Utilising 'Toh' Models in Reducing Misconceptions in Orbital Hybridisation among Matriculation College Students

Amal Harun*, Rosmawati Jamluddin, Nik Abibahton Nik Ali, Norleha Md Dukol

Department of Science Chemistry, Negeri Sembilan Matriculation College
Kuala Pilah, Negeri Sembilan, Malaysia
**Email: bm-0264@moe-dl.edu.my*

Abstract

The concept of hybridisation is one of the most difficult concepts for chemistry students to grasp at all levels of learning. Research showed the students conceptual difficulty ranged from their lack of the pre-requisite knowledge for grasping the topic hybridisation to chemical bond formation and orientations of atomic orbitals. This study investigated the difficulties and misconceptions held by matriculation students about atomic orbitals and hybridization. A total of 88 students were used in the study in Negeri Sembilan Matriculation College. The participants responded to multiple choice and constructed response questions on hybridization at the start of the research. They answered the different set of questions but same difficulties level at the end of a two weeks treatment period. The responses were analyzed and response categories established on their misconceptions. The post-test was to assess their gain in conception at the end of the treatment period after using TOH Model. The findings showed that matriculation students' knowledge of atomic orbitals and hybridization was seriously distorted. Suggestions have been made for more effective teaching approaches to ensure better understanding of the concept and encourage active learning among students.

Keywords: Hybridisation; Hybrid orbitals; Matriculation; Chemistry

1. Introduction

Misconceptions are ideas about things that do not match what is known scientifically. These develop when the prior knowledge that a student needs to process new information is poorly communicated as a result of inadequate bridging, leading to confusion and faulty reasoning. As a result, prior knowledge of students is crucial to effective learning. Marifa et al. (2023) claims that because of the student's prior knowledge information is reconstructed during lessons, incorrect prior knowledge will lead to further improper reasoning and a resulting permanent inaccurate concept construction.

Misconceptions have a far bigger part in learning chemistry than just giving poor answers to questions. Students either consciously or subconsciously construct their concepts as explanations for the behaviours, properties or theories they experience. They believe most of these explanations are correct because they make sense in terms of their understanding of the behavior of the world around them (Atchia, 2022). Consequently, if students encounter new information that contradicts their alternative conceptions it may be difficult for them to accept the new information because it seems wrong and unacceptable to them. The anomalies do not fit into their cognitive structures. Under these conditions the new information may be ignored, rejected, disbelieved, deemed irrelevant to the current issue, held for consideration at a later time, reinterpreted in light of the student's current theories, or accepted with minor changes in the student's previously held concept (Islamiyah et al., 2022).

Understanding the concept of hybridisation in the matriculation level is important since this concept will be applied at the higher education level. Students will relate the orbital shape and hybridisation to chemical and physical effects including the mechanism of reactions. The hybridization of orbitals is favored because hybridized orbitals are more directional which leads to greater overlap when forming bonds, therefore the bonds formed are stronger. This results in more stable compounds when hybridization occurs. Therefore, the basic concept of hybridisation and the ability to visualize three-dimensional molecules of overlapping orbitals will help students understand further inorganic chemistry topics in higher level educations.

2. Problem Statement

Matriculation education provides transition period from school to university level education. During this transition period, matriculation students exposed to independent, accessible and inclusive learning. However, students that take chemistry in the matriculation course come from a variety of academic backgrounds; some are excellent at the subject, while the majority struggle with the fundamentals. This phenomenon creates a gap between the two groups and makes it difficult for teachers when teaching orbital hybridisation. Analysis of the students' answer scripts reveals that in addition to having incorrect conceptualizations of orbital overlap, students also exhibit inaccurate drawing of orbital overlap.

Furthermore, teaching hybridisation orbitals require students to visualise abstract concept. Chemistry requires a lot of intricate spatial and dynamic thinking, which makes chemistry challenging for many students. Chemistry molecules are three-dimensional entities that are invisible to the naked eye (Ping et al., 2021). Traditionally, teachers have used spoken language, written text, and two-dimensional diagrams to teach chemistry phenomena, but these instructional tools may not be particularly well suited to teaching orbital hybridisation (Ping et al., 2021).

To overcome this problem, chemistry teachers in Kolej Matrikulasi Negeri Sembilan (KMNS) develop TOH (*Type of Hybridisation*) Model to help students determine the type of hybrids orbital and draw the orbital overlapping. By using the model, teacher helps students to develop their basic concepts and apply it to draw orbital overlapping. Identification of misconceptions among the students in hybridisation concept and problem drawing overlapping orbital will be discussed in this article.

