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Understanding Pre-Service Teachers' Conceptual Difficulties in Learning Newman Projections

Muhammad Adlim[1]*, Syahrial[1], Sri Winarni[1], Deriyani[1], Abdul Gani[1], Rusman[1] and Subhan Salaeh[2]

[1]Department of Chemistry Education, Faculty of Teacher Training and Education, Syiah Kuala University, Banda Aceh, Indonesia
[2]Faculty of Science and Technology, Prince of Songkla University, Pattani Campus, Pattani, 94000, Thailand

**E-mail: adlim@usk.ac.id*

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Abstract

Challenges in mastering chemistry content among pre-service chemistry teachers remain a critical concern in teacher education institutions. This study aims to analyze the most difficult concepts and the underlying conditions contributing to students' failure in mastering specific chemistry courses. Data were collected through questionnaires, interviews, and document analysis. The research began by identifying courses with the highest proportion of failing grades (≤ D) based on academic transcripts from 235 students across four cohorts in a chemistry education program. Organic Chemistry I was identified as the course with the highest failure rate, affecting 141 students. From this group, ten students from each cohort with a GPA ≥ 3.0 were randomly selected to complete a questionnaire identifying the most difficult topics in the course. In-depth interviews with students and lecturers were then conducted to explore the conceptual difficulties and their possible causes. Findings consistently revealed that Organic Chemistry I had the highest proportion of D grades (10%) compared to other courses, with more than 60% of students in each cohort receiving low grades. Students reported that the Newman projection was the most challenging topic, citing both the abstract nature of the concept, which requires spatial reasoning and mental rotation of molecular structures, and the lack of effective instructional strategies to support understanding. These results highlight the need for pedagogical innovations targeting spatial visualization skills to enhance conceptual comprehension in organic chemistry education.

Keywords: conceptual difficulties, newman projection, pre-service teachers, organic chemistry, spatial visualization

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1. Introduction

Chemistry is one of the natural sciences with a study focus on the properties, composition, and structure of substances (Oladejo et al., 2023; Sukmawati, 2020), as well as on their synthesis, separation, transformation, and the energy changes involved in chemical reactions. The main branches of chemistry include organic chemistry, physical chemistry, analytical chemistry, inorganic chemistry, and biochemistry, each offering distinct perspectives and methodologies to understand matter and its interactions at the molecular and atomic levels.

Chemistry subject is considered difficult to learn by many students for several reasons including the negative perception that makes them avoid learning it (Sheehan, 2010). Physical and inorganic chemistry involves several mathematical concepts mainly algebra, geometry, trigonometry, and calculus. Learning chemistry is also progression, many have integrated concepts. Students who miss the basic concepts will not master advanced lessons. Chemical terminologies including chemical nomenclature, physical quantity, and unit are often used. Figures, tables, and graphical interpretations known as multiple representations require integrated concepts to be understood. Interpreting phase equilibrium is one of the difficult graphical concepts. Some conceptual rules are applied but many have exceptions. Chemistry laboratory work also requires mastered concepts to conduct it. Chemistry involves visualizing particles and processes that are abstract and imaginative, like subatomic particles, atoms, molecules, and chemical reactions. Spatial intelligence which is the ability to understand space both real and images is required in learning stereochemistry, symmetry-point groups concept, and bonding chemistry (Sheehan, 2010).

Pre-service chemistry teachers are students in teacher-teaching faculty who are required not only to learn all chemistry concepts but also to teach those concepts to high school students. The Chemical Education Study Program has sixty-eight courses consisting of fifty-two chemistry courses, six elective chemistry courses, six general courses, and four educational courses. In taking these courses, many students experience learning difficulties, resulting in many students not passing certain courses and finally their cumulative grade point average (GPA) decreased to below two in two semesters, then they will automatically drop out (DO) by the system, therefore analysis of their learning difficulty will help to anticipate and propose a better the learning strategy. Typically, it is more than 60% of students show learning difficulty (≤ D score) in organic chemistry and physical chemistry. (Sendur, 2020; Eticha & Ochonogor, 2015; Aydin-Gunbatar et al., 2020).

