 25 pelajar, bertujuan untuk menilai kemahiran menyelesaikan masalah mereka selepas terlibat dengan MOM. Analisis tematik menunjukkan bahawa MOM menggalakkan penglibatan pelajar secara berkesan dalam aktiviti penyelesaian masalah. Untuk menilai amalan SRL pelajar selepas penggunaan MOM, data dikumpul melalui temu bual separa berstruktur terhadap lima pelajar teratas yang berprestasi tinggi dan 25 nota lapangan reflektif. Temu bual mendedahkan bahawa MOM boleh memotivasikan pelajar, menyokong pembelajaran kendiri, menggalakkan interaksi sosial, membantu pelajar menyesuaikan diri dengan cabaran, dan bertindak balas terhadap keperluan pembelajaran pelajar untuk berjaya. Secara keseluruhannya, modul ini didapati dapat meningkatkan kemahiran menyelesaikan masalah dan amalan SRL serta menyokong pembelajaran sepanjang hayat pelajar. Implikasi kajian ini termasuklah peningkatan kemahiran menyelesaikan masalah dalam kimia organik serta membolehkan pelajar mengaplikasikan pemikiran kritis dan kebolehan analitikal untuk menyelesaikan masalah yang kompleks. Kemahiran ini juga boleh dipindahkan kepada disiplin saintifik lain dalam konteks dunia sebenar. Pelajar yang dilengkapi dengan modul penyelesaian masalah dan amalan SRL, mereka bersedia untuk menangani cabaran saintifik, melibatkan diri dalam penyelidikan bebas dan meneruskan pembangunan profesional yang berterusan.

Kata Kunci: Kimia Organik, *Mechanistic Organic Module*, Mekanisme Tindak Balas Organik, Kemahiran Penyelesaian Masalah, Pembelajaran Regulasi Kendiri

SDG: MATLAMAT 4: Pendidikan Berkualiti

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LIST OF ABBREVIATIONS

STEM	Science, Technology, Engineering, the Arts and Mathematics
EPF	Electron-pushing Formalism
ORM	Organic Reaction Mechanisms
IEA	International Association for the Evaluation of Educational Achievement
TIMSS	Trends in International Mathematics and Science Study
PISA	Program for International Assessment
OECD	Organisation For Economic Co-operation and Development
SRL	Self-Regulated Learning
4C	Collaboration Skills, Communication Skills, Critical Thinking Skills, and Creative Skills
GPA	Grade Point Average
STPM	Malaysian Higher School Certificate
MPM	Malaysian Examinations Council
MOM	Mechanistic Organic Module
RQ	Research Question
DDR	Design and Development Research
FGD	Focus Group Discussion
FDM	Fuzzy Delphi Method
MOE	Ministry of Education
LO	Learning Outcome
MQA	Malaysian Qualifications Agency
CLO	Course Learning Outcome
PLO	Programmes Learning Outcome
MQF LOD	Malaysian Qualifications Framework Learning Outcome Domain

EPRD	Education Policy Planning and Research Division
JKEUPM	Ethic Committee for Research involving Human Subjects of Universiti Putra Malaysia
SLR	Systematic Literature Review
CGPA	Cumulative Grade Point Average
IRR	Inter-rater reliability
CVI	Content Validity Index
PCM	Percentage Calculation Method
SPSS	Statistical Package for Social Sciences

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter deliberates the main concepts of the study. The research background starts by presenting the research background in organic chemistry which is a part of Science, Technology, Engineering, the Arts and Mathematics (STEM) subject before addressing and associating the mechanistic approach through Electron Pushing Formalism (EPF) with problems pertaining to teaching and learning Organic Reaction Mechanisms (ORM). In converging the study issue, problem statement including research objectives are discussed followed by research questions and research hypothesis. Subsequently, the operational definition, significance and limitation of study are presented. The chapter is closing by summarizing of thesis structure.