2.1 Research Objective

This study was carried out to achieve the following objectives:

1. Identify students' misconceptions in orbital hybridization.
2. Evaluate how effectively TOH works for teaching students how to draw overlapping orbital.

2.2 Research Question

1. What are the common misconceptions among students regarding hybridization?
2. Is there an enhancement in performance between utilising the TOH model and not?

3. Literature Review

Chemistry primarily focuses on the nature and behaviour of atoms, including how they bond together to generate new species, their structures and formulas, and the forces that keep them together. According to Hunter and Becker (2022), students have trouble comprehending the structure of atoms and chemical bonding. In addition, (Vladusic et al., 2023) have examined students' challenges with hybridization. According to Morgante and Autschbach (2023), students thought orbitals, shells, and orbits were all interchangeable. They were unable to tell the difference between atomic orbitals and molecular orbitals. Students addressed bonding electrons in molecules' hybrid orbitals, and at other times they described these bonding electrons as being in the *s, p, or d* orbitals.

Morgante and Autschbach (2023) defines hybridisation as the mixing of atomic orbitals into new hybrid orbitals with different energies and shapes, suitable for the pairing of electrons to form chemical bonds. Yang et al. (2022) views hybridisation as an idea that atomic orbitals fuse to form newly hybridised orbitals, which in turn, influences molecular geometry and bonding properties. Learning the concept of hybridisation necessitates the connection of different abstract concepts such as atomic orbitals, chemical bonding and molecular compounds. Hunter and Becker (2022) posit that for the prediction of molecular and electronic properties of a substance, a clear understanding of the concept of hybridisation is important to students of Chemistry.

The traditional classroom methods on their own are not enough to prepare students for the microscopic world of modern Chemistry. Students need to become familiar with molecular level concepts and must learn to use the new tools of Chemistry. Several studies have noted that the concept of hybridisation is one of the topics students find it difficult to understand at all levels of education (Okebukola et al., 2023). Although, most students do not understand some of the fundamental ideas of the concept of hybridisation, their misconceptions diminish with schooling. Students either consciously or subconsciously construct their concepts as explanations for behaviours, properties or theories they experience (Boothe et al., 2023).

One of the most difficult problems in teaching hybridisation is conveying to students the three-dimensional structure of molecules and how molecules interact (Reshmi, 2023). The molecular level concepts are not visible to the eye and appear complex and abstract to students. Many students are not able to comprehend the molecular basis for chemical phenomena because of the differences in visual ability of unseen structures in three-dimensions (Boothe et al., 2023). This implies that we need to ensure students have a firm grasp of the particulate state of matter before pursuing advanced studies in Chemistry.

Alternative approaches like the newly developed two-dimensional model, help students build molecular models of interest and visualise a variety of representations, including bond angles, lone pairs, and molecular shapes, bridging the gap between Chemistry's status as a molecular science and their understanding. Learning science obviously has as its objective developing conceptual understanding, which enables one to transfer explanation of a reality in many ways. The students must put in time and effort if instruction is to induce conceptual change (Orosz et al., 2023).

However, the practice of science instruction has encouraged memorising many science concepts without any understanding (Sombria et al., 2023). Students who are excellent at memorizing facts and definitions often engage in what may be called lateral memorisation. For instance, in the concept of hybridisation, students rely on memorising the terms and process, but lack the conceptual understanding of what happens at the molecular level such as mixing of atomic orbitals. The students make use of the word hybridisation, yet do not understand what necessitate bonding formation and the mixing of the atomic orbitals. Meaningful science learning requires conceptual understanding rather than rote memorisation (Orosz et al., 2023). Meaningful learning requires knowledge to be constructed by the learner and not transmitted from the teacher to the students or the passive nature of learning where the teacher possess the repository of knowledge.

Constructivists on the other hand, often believe that actively involving learners in exploring and discovering make them understand scientific concepts better. Therefore, TOH Model proposed in this research provides alternative method for students to help them visualising shape of hybrids orbital and draw the orbitals.

4. Methodology

A pre-test administered to measure the performance of students with regard to their previous knowledge on the topic. 88 students taken through a treatment session for two weeks, where they were exposed to TOH model. This was done to assess whether the performance of the students improve much more with the introduction of the concept of learning hybridisation using TOH model instructional approach which were.