The process of learning chemistry will be more effective if sufficient effort is made, such as knowing or identifying learning difficulties experienced by students. Learning problems caused many aspects including student personal characteristics, the learning environment and motivation, the pedagogy, and the nature of the lesson. Learning difficulties in chemistry mostly focus on misconceptions of chemistry concepts (Tumay, 2016; Rosyidah et al., 2024; Munawwarah & Side, 2022; Ningrum et al., 2022; Sheehan, 2010). Analysis of learning problems is mostly done through interviews and concept mapping tests (Heron et al., 2018; Timilsena et al., 2022). A chemistry learning problem has been reported in the buffer concept and others (Ali et al., 2022; Atika & Latisma, 2022; Kajornklin et al., 2022; Sanjiwani et al., 2020). Generally, the chemistry concept will be difficult to learn if it does not relate to daily life (Treagust et al., 2018). The learning difficulty is also affected by other factors (Tumay, 2016). Learning difficulty can be interpreted as a condition in the learning process characterized by certain obstacles to achieving maximum learning outcomes. Most learning difficulties in chemistry are related to some chemistry phenomena that contradict student intuition in the everyday views of students (Treagust et al., 2018).

Education and psychology have different perspectives on learning difficulty issues. Educational views define learning difficulty as a lack of systematic mental development that is indicated by an academic deficiency in reading, writing, and performing simple arithmetic calculations. These difficulties are limited to comprehension, writing skills, and misconception. The psychological perspective states that learning difficulty is related to students' attention affecting solving problems as a representation of thinking patterns. Students usually lack attention to appropriate stimuli due to defects in perception, concept formation, remembering, problem-solving, and failure to develop thinking methods and knowledge organization. The third interpretation of learning difficulty was based on the physical organ perspective. Environmental and genetic aspects can affect learning difficulty (Zidan, 2023).

Since indicators of student learning difficulties include low learning outcomes (Zidan, 2023) therefore, this study focuses on identifying difficult courses and follows up with an interview on a difficult concept and student perception that caused their failure and related circumstances. This study can be a model for analyzing student learning difficulty in other subject matter at the University level, and most publications on learning difficulty were on early school grades (Tumay, 2016; Syamsi & Dharma, 2023).

2. Research Method

The student transcripts of final year students from the four enrolment years were analyzed to explore the chemistry course that most students failed (D or E scores). After identifying the problematic chemistry course, the course contents were scrutinized to be confirmed by students and lectures, which are the most difficult topics. Four generations (enrolment period) of chemistry students in teacher training faculty with 235 students was the population. The difficult courses with student distribution were identified by analyzing their academic transcript. Among 141 failed students; 10 students from each enrolment period with a GPA of ≥ 3.0 (40 students) were asked to fill out a questionnaire to identify the most difficult topics within the unmastered courses. The interview was conducted with 3 of each group of students; smart students (A grades), moderate scores (C grades), and failed students (D/E grades) to explore what causes the topics to become difficult to comprehend. The interview protocol included the reasons that made students fail and their perception; a) feelings after taking the problematic course, b) teaching materials used in the learning process, c) learning method, d) learning media used in the learning process, e) learning outcomes evaluation system, f) suggestions for students to improve problematic course. Discussing with experts/lecturers was carried out to analyze the teaching materials of the problematic courses to identify the composition of the course content involving mathematical requirements, the abstract concept composition, and the complexity of the course due to its relation to other courses.

3. Result and Discussion

Based on student transcripts from 4 periods of enrolment data, there are 11 courses with a high percentage of D scores, among 21 chemistry courses in the chemistry curriculum as displayed in Table 1.

Table 1. Difficult Chemistry Course According to High D Score Percentage in Four Generations (4 Period Enrollments)

No.	Course names	Percentage of D Score (%)
1.	Organic Chemistry I	10.0
2.	Organic Chemistry II	7.5
3.	Physical Chemistry I	7.5
4.	Inorganic Chemistry II	5.0
5.	Solution Chemistry	5.0
6.	Physical Chemistry II	2.5
7.	Inorganic Chemistry I	2.5
8.	Analytical Chemistry I	2.5
9.	Basic Chemistry II	2.5
10.	Stoichiometry	2.5
11.	Chemical Bonds	2.5

Courses with high percentage of D scores indicate a difficult course to master. Among 11 difficult courses, "Organic Chemistry I" has the highest proportion of failed students. Students followed the lecture, handed in assignments, and took the exams, but did not sufficiently give the right answers. Many students already studied seriously but their scores are still low expectations.