1.2 Background of the Study

International Association for the Evaluation of Educational Achievement (IEA) has conducted an international comparative study through Trends in International Mathematics and Science Study (TIMSS) in every four years. While Programme for International Student Assessment (PISA) is an international assessment which launched by Organisation for Economic Co-operation and Development (OECD) which will accomplish by students in three years. Malaysia's participation in both studies is to measure the effectiveness of Mathematics and Science learning among Malaysian students compared to their peers in other countries (MOE, 2015). Science achievement in TIMSS 2019 has shown a decrease compared to TIMSS 2015 (Ministry of Education, 2019). Meanwhile, Malaysian students' performance in PISA showed that 63% them attained Level 2 in science which 15% below the OECD average. The downward trend in Malaysian students' performances in both study has been raised a concern for academician and government to implement STEM for ensuring that Malaysia has a sufficient number of qualified STEM graduates to fulfil the employment needs of the industries besides preparing students to compete globally (Hin, 2020; Malaysia Education Blueprint Malaysia, 2013). These similar issues have been semblance by many other countries as well.

Pursuing the history of STEM education in Malaysia, it started since 1970 when government was giving priority to science and technology education by focusing on increasing the enrolment of science stream students. The Higher Education Planning Committee (1967) introduced the enrolment policy called the 60:40 policy with aim towards science stream students to humanities students with ratio of 60% and 40% respectively (Suhanna Zainudin et al., 2015). However, according to the Malaysia Educational Statistics 2020 and 2021 reports (Table 1.1), the enrolment at the post-secondary level for Malaysian upper-six students in government and government-aided Malaysian schools still falls far behind the 60:40 policy. Humanities students monopolized the enrolment with 35,823 students in Year 2020 and 35,843 students in Year 2021, outnumbering the total number of Malaysian upper-six students, which stood at 39,021 and 39,295, respectively.

Table 1.1 : Enrolment at the Post-Secondary Level (Upper-Six) in Government and Government-Aided Malaysian Schools in the Year 2020 and Year 2021

	Humanities	Science	Religious	Total
2020	35,823	3,165	33	**39,021**
2021	35,843	3,312	140	**39,295**

Further, the value of high quality of STEM education to deliver not only STEM content knowledge but also 21st century skills that all students need to engage as successful human capital in workforce as well as the society. Apparently, problem-solving is one of them. Therefore, PISA which initially covers the domains of mathematics, reading and science sought to address this when its 2012 assessment, contained the first international metric of individual problem-solving skills and the 2015 assessment took this further, assessing collaborative problem-solving skills. The assessment of problem-solving has been significantly revised since it was last administered as additional domain in PISA 2003. However, this skills had governed as an option by certain countries (Csapó & Funke, 2017; OECD, 2013). Realising the importance of problem-solving skills, witnessed the chemistry curriculum infusing the elements of problem-solving.

Chemistry is one of the subjects included in STEM Education. Due to the decreasing of enrolment in STEM majors including chemistry, national curriculum of certain countries such as United State, Australia and United Kingdom is implementing an integrated STEM Education to prepare students for future career (Aydin-Gunbatar et al., 2018 ; Martín-Páez et al., 2019). Students majoring in fields such as chemistry, biology, pharmaceutical sciences, chemical engineering, applied sciences, or public health science need a solid understanding of organic chemistry (Lopez et al., 2011). Mastery of organic chemistry requires strong problem-solving skills, as the subject often challenges students with complex reaction mechanisms and analytical thinking. Unfortunately, the high failure rates in organic chemistry courses act as a barrier for many students, preventing them from advancing in their chosen fields. By enhancing students' problem-solving skills in organic chemistry, educators can help reduce failure rates and better equip students for the demands of STEM careers. Consequently, organic chemistry is not just a gatekeeper but a crucial enabler within STEM education (Gupta & Hartwell, 2019).

An organic chemistry has certain topics namely structural formulae, functional groups, characteristics of organic compounds and organic reactions (types of reactions and ORM) that were reported by teachers and students as difficult to understand and become barrier for them to succeed (O 'Dwyer et al., 2012). The abstraction and interpretive understanding of organic chemistry tend to produce unsuccessful mechanisms though perceived as the most difficult topic to learn (O 'Dwyer & Childs, 2017). Traditional methods in learning ORM often rely heavily on rote memorization and the use of symbolic representations, which can lead to superficial understanding among students. Hence, in making sense of chemical phenomena in ORM and reducing students' alternative conceptions, the learning of organic chemistry requires thinking encompassing macroscopic, sub-microscopic, and symbolic aspects. This is known as the Johnstone Triangle, which has become a model for the chemistry learning process and aims to help reduce information overload

(Johnstone, 2000; Keiner & Graulich, 2020a; Thomas, 2017; Treagust et al., 2003).