Pre and post-test were developed at the same difficulties level to collect the data for the study. The content of the test then revised by the Chemistry Subject Matter Expert lecturer in matriculation. In order to ensure that the research instruments produced scores that are stable and consistent and test items are devoid of ambiguities (Creswell, 2014) as much as possible, the pre-test and post-test were pilot-tested on 10 students from other tutorial group. The data from the pilot test were statistically analysed to determine the reliability of the test instruments using the Spearman-Brown prophecy formula since all items on both pre- and post-test were dichotomously scored. The analysis yielded reliability coefficients of 0.59 and 0.62 for the pre-test and post-test respectively. The above reliability coefficients for the pre-test and post-test signified that both test instruments were considerably reliable. Reliability coefficient within the range of 0.5 to 0.6 is taken to depict an agreeable level of reliability for the instruments. Thus, the items of the instruments were considered reliable. The pre-test and post-test were both 10 item paper and pencil tests, which were made up of two sections, A and B repeated for pretest and post-test. Section A of the pre-test and post-test were both made up of 10 multiple-choice questions, while section B asking students to draw the orbital overlapping to identify misconceptions among students. Data obtained (Section A) from students were analysed by the increasing percentage each question after employing TOH Model. Data obtained from section B qualitatively analysed by teacher to identify the misconceptions before and after using the TOH model.

5. Results and Discussion

Section A items had two main objectives. They were meant to assess the student's understanding and their misconceptions about atomic orbitals and hybridization. Section B asking students to draw the orbital overlapping to identify misconceptions and skills among students in drawing orbital overlaping. A summary of participants' understanding as depicted through their responses is presented in a tabular form, item by item. The students' conceptions were put into three main categories;

i. Concepts that demonstrated sound and partially sound understanding (categorized as A)
ii. True misconceptions (categorized as B)
iii. No response to items or guessing answer due to the trends of answer chosen (categorized as C)

The simple percentages observed in Table 1, indicate that more than half of the participants did not understand the meaning of the term, hybridization. Here, 72 of the participants (93.2%) failed to respond correctly to the set question, did not answer it at all or guessing answer detected from the trend of answering.

Table 1: Summary of levels of understanding for the Hybridization

	Type of response	Number (n=88)	Percentage
A	Sounds understanding		
	• It is the mixing of two or more orbitals to form hybrid orbitals	4	2.06
	• Mixing of atomic orbitals	2	1.13
B	Misconceptions		
	• Mixing of two or more electrons • Mixing of atomic orbitals of different shapes • The pairing of more than one atom • Overlapping of atoms to form stable bonds • Mixing up of two or more atoms • Overlapping of orbitals to form hybrid orbitals • Mixture of atomic orbitals of two or more atoms • Combination of two or more orbitals to give a stable species	63	71.6
C	No response or guessing response	19	21.6

In Table 1, more than half of students were completely no idea of the differences between hybrid and pure atomic orbitals. This supports the different ideas students have about the terms "hybridization" and "atomic orbitals." 21.6% student had no conceptual understanding of why atomic orbitals undergo hybridization. Table 1 also highlighted the students' limited understanding of 'Molecular orbital theory'. No student showed a partial or full sound understanding. At least 42 students (47.72%) failed to supply answers to the test item on whether the molecular orbital theory could adequately explain the kind of bonding in the SO molecule. The scenario also reveals the challenges that students face in using the Lewis Structure concept as a prerequisite knowledge.

Table 2: Prediction sulphur atoms in given sulphur molecules

Molecule	Type of hybridisation	Correct	Wrong	No answer
SO_2	sp^2; v-shaped	10	78	0
SO_3	sp^2; trigonal planar	12	76	0
SO_4^{2-}	sp^3; trigonal pyramidal	8	38	42
SO_3^{2-}	sp^3; tetrahedral	9	33	46

A quick view of the pre-test showed that students hold misconceptions about hybridization. Results show very high percentages of misconceptions among students. Answers provided exposed their alternative concepts which were scientifically incorrect. The atomic orbital concept is one of the most important pre-requisites for learning about hybridization. The terms orbitals, shells and orbits were used interchangeably. In secondary schools, students demonstrated their understanding of the solar system from the Bohr atomic models. The complex wave function and Bohr atomic model described in matriculation chemistry could not erase their false thinking.