The distribution of student scores in Organic Chemistry I among 235 students is tabulated in Table 2 showing none of them got an A score, the majority had a C score which was 63.8%, 28.9% of B, 14% of C, and 1.3% of E.

Table 2. Student Scores Distribution in Organic Chemistry I

Course names	Student Grades					Total
	A	B	C	D	E	
Organic Chemistry I	0.0	68	150	14	3	235
Percentage (%)	0.0	28.9	63.8	6.0	1.3	100

Besides transcript data (documentation), students also confirmed that Organic Chemistry I was the most difficult course to learn, as listed in Table 3. This finding is particularly interesting since students did not consider Physical Chemistry as the hardest course, even though it involves a high level of mathematical content, especially in topics such as chemical quantum theory, chemical thermodynamics, and chemical kinetics. Therefore, it can be inferred that students' learning difficulties in Organic Chemistry I were not primarily due to mathematical weaknesses, but rather could be associated with other factors such as conceptual complexity, abstract reasoning, cumulative memorization, unfamiliar reaction mechanisms, or the overall volume and intricate detail of the material.

Table 3. Student Responses on Difficult Courses

No.	The most difficult courses	Student response frequency (%)
1.	Physical Chemistry I	10.0
2.	Physical Chemistry II	5.0
3.	Organic Chemistry I	60.0
4.	Organic Chemistry II	25.0

A deep analysis of Organic Chemistry I contains several chemistry concepts, as shown in Table 4. Some of the concepts require spatial ability to be understood such as hybridization of sp^3, sp^2, sp, Newman's projection, and Fisher's projection. The majority of students (>77%) responded that sp^3 and sp^2 hybridization were the difficult concepts and all students claimed that Newman's and Fisher's projects were the worst.

Table 4. Percentage of Student Responses on Difficult Concepts

No.	Subject	Sub Topic	Sub-subject matter	Student Response (%)	
				Hard	Not Difficult
1.	Hybridization	Hybridization sp^3		80.00	20.00
		Hybridization sp^2		77.50	22.50
		Hybridization sp		57.50	42.50
		Structure Formula	Newman's projection	100.00	0.00
			Fisher's projection	97.50	2.50
2.	Organic Compounds	Alkane	Alkane nomenclature	5.00	95.00
			Reactions for the synthesis of alkanes	67.50	32.50
		Alcohol	Primary alcohol	42.50	57.50
			Secondary alcohol	37.50	62.50
		Ether	Ether nomenclature	42.50	57.50
			Ether reactions	75.00	25.00
		Aldehyde	Aldehyde nomenclature	30.00	70.00
			Aldehyde reactions	70.00	30.00
		Ketones	Ketone nomenclature	22.50	77.50

Students were asked what made them fail to master the difficult concept. Although not all students were able to articulate their difficulties in writing, they provided oral explanations, some of which are displayed in Table 5. To further explore the source of difficulty, the learning module and exam questions related to challenging concepts were examined. One such concept was hybridization, and both the exam questions and the lecturer's provided solutions are presented in Table 6. In the hybridization task, students were asked to identify which bonding types exhibit sp, sp^2, or sp^3 hybridization. If the lecturer had clearly explained the relationship between hybrid orbital notation (sp, sp^2, sp^3), the number of chemical bonds, and the total electron domains—while emphasizing that multiple bonds count as a single domain—this identification process could have been more accessible to students. For instance, sp hybridization corresponds to 2 electron domains, sp^2 to 3, and sp^3 to 4. In the molecule H–CH=CH–H, each carbon forms four bonds, but since the double bond is counted as one domain, each carbon is considered to have a total of 3 domains, thus corresponding to sp^2 hybridization. This conceptual difficulty aligns with findings reported in previous studies (Salame et al., 2022).