Currently, the approaches to teaching and learning ORM emphasize a combination of traditional and innovative strategies to enhance student problem-solving and engagement. Active learning techniques, such as peer instruction and collaborative problem-solving encourage students to engage with the material actively, promoting a more profound understanding of complex concepts like reaction mechanisms (Haindfield et al., 2024). Additionally, the integration of technology, such as interactive simulations and digital tools, has been shown to support students in visualizing and manipulating molecular structures, thereby enhancing their grasp of mechanistic pathways (Trabert et al., 2022). However, challenges remain, particularly in ensuring that students can transfer their understanding of mechanisms to novel problems, a skill that is crucial for success in organic chemistry (Sabitu et al., 2020).

Meanwhile, the mechanistic approach, particularly through EPF, is widely used for understanding reaction mechanisms. This formalism uses curved arrows to depict the movement of electrons during chemical reactions, providing a visual representation of electron flow and bond formation or breaking. Wilson and Varma-Nelson (2019) emphasize the importance of this approach in teaching organic chemistry, as it helps students conceptualize complex mechanisms more intuitively. Flynn and Ogilvie (2015) highlight that electron-pushing not only clarifies the mechanistic pathways but also aids in predicting the outcomes of reactions, thereby enhancing problem-solving skills in organic synthesis. Bhattacharyya (2013, 2014) supports this by demonstrating that a solid grasp of electron-pushing principles can lead to improved understanding of reaction selectivity and stereochemistry. However, while EPF is a powerful tool, it may oversimplify certain reactions, necessitating a more nuanced approach in complex scenarios (Othman Talib et al., 2014).

Moreover, students must also actively manage their own learning process, known as Self-Regulated Learning (SRL), during and after classroom lessons. With SRL practices, students can effectively participate in monitoring their organic chemistry learning, maintaining motivation, and employing specific strategies (Lopez et al., 2013; Zimmerman et al., 1992). In educational modules, SRL is a critical component to influence students' ability to manage their learning processes effectively. Various research indicates that SRL strategies enhance academic performance and engagement in various learning environments. Sun et al., (2024) highlight the importance of metacognitive strategies in fostering self-regulation among students, which leads to improved learning outcomes in module-based settings. Students can reflect on their thought processes and adjust their learning strategies accordingly, which is essential for mastering complex subjects like organic chemistry. Wahyuni et al. (2024) further emphasize that structured modules that incorporate self-assessment and goal-setting can significantly boost students' self-regulation skills. In addition, Rosyada et al. (2024) found that integrating technology into learning modules supports SRL by providing students with tools for tracking their progress and reflecting on their learning. However, not all students may benefit equally from these modules, as individual differences in motivation and prior knowledge can affect the implementation of SRL practices (Umamah et al., 2023).

The evolution of teaching methods for ORM, particularly in the integration of mechanistic problem-solving and SRL elements, underscores the necessity for teaching strategies to adapt to the changing educational landscape. In the Malaysian context, educators face challenges in implementing mechanistic approaches to teaching ORM that effectively promote problem-solving skills. It has been observed that students often resort to memorization rather than genuine problem-solving (Su-yin Kan et al., 2015; Sabitu et al., 2021; Othman Talib et al., 2012), and they remain heavily reliant on teachers, struggling to manage their own learning in organic chemistry (Othman Talib et al., 2017). Traditionally, teachers have used conventional modules to teach ORM, which may not fully support the development of problem-solving and SRL skills.

Given the growing emphasis on fostering problem-solving skills and SRL practices, it is crucial to reconsider the teaching aids that can enhance educators' ability to better support their students. One approach is to shift the focus from memorization to problem-solving, a strategy more prevalent in international contexts (Dood & Watts, 2022; Flynn & Ogilvie, 2015; Jolanda & Helen, 2022) but still underutilized in Malaysian organic chemistry education. Moreover, with the rise of technological advancements in learning, students now have the opportunity to engage in managing and solving problems on their own in organic chemistry.