In question 3, most students wrote that the idea of hybridization was to obey the octet rule. This is a wrong assertion which does not conform to valid scientific reasoning. The observation made in this research is in line with Reshmi (2023) observation about the octet rule. He found that students used the octet rule as the basis of a principle to explain chemical reactions and bonding. In summary, atomic orbitals overlap to facilitate the sharing of electrons and the formation of chemical bonds between atoms.

Another misconception identified in this research is some students also stated that electrons play a role in hybridisation. They said "hybridisation is a mixing up of electrons in atoms". According to Silberberg (2017) hybridisation is a concept in chemistry that describes the mixing of atomic orbitals to form new hybrid orbitals. It is commonly observed in molecules where the central atom participates in bonding with other atoms. The process of hybridisation occurs when atomic orbitals of similar energy levels, but different shapes, combine to form hybrid orbitals. The hybrid orbitals have specific geometries and energies that are optimal for bonding.

Table 3: Quantitative summary of improved conceptual understanding

	Item	**Percent of students with understanding**		**Changed score**
		Pre-test	**Post-test**	
1.	Term hybridisation.	6.8	57	50.2
2.	Concept of atomic orbital	4.5	25.1	20.6
3.	Why atomic orbitals overlap	18.2	54.7	36.5
4.	Determine type of hybridisation from Lewis Structure	10.3	46	35.7
5.	Molecular orbital theory	0.0	32	32.0
6.	Hybridization of S in SO_2	11.4	63	51.6
7.	Hybridization of S in SO_3	13.6	65	51.4
8.	Hybridization of S in SO_4^{2-}	9.0	58	49.0

9.	Hybridization of S in SO_3^{2-}	10.2	75	64.8
10.	Relation between hybridization and molecular geometry	33	88	55.0

After using the TOH model, students' understanding of ideas improved from 20 to 64.8%, according to the post-test. Because students will need to create overlapping orbitals with the correct geometry at more advanced levels, it is essential that they understand the hybridization idea. Students must first draw the Lewis structure accurately before determining the type of hybridization. Students need to be able to explain how electrons travel in hybrid molecules to establish chemical bonds at a higher level. The script analysis of the students' responses to the misconceptions made while drawing orbital hybrids is shown in Figure 1 below.

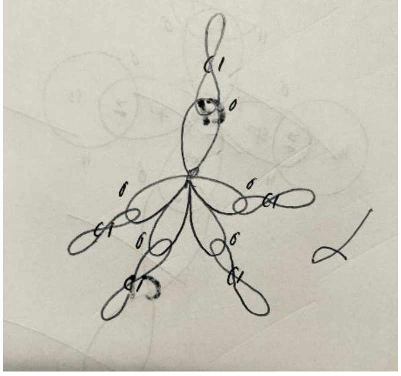


Figure 1: Common mistakes among students while drawing orbital overlapping

Figure 1 show the sp^3d hybrid orbital diagram is inaccurate due to absence of electron shared between atoms. Furthermore, it was discovered that students did not label the hybrid orbitals. Although the sp^3d orbital is a trigonal bipyramidal, the student failed to illustrate the hybrid orbital in an appropriate geometry. Besides, 30 out of 88 students failed to draw the hybrid orbitals correctly due to the different size between the lobes.

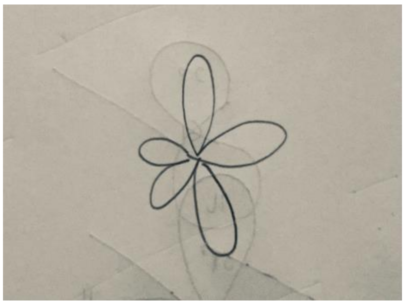


Figure 2: Each hybrid orbital must be drawn in the same size

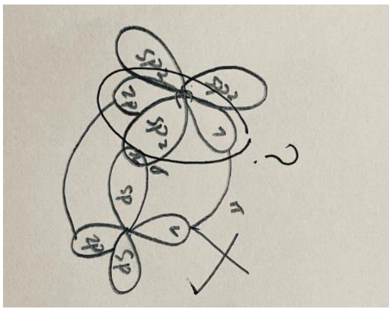


Figure 3: Failure to draw the correct hybrid orbital diagram makes it difficult for the student to draw the overlap of the central orbital with the terminal atom

5.1 The process of using TOH Model

The following diagram shows the process of using the TOH Model in class during teaching session. The usage of TOH helps students to use the basic concepts and apply to draw the hybrids orbital.

Figure 4: Introducing basic knowledge type of hybridisation.