Table 5. Failure Reasons Stated by Students to Master the Concepts

No.	Concept	Student response frequency (%)	Student reasons
1.	Hybridization sp^3	27.50	*It was difficult to understand the lecturer's way of delivering lectures*
2.	Hybridization sp^2	30.00	*We did not understand what the lecturer explained*
3.	Hybridization *sp*	22.50	*It's hard to understand the lesson*
4.	Newman's projection	40.00	*The lecturing was difficult to understand and it was also difficult to determine the Newman projection structure*
5.	Fisher's projection	40.00	*It was a difficult topic, the teaching method is hard to understand in the Fischer projection material*
6.	Synthesis of alkanes	22.50	*It was difficult to understand the reaction of making alkanes and it was also difficult to understand the reaction mechanism*
7.	Ether reactions	32.50	*Most of these topics were not interesting and also we had to think hard in writing the ether reactions*
8.	Aldehyde reactions	25.00	*It's hard to understand the reaction mechanism and it's hard to understand how the lecturer delivers it.*

In the case of Newman's projection, students were asked to draw Newman's projection of a given organic IUPAC name of a chemical compound. To do so, they had to understand multiple interconnected concepts and follow specific sequences. From the given name, students first needed to draw the correct Fischer projection of the compound, which required knowledge of proper carbon numbering. Once the Fischer structure and numbering were correctly written, students then had to visualize which carbon atom was in the front and which was at the back. Additionally, they needed to be familiar with the terminology of "eclipse" and "gauche" and know how to accurately illustrate them in the Newman projection format.

In question number 2, according to the lecturer, most students were unable to mentally transform molecular representations from two-dimensional structures to three-dimensional forms, such as converting Fischer or ball-and-stick models into Newman projections. They also struggled to draw eclipse, staggered, and gauche conformations of the given compounds. The lecturer further noted that many students lacked understanding of the fundamental requirements for drawing Fischer projections. According to Fessenden and Fessenden (1992), there are three essential rules: (1) the carbonyl group or the highest-priority nomenclature group must be placed at or near the top, (2) each intersection point of horizontal and vertical lines represents a chiral carbon atom, and (3) each horizontal line indicates a bond pointing toward the viewer, while each vertical line indicates bonds pointing away from the viewer, as illustrated in Figure 1.

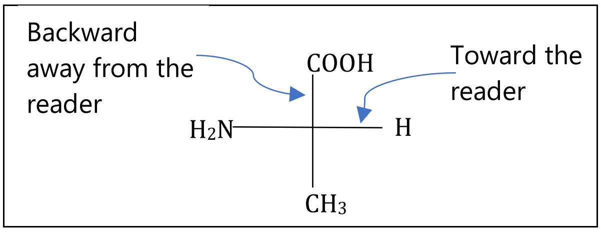
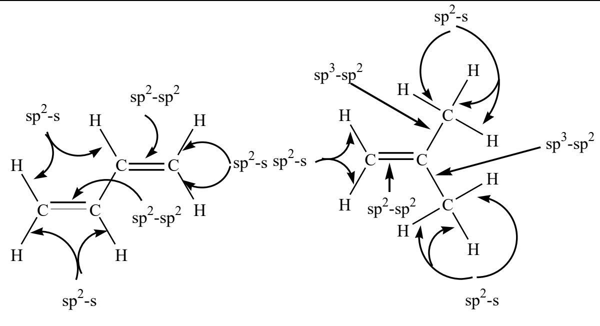
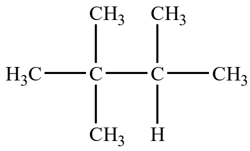
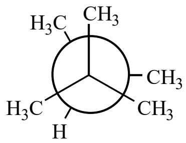
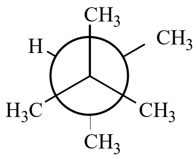
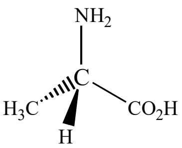
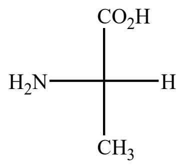
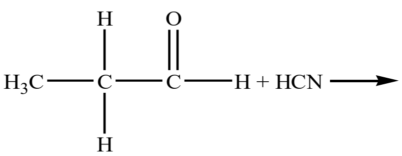
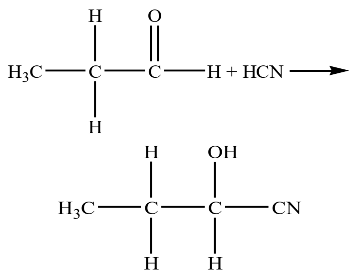