To make learning more meaningful, well-designed modules that provide adequate support and feedback are needed to enhance students' learning and allow them to learn at their own pace. Thus, teachers serve as coaches by guiding students to their prior knowledge, summarizing the output, and providing summative evaluations (Schunk, 2005; Tugade, 2016; Yani & Adiansyah, 2017). This approach not only enhances students' ability to solve mechanistic problems but also promotes lifelong learning skills. Therefore, this is an opportune moment to revamp instructional strategies and teaching aids, particularly for the ORM topic, to meet the new challenges in education.

1.3 Problem Statement

STEM educational objectives are focused on the integration of two or more disciplines which are either science, technology, engineering, or mathematics as well as the mastery of 21st century skills such as collaboration skills, communication skills, critical thinking skills, and creative skills (4C). STEM has a far-reaching goal of preparing students to face challenges and global competitiveness (Malaysia Education Blueprint Malaysia, 2013). Therefore, chemistry as part of STEM education has not been left behind for implementing STEM in teaching and learning. However, there are many existing studies (El Nagdi et al., 2018; Nur Farhana Ramli & Othman Talib, 2017; Permanasari et al., 2021; Shidiq et al., 2020) have been reporting about chemistry students and teachers who are still unfamiliar with learning by STEM integration. In fact, based on the results of TIMSS in 2019, chemistry subjects got the lowest average score of 434 compared to the other science subjects that are biology, physics and earth science which the score were 463, 475 and 452 respectively (Ministry of Education, 2019).

Instead of enhancing the 4C skills, problem-solving is also highlighted as importance life skill for the integration of STEM. Problem-solving plays vital role to scientific practice and research which needed by students in learning science, nonetheless enhancing those skill on students become one of educational challenges (Graulich, 2014; Mayer & Wittrock, 2006; Md, 2019). Most studies on STEM Education deal with each discipline singly and do not measure students' ability in making connections across disciplines or their competency with skills such as collaboration and problem-solving (Mohr-Schroeder et al., 2015). Obviously, todays' workplaces including an educational institution demand students who can solve non-routine problems until the OECD sought to address problem-solving on the PISA 2003, 2012 and 2015 assessment (Csapó & Funke, 2017; Mayer & Wittrock, 2006; OECD, 2014). The key findings of the PISA 2003 survey found that in most countries, more than 10% of students were unable to solve basic problems on average in OECD countries, half of the students were unable to solve difficult problems. Meanwhile, in PISA 2012 result on problem-solving, Malaysian 15 years old students scored below the OECD average and about one in five students is only able to solve very basic problems (OECD, 2004, 2014).

With regard to organic chemistry, the students seem struggle with problem-solving so that chemistry education determine a key goal to help students develop the problem-solving skills (Lieber & Graulich, 2020). Much studies found organic chemistry is difficult to learn especially for novice students (Finkenstaedt-Quinn et al., 2020; O ’Dwyer & Childs, 2017). Even since 1971, Johnstone (2010) had listed organic chemistry as one of nine areas of chemistry that were established as challenging subject. The content is almost entirely abstract then this lead students to face many complications and misunderstandings in organic chemistry (Chonkaew et al., 2019; Eticha & Ochonogor, 2015; O ’Dwyer et al., 2012; O ’Dwyer & Childs, 2017). Besides, there are no problem-solving algorithms in organic chemistry learning and requires three-dimensional thinking (Azraai Othman, Dani Asmadi Ibrahim, et al., 2015; Stowe et al., 2020). As a result, many students resorting to outright memorisation of the content in organic chemistry rather than learning for understanding. Due to the rote learning in order to pass the certain examinations, students have higher tendency to face misunderstanding in the organic concepts concurring.

This also hinders their proficiency to incorporate new information into existing knowledge structure and limits their problem-solving skills (Carle et al., 2020; O ’Dwyer et al., 2012; Salame et al., 2020). In O ’Dwyer and Childs (2017), they reported that reaction mechanism was the most difficult topic to learn which has a high cognitive demand. In transforming reactants to products, the students focus more on the products than to the process involved in the reaction mechanisms (Bodner, 2015; Ferguson & Bodner, 2008). Therefore, many students do not understand the process of organic mechanisms and struggle with synthesis problems due to lack of problem-solving methods, no appropriate approach to produce successful mechanisms, and a lack of strategy in solving organic reaction mechanisms (Bodé et al., 2016; Salame et al., 2024).