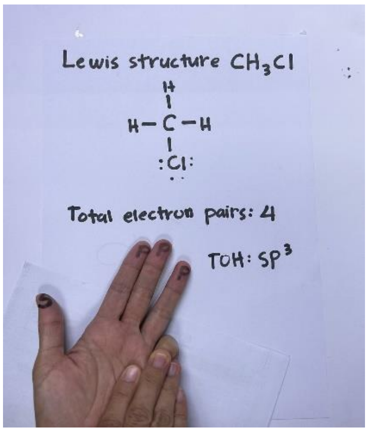
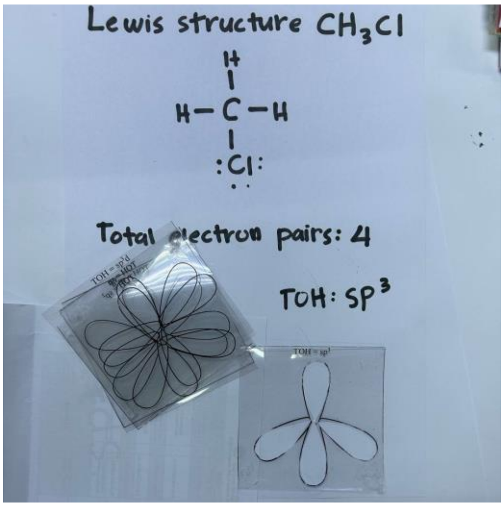


Figure 5: Determine type of hybrid from Lewis Structure then determine numbers of hybrids orbital generated.



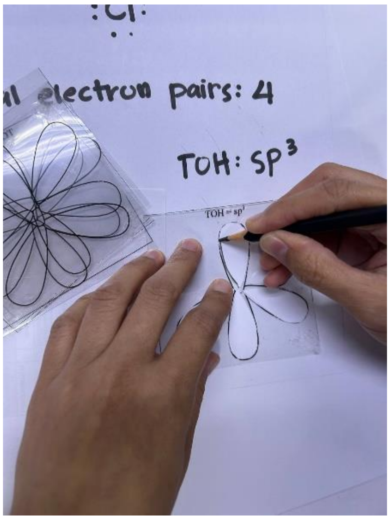


Figure 6: Determine type of hybrids.

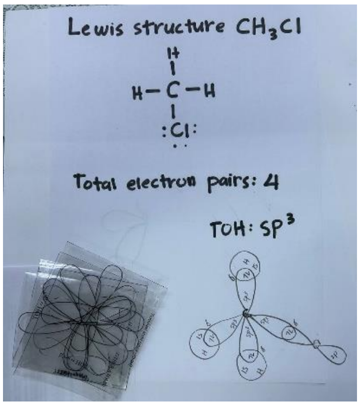


Figure 8: Student overlap the hybrids orbital with Hydrogen orbital.

Figure 7: Student tracing the hybrids to get a uniform shape and correct bond angle.

5.2 Implication for instruction

According to the findings, matriculation students have misconceptions regarding hybridization. They have a poor understanding of the fundamental understanding needed to learn about hybridization. In the administered conceptual tests, they did poorly. But the systematic application of a conceptual teaching strategy in line with cognitive theory enhanced their conceptual knowledge by 20–60%. This provides an answer to the question of whether purposeful use of conceptual teaching would enhance students' understanding of the hybridization concept. In light of the aforementioned, the following educational strategies are recommended:

1. Before beginning to teach a topic, teachers have to find out what student's existing ideas are about it. They will be able to plan in this situation taking the students' misunderstandings into consideration to aid the students in developing a better conceptual understanding of chemical concepts.
2. Emphasis should be placed on the differences between terms that are likely to interchanged by students and thereby create problems for themselves. In this instance, students interchanged terms such as orbits, shells, orbitals, sub-orbitals and energy levels.
3. Teacher explain why atoms undergo hybridisation. This will enable students to understand why atoms undergo hybridization.
4. The relationship between the type of hybridization of the central atom and its molecular geometry must be emphasized. The role of hybridization must be kept in perspective. It cannot be used to predict molecular shapes.

6. Conclusion

The study concluded that matriculation students lacked of most basic concept of hybridisation. Teachers need to use conceptual change instructional approaches to teach hybridisation in order to foster students' understanding and reduce misconceptions. Teaching tool such as TOH model is one of the alternative methods in helping students understand the hybridisation concept and drawing the orbital overlapping correctly.

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