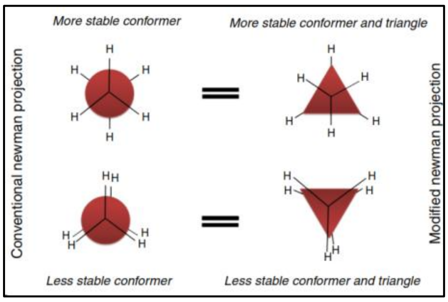
Figure 1. The Rule for Drawing Fisher's Projection that Guides for Drawing Newman's Projection

Table 6. Examples of Questions Related to Topics that are Difficult for Students to Master and Their Solutions

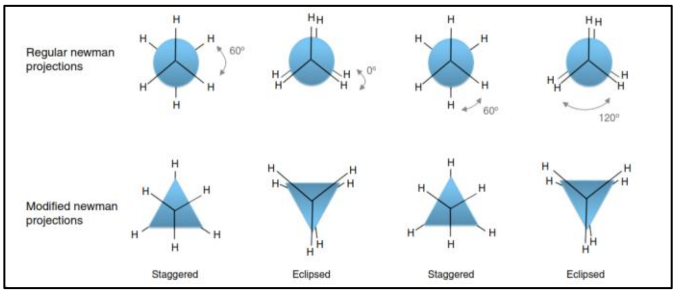
No.	Problems Example	The Solution (The Answers)
1.	Give the complete structural formula for each of the following compounds. State the type of orbital used to form each bond. a. $H_2C{=}CHCH{=}CH_2$ b. $H_2C{=}C(CH_3)_2$	 A B
2.	Draw the possible conformations for 2,2,3-trimethylbutane using the Newman projection (observation centers for C2-C3 atoms)	  *eclipse*  *gauche*
3.	Convert the dimensional formula below into a Fisher projection : 	
4.	Write the products of the following reactions: $H_2C{=}CH_{2(g)} + H_{2(g)} \longrightarrow$	$H_2C{=}CH_{2(g)} + H_{2(g)} \longrightarrow H_3C{-}CH_{3(g)}$
5.	Write the products of the following reactions: $CH_3^- Na^+ + H{:}CH_2CH_2OCH_2CH_3 \longrightarrow$	$CH_3^- Na^+ + H{:}CH_2CH_2OCH_2CH_3 \longrightarrow$ $CH_4 + CH_2{=}CH_2 + CH_3CH_2O^-Na^+$
6.	Write the products of the following reactions: 	

The multiple concepts, gap linkage with previous concepts, and molecular spatial orientation made this section difficult to master. Analog phenomena have been recognized previously although on a different topic, it has a similar case. Newman's projection has been recognized as a potentially confusing concept among students. Therefore, (Khalilian et al., 2016) suggested using the real model as the instructional media and using a triangle instead of a circle in drawing the central carbon projection as shown in Figure 2.

Writing chemical reaction equations is also a difficult lesson for many students, further confirming previous study findings that linguistic dualism in symbols and representations also leads to significant difficulty in chemistry learning (Timilsena et al., 2022).



(a)



(b)

Figure 2. Comparison of Conventional and Modified Newman Projections, Reproduced from (Kalilian et al., 2016).

The Organic Chemistry-I was confirmed as a difficult lesson by interviews with students who have taken the course. Students felt less interested in studying because it was difficult. Some students felt happy once they passed it although with low scores, and others did not understand the class.