In pre-university chemistry, the subject is typically divided into organic, physical, and inorganic chemistry. The complexity of organic chemistry, however, stands out due to its demand for advanced problem-solving skills. While physical and inorganic chemistry often involve more straightforward principles and equations, organic chemistry requires a deep understanding of complex reaction mechanisms, molecular structures, and synthetic pathways. Organic chemistry is inherently tied to problem-solving, requiring skills like predicting reactivity, proposing mechanisms, and designing syntheses, which are crucial for students' success (Helix et al., 2022). Additionally, the discipline's problem-solving nature has inspired the development of algorithms for solving organic chemistry challenges, a key element in advancing digital tools (Yu et al., 2021). Research by Salame et al. (2024) shows that students frequently use strategies like annotation and trial and error, but their inconsistent application of these methods can hinder their ability to tackle complex organic chemistry problems. This inconsistency may contribute to lower grades and indicates a need for improved instructional strategies that strengthen effective problem-solving skills in organic chemistry.

This problem is experienced by Malaysian students in daily schools as well as students in selected schools. The Grade Point Average (GPA) of Malaysian Higher School Certificate (STPM) for science stream showed that organic chemistry subject was lower than physical chemistry and inorganic chemistry. Table 1.2 represent the data which is the analysis of STPM results in 2017 - 2021 at Form Six Science Stream Centre in Kuantan District, Pahang for physical chemistry, inorganic chemistry and organic chemistry over a period of five years. Referring to this table, for five consecutive years of organic chemistry results has obtained GPA below 2.00 and the result indicates that this subject is problematic compared to physical chemistry and inorganic chemistry. Meanwhile, 2018, 2019 and 2020 Annual Report of Malaysian Examinations Council (MPM) recorded that organic chemistry syllabus which have been taught in Semester Three have shown highest percentage of failure (Table 1.3).

Table 1.2 : Analysis of STPM Results in Chemistry for the Years 2017-2021 at a Form Six Science Stream Centre in the Kuantan District, Pahang

Subjects	2017	2018	2019	2020	2021
Physical Chemistry	2.49	2.31	2.82	3.07	3.16
Inorganic Chemistry	2.85	2.53	2.49	2.31	2.80
Organic Chemistry	1.99	1.61	1.79	1.61	1.45

Table 1.3 : Candidates' Percentage Achievements in Physical Chemistry, Inorganic Chemistry and Organic Chemistry for STPM 2018, 2019 and 2020

	STPM 2018		**STPM 2019**		**STPM 2020**	
	Pass (%)	Fail (%)	Pass (%)	Fail (%)	Pass (%)	Fail (%)
Physical Chemistry	77.97	**22.03**	79.79	**20.21**	84.60	**15.40**
Inorganic Chemistry	74.18	**25.82**	78.45	**21.55**	77.85	**22.15**
Organic Chemistry	72.81	**27.19**	71.96	**28.04**	72.21	**27.79**

Notes: Pass = Grades in STPM within A, A-, B+, B, B-, C+, C, C-, D+, and D; Fail = Grades in STPM of F.

Nur Syuhada Rusli and Nor Hasniza Ibrahim (2021) highlighted a significant gap in research focused on challenging topics in pre-university chemistry, particularly those encountered in form six and matriculation courses in Malaysia, for both students and teachers. Consequently, effective teaching strategies for ORM have not been adequately developed. Interviews conducted by Sabitu et al. (2021) with Malaysian chemistry subject matter experts revealed that many teachers still illustrate mechanisms on the whiteboard and rely on Microsoft PowerPoint presentations to demonstrate mechanistic processes. Also, due to time constraints, teachers often choose to reference mechanisms directly from textbooks. Lok Wai Foong et al. (2012) attempted to use the collaborative learning method in a pre-university chemistry class on the topic of alkenes; however, many students remained uncomfortable with group discussions, preferring instead to review answers with their peers. Additionally, limited use of modern technology by teachers has hindered students' ability to visualize reaction mechanisms, such as alcohol dehydration. In response, Salwati Yaakub et al. (2022) introduced the flipped classroom approach, providing videos to support learning, though students faced challenges accessing them due to large file sizes and the need for high-speed internet. Moreover, they struggled with understanding the content, as they lacked the initiative to engage in SRL, which further hindered their problem-solving skills.

Presently, teacher-centered approach dominates the organic chemistry classrooms which leads students participate in a passive and dependent role. The content overload of organic chemistry required students to stimulate independence and engage actively for their own learning activities. Several studies on organic chemistry learning found that students become inactive, struggle academically, low motivation and unable to control their own learning independently due to lacking with appropriate self-regulation (Alvi, 2020; Lopez et al., 2013; Olakanmi & Gumbo, 2017; Silverajah & Govindaraj, 2018). Moreover, the outcome of Laureano and Espinosa (2015) study highlighted deficiencies in high school students' abilities of communication, thinking logically and solving problems because students unable to manage their own SRL. On the other hand, having higher levels of SRL could help students to overcome extraneous load in learning the organic content (Lange & Costley, 2017). Meanwhile, for Malaysian classroom context as reported by Lim et al. (2020), self-regulation give positive effect on students' learning in general. However, studies on SRL with implementing mechanistic approach in organic chemistry subject has not been the focus of previous studies. Furthermore, existing teaching materials are typically organized based on functional groups, covering a wide range of organic chemistry topics in this format.

Teaching materials like modules demands student's independency and capacity for achieving the objectives of a specific concept (Noreen et al., 2019; Tugade, 2016). Regarding to the important components of learning modules, some teachers are using module's approach in addressing students' skill to learn ORM, but they are still inadequate to explore the content in a learning module at their own pace. Moreover, the availability of learning modules which built-in assessment of progress and provide student with immediate feedback is currently highly demanded in schools (Setiyadi, Ismail, & Gani, 2017). Thus, module development can be one strategy in assisting schools or higher institutions to achieve quality learning. So that, teachers should be encouraged to utilize module by incorporating SRL (Carle et al., 2020 ; Olakanmi & Gumbo, 2017). Despite the availability of various teaching materials and current approaches for ORM, problems remain due to the limited modules focused specifically on ORM. This research, therefore, introduces a novel approach called the Mechanistic Organic Module (MOM) which integrate the mechanistic problem-solving approach to implicit the meaningful learning in understanding ORM among students. By the combination of SRL with the module, it is anticipated to produce the good impact on students' performance.

1.4 Research Objectives

(i) To identify the needs of the development of the MOM for teaching ORM among pre-university chemistry students based on experts' views

(ii) To develop a module namely MOM for learning ORM based on experts' opinion and decision

(iii) To evaluate the usability of the MOM for pre-university chemistry students

(iv) To explore students' problem-solving skills after undergoing MOM in learning ORM

(v) To explore students' SRL after undergoing MOM in learning ORM

1.5 Research Questions

From the objectives of this study, four main research questions (RQs) have been formulated to guide the research. Additionally, RQ1, and RQ2 are further subdivided into sub-research questions. The RQs for this study are presented in Table 1.4.

Table 1.4 : Main Research Questions and the Sub-Research Questions of Study

Main research questions	Sub-research questions
RQ 1:What are the needs in developing MOM for teaching ORM among pre-university chemistry students?	RQ 1.1: How did teaching and learning strategies of ORM were implemented in previous studies? RQ 1.2: What aspects should be taken into account when teaching and learning ORM, in the opinion of experts?
RQ 2: What are the components for developments of MOM based on experts' opinion and decision?	RQ 2.1: What are the objectives of MOM? RQ 2.2: What are the appropriate contents of MOM? RQ 2.3: What are the appropriate teaching strategies of ORM in MOM? RQ 2.4: What are the appropriate learning activities in MOM? RQ 2.5: What is the appropriate assessment method to be used in MOM? RQ 2.6: To what extent the experts agree with validity of MOM?
RQ 3: How is the usability of the MOM for pre-university chemistry students?	
RQ 4: How does MOM improve students' problem-solving skills?	
RQ 5: How could MOM enhance students' Self-Regulated Learning?	

1.6 Significant of the Study

Mechanistic problem-solving is a pedagogical approach in organic chemistry mechanisms that requires diverse skills and knowledge to shift from product-oriented thinking to process-oriented thinking in deducing the correct mechanism (Davis, 2020; Graulich, 2014; Schmitt & Schween, 2018). However, this approach still presents various challenges for students striving to master ORM. Therefore, implementing SRL in the mechanistic problem-solving approach could potentially improve students' performance. Theoretically, this study contributes to the literature on mechanistic problem-solving by integrating the Johnstone's Triangle with the Zimmerman Cyclic model of SRL culminating in the development of the MOM Stages.