Table 7. The Interview Script with Smart Students (A Grade)

Questions	Student Answers
How did you feel after taking the Organic Chemistry 1 course?	*It was difficult and not interesting, but the difficulty challenged us to study it. Even though the courses are challenging, our logic doesn't end there.*
What was the learning method used?	*The learning method was memorizing, but as I said before our logic doesn't go that far.*
Last question, what are your suggestions for improving this course?	*It's better to do the practical thing so that we can understand better but unfortunately, our field of study is not pure science or engineering*

Table 8. The Interview Script With Students Having Moderate Academic Grade (B/BC Grades)

Questions	Student Answers
How did you feel after taking the Organic Chemistry 1 course?	*I felt happy because the difficult course was over although I got a bad score*
What was the learning method used?	*The learning method used was monotonous, because the subject was difficult, then was not easily mastered by students to understand what was being taught.*
Last question, what are your suggestions for improving this course?	*Lecturers should use various learning methods so that students can quickly grasp difficult concepts.*

From the interview script, the students confirmed the difficulty of the course. Smart and moderately competent students stated that the course was not interesting, but it was challenging to study harder (Table 7). The moderate level of students felt reluctant to take the course. They were happy once it was over (Table 8). The less smart students knew their weaknesses and were not concerned about the course. They said the teaching method was already good (Table 9).

Despite differences in academic performance, all groups of students—whether high-achieving, moderate, or low-achieving—acknowledged the difficulty of the Organic Chemistry I course. However, their responses reflected varying coping mechanisms and expectations. While smart students emphasized the importance of logical thinking and suggested more practical learning approaches, moderately performing students criticized the monotony of the teaching method and called for varied instructional strategies. In contrast, failed students tended to blame their own lack of understanding and effort rather than the teaching method, indicating a more passive learning attitude. These differences suggest that tailored teaching strategies may be needed to accommodate diverse student needs and learning styles.

Table 9. Interview Script with Failed Students (D/E Grades)

Questions	Student Answers
How did you feel after taking the Organic Chemistry 1 course?	*It's normal, after taking the course I didn't get anything because I didn't understand what was being explained.*
What was the learning method used?	*Lecturing used an LCD projector, the lecturer asked each student to answer questions in front of the classroom.*
Last question, what are your suggestions for improving this course?	*I needed to study harder and pay attention when the lecturer was teaching. For lecturers, the method of delivering material was already good.*

The abstractness and complexity level of the organic chemistry course were confirmed through interviews with the lecturers. The lecturers claimed that the course is not easy, and highly abstract although fewer mathematical concepts (algorithmic skill) are involved, and the transcript is summarized in Table 10.

Table 10. Quotations from Interviews with Lecturers

Questions	Answers
In your opinion, How was the abstractness of the Organic Chemistry I concept?	*It is more abstract than some mathematical concept. The abstract concepts are difficult to understand, for example, the shape of a molecule. The shape of the molecule will be easier to understand if it is depicted in 3 dimensions using the ChemDraw program. In the lab, the shape of a molecule can be modeled by molymod media.*
In your opinion, how many mathematical concepts are involved in the organic chemistry I course?	*It is a less mathematical concept except for calculating the binding energy.*
How does organic chemistry relate to other subjects?	*The organic chemistry course has a strong relation to other subjects, such as biochemistry (metabolism processes), organic chemistry of natural products, chemical bonds (phi bonds, sigma bonds), and determination of the structure of organic compounds.*

These findings indicate that students' perceptions of the organic chemistry course vary depending on their academic ability, motivation, and prior knowledge. While more competent students view the course as a challenge worth pursuing, students with average or lower performance levels often struggle with engagement and comprehension. The lecturers' insights reinforce the notion that the inherent abstractness of organic chemistry—especially in visualizing molecular structures—poses a significant barrier to learning. This mismatch between the course's cognitive demands and students' preparedness underscores the need for enhanced instructional strategies, including the integration of visual tools and scaffolded content delivery to support diverse learners (Boateng, 2024; Hermanns, 2021).

4. Conclusion

Within the chemistry curriculum, dominantly students failed in the Organic Chemistry 1 course consistently in four periods of enrolment. The learning difficulty in this course was confirmed by students, and lecturers, and verified the previous studies. The complexity of the course is related to its content integrating many concepts, abstract and needed spatial shapes to comprehend it with an analog case in spatial molecular recognition. Respond students on the difficult course; smart and moderately competent students said the course was not interesting and the learning media needed to be improved. The failed students realized their weaknesses, therefore they accepted with a low score and responded that the learning method was already good. It is suggested that less spatial comprehension might be resolved by introducing a triangle shape for the carbon rotation concept instead of the circle model. Teaching with molecule props might improve student comprehension of spatial molecular orientation.

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