This study is methodologically developing the MOM through a systematic Design and Development Research (DDR) approach that focuses on the module's usability in actual student implementations. It aims to contribute to the literature review for other researchers engaged in DDR studies. Practically, this study could provide a comprehensive module for chemistry teachers to teach ORM, simultaneously facilitating them in conducting systematic classroom activities. Additionally, the development of this module will contribute to the body of knowledge in chemistry education.

Mechanistic problem-solving is a pedagogical approach in organic chemistry mechanisms that requires students to transition from product-oriented thinking to process-oriented thinking. Specifically, this approach is vital in mastering ORM, as it demands a deep understanding of the step-by-step processes involved in reactions. Nevertheless, despite its potential, students often face significant challenges in its application. Thus, by incorporating SRL strategies into the mechanistic problem-solving approach, this study aims to improve students' performance and enhance their ability to navigate the complexities of ORM.

Theoretically, the study contributes to the growing body of literature on mechanistic problem-solving in organic chemistry by integrating the Johnstone’s Triangle with the Zimmerman Cyclic Model of SRL. This theoretical integration offers a novel perspective on how students can be guided to shift their thinking from static product-focused approaches to more dynamic, process-oriented problem-solving. In addition, the findings will provide a deeper understanding of how SRL strategies can be effectively utilized within this context, enriching both the pedagogical framework and the theoretical discourse in chemistry education.

From a methodological standpoint, this research employs a systematic DDR approach to create the MOM. By focusing on the module's design, development, and usability through real-world student implementation, this study offers a methodological contribution to the field of chemistry education. Consequently, researchers engaging in DDR studies can reference this work for its structured approach to module development and its focus on evaluating actual classroom usability, thereby advancing methodological practices in the field.

Practically, this study provides chemistry educators with a comprehensive teaching module for ORM, incorporating SRL strategies. This module not only supports educators in delivering ORM content more effectively but also serves as a tool for conducting systematic classroom activities. Moreover, the development and implementation of the MOM contributes to the body of knowledge in chemistry education by offering a practical resource that can be adapted for broader use, enhancing teaching practices and student outcomes in organic chemistry.

1.7 Scope and Limitations

This study focuses on the development and evaluation of the MOM aimed at enhancing students' problem-solving skills and SRL in the context of organic chemistry, specifically ORM. The scope of this study encompasses the entire process of module development, from the needs analysis through design and development to the evaluation phase. The needs analysis involved a SLR and semi-structured interviews with chemistry teachers and matriculation lecturers, providing insights into the need for such a module. The design and development phase used a combination of expert evaluations, document analysis, focus group discussion (FGD) and Fuzzy Delphi Method (FDM) to produce the module's prototype. In the evaluation phase, the module's usability was assessed through usability questionnaires, classroom observations, document analysis of student assessments, and thematic analysis of semi-structured interviews and reflective field notes from students.

The study is limited to pre-university chemistry students, specifically those enrolled in matriculation programs in Malaysia. As such, the findings may not be directly applicable to other educational contexts or student populations, particularly those outside of the Malaysian pre-university system. The sample size for student evaluations (25 students) may also limit the generalizability of the results, as a larger, more diverse sample might yield different insights. Furthermore, the study is confined to the evaluation of the MOM module's impact on problem-solving skills and SRL within the specific domain of ORM in organic chemistry, and does not address other potential uses of the module in other branches of chemistry or scientific disciplines. Another limitation is the reliance on self-reported data from students through interviews and reflective field notes, which could be subject to biases such as social desirability or recall bias. While the study employed triangulation to strengthen the findings, the module's impact was assessed over a limited timeframe, and long-term effects on students' problem-solving skills and SRL practices remain uncertain. Finally, the development of MOM was guided by expert evaluations, but the evolving nature of educational technology suggests that continual updates and improvements to the module are necessary for optimal usability and effectiveness.

Despite these limitations, the study provides valuable insights into the potential of integrating technology, problem-solving skills, and SRL in organic chemistry education, with implications for future enhancements and applications in similar educational settings.

1.8 Definition of Terms

1.8.1 Mechanistic Organic Module (MOM)

Russell (1974) states that module must be accomplished to bring an individual to positive changes and can be applied in any condition whether in individual, group, academic or non-academic activity. Modules can be defined as self-contained and independent instructional materials that can help students to proceed their learning according to well-defined objectives (Estranero, 2001 ; Rumpus, 2003 ; Tugade, 2016). The modules commonly contain the specific skills to be achieved by implementing the particular approach with enrichment of activities and provide a set of test which administer students to catch up with the missed lessons (Estranero, 2001 ; Torrefranca, 2017).

This study developed the module (MOM) in two formats: a website and a booklet, both comprising activities that integrate mechanistic problem-solving in teaching ORM and incorporate SRL practices. The mechanistic approach, which focuses on the pattern of electron movement, is considered more general, easier to apply, and effective in providing a deeper understanding of chemical reactivity. Visualizing these steps offers a powerful and systematic method for learning organic chemistry (Okuyama & Maskill, 2013). The activities in MOM were designed based on the lesson objectives outlined in the pre-university Chemistry Syllabus (STPM and matriculation). For effective lesson delivery, MOM utilizes Google Sites and integrates various tools, such as Microsoft PowerPoint, YouTube, and Quizzes. This research applies organic chemistry through a mechanistic problem-solving method, aligning with the PISA problem-solving framework and fostering SRL. Within MOM, several materials are used, including lesson plans and student assessments, which consist of both formative and summative questions. The prototype of the MOM booklet is provided in **Appendix A**.

1.8.2 Problem-Solving Skills

Problem-solving is defined as a cognitive process that focused on accomplishing an objective to reach the desired goal which the students do not primarily know the solution (Mayer, 1992, 2003; Mayer & Wittrock, 2006). In PISA 2003 framework, problem-solving is referred as an individual's capacity to use cognitive processes to resolve real, cross-disciplinary situations where the solution path is not immediately obvious includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen (OECD, 2004, 2013). This study is measuring the mechanistic problem-solving skills on learning ORM for organic chemistry subject. Mechanistic problem-solving is referring to a mechanism of step by step synthesis to represent a new way of thinking for organic chemistry students (Graulich, 2014). In the context of this study, problem-solving activities were based on the MOM Problem-Solving Processes: (1) Plan, (2) Implement, and (3) Reflect. These variables were developed using the PISA Problem-solving Framework, Zimmerman and Moylan's Cyclic Model, and Johnstone's Triangle Model.

1.8.3 Self-Regulated Learning Practices

Self-Regulated Learning (SRL) refers to the extent to which students actively engage in their own learning process through metacognition, motivation, and behavior, ultimately leading to academic achievement (Schunk & Zimmerman, 2013). SRL emphasizes the active role of learners in setting goals, monitoring their progress, and adapting their strategies to achieve desired learning outcomes (Zimmerman & Moylan, 2009). In this study, the students' SRL practices were measured qualitatively through the triangulation of data from semi-structured interviews and reflective field notes, focusing on three phases: (1) forethought, (2) performance, and (3) self-reflection.

1.9 Thesis Structure

The thesis is structured into seven chapters. Chapter 1 addresses the focal issues of the study, while Chapter 2 provides an overview of relevant literature pertaining to the research theme. The literature review concentrates on topics such as the organic chemistry curriculum, problem-solving skills, and SRL. This chapter introduces the variables encompassed within the study's framework. In Chapter 3, the research methodology is outlined, aligning with the three phases of DDR. The theoretical underpinnings of MOM development are detailed. Additionally, the chapter explains both qualitative methods (semi-structured interviews, document analysis, FGD and observation) and quantitative methods FDM and survey). The validity, reliability, and data analysis protocols for each approach are discussed. Chapters 4, 5, and 6 report the study's findings, organized according to the needs analysis, design and development, and evaluation phases, respectively. Chapter 7 further examines and interprets these findings, with qualitative results complementing the quantitative data. The chapter concludes by summarizing the research's implications and providing recommendations for future studies.

1.10 Chapter Summary

This chapter introduces the issue related to the study and shortly explains the current issue of organic chemistry specifically on ORM. Based on the argumentative discussions, the research objectives, the significance, the operational definition and overall structure of this study are drawn. The next chapter then will discuss about literature review and the theories that are underpinned by the issues related to the organic chemistry curriculum, problem-solving and SRL.

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