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Reducing Student Misconceptions Through Problem-Based Learning with a Computational Chemistry-Assisted Question Map Approach

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Abstract: The aim of this research is to reduce student misconceptions using problem-based learning with computational chemistry assistance and a question map approach in the study of organic compound molecular structures and events resulting from the exposure of organic molecules to instruments with high-energy electron bombardment. This study employs a qualitative descriptive research design, focusing on in-depth descriptions and understanding of phenomena or events. The research focuses on a deeper understanding of students' capabilities in analyzing and interpreting the structure of organic chemical molecules. The research specifically examines students' ability to dissect questions outlined in the question map, interpret reasons, and describe problematic phenomena within the learning context. The issues addressed by students involve critical and in-depth examinations of theoretical concepts. In this study, data analysis is carried out inductively, wherein the researcher develops theories or findings based on collected data rather than preconceived hypotheses. The research findings demonstrate that problem-based learning with computational chemistry assistance using a question map approach is effective in reducing student misconceptions when analyzing the molecular structure of biodiesel.

Keywords: Computational chemistry; PBL; Question map

Introduction

The strength of questions lies in their ability to unearth information, stimulate reflection, expand understanding, and trigger critical thinking (Acquah & Commins, 2015; Dohrn & Dohn, 2018; Lin et al., 2021). Well-crafted questions can generate deep discussions, reveal different perspectives, and inspire creative thinking (Amanda et al., 2018; Holdbrook et al., 2006). Precise and accurate questions can encourage people to consider different viewpoints or see problems from previously unexplored angles. Challenging questions can foster critical and analytical thinking (Aritia et al., 2019; Norman., 1988; Sholihah et al., 2020). Questions can compel individuals to contemplate arguments, test beliefs, or seek strong evidence and logic to support their views. Intriguing questions can motivate people to conduct further research.

Questions can spark curiosity and help direct individuals towards relevant information to answer those questions (Undersander et al., 2017). Problem-solving questions can assist in identifying the root of problems, finding alternative solutions, or encouraging creative thinking to discover innovative approaches (Aritia et al., 2019; Norman, 1988; Sholihah et al., 2020). Powerful questions can provoke social change, shifts in thinking, or behavioral changes. Questions can provoke self-reflection and encourage people to see situations in new or innovative ways (Ahdhianto et al., 2020; Amin et al., 2020; Anazifa & Djukri, 2017; Aritia et al., 2019; Bernadetha Nadeak et al., 2020). The strength of questions lies in their ability to unearth information, stimulate thinking, and promote intellectual growth. By using questions wisely, we can gain deeper insights, solve problems more effectively, and achieve a broader understanding of the world around us (de Schepper, J.

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et al., 2021; Giovanni Sala & Fernand Gobet, 2019; Motter et al., 2016).

Questions will be effective if structured in a specific pattern to achieve the desired goals. Question mapping is essential to create patterns and achieve the expected goals. Concept maps, also known as mind maps or mental maps, are visual tools used to organize and represent ideas, concepts, or information hierarchically. Concept maps typically consist of a central or main topic surrounded by branches or related subtopics. This helps to illustrate the relationships between various concepts and aids users in understanding how these ideas are interconnected (Aritia et al., 2019; Burrows & Mooring, 2015; Gani et al., 2017; Johnstone et al., 2006; Oluk et al., 2018; Talbert et al., 2020; Turan-Oluk & Ekmekci, 2018). Concept maps can be used for learning, organizing information, planning projects or presentations, generating new ideas, or illustrating concepts in various disciplines. It is a flexible tool that can be customized to individual needs and preferences (Anzovino et al., 2016). Addressing social and environmental issues can motivate learning and provide meaning to learning. Independent learning is promoted in the free learning curriculum. Contextual learning can produce students who are responsive and solution-oriented in addressing problems (Aritia et al., 2019; Choi et al., 2014; Joseph et al., 2018). Problem-based learning is one example of a learning model that emphasizes a specific context raised as a problem and examined in the learning process.

Problem-based learning is an approach to the learning process that emphasizes real problem-solving as the core of the learning experience. In problem-based learning, students are presented with challenges or problems that require critical thinking, problem-solving, and the application of learned concepts in a relevant context (Joseph et al., 2018; Khoiriyah et al., 2018; Norman, 1988). Problem-based learning encourages students to be active in the learning process. Students feel more engaged as they tackle real problems relevant to their lives. Students develop critical thinking skills that are vital in their everyday lives (Choi et al., 2014). Students learn to question assumptions, gather evidence, and make decisions based on information, strengthening their critical thinking abilities. Through problem-based learning, students face complex and open-ended problems that require them to apply their knowledge and skills creatively. Students learn to break down problems into manageable parts, consider different perspectives, and develop innovative solutions (Ahdhianto et al., 2020; Amin̈ et al., 2020; Joseph et al., 2018; Khoiriyah et al., 2018).

Aritia et al. (2019), Bernadetha Nadeak et al. (2020), Khoiriyah et al. (2018), and Sholihah et al. (2020) report that problem-based learning (PBL) is a widely recognized educational approach for improving students' thinking abilities and fostering creativity in problem-solving. PBL is a student-centered teaching method in which students actively engage in solving real-world problems or case studies. Instead of traditional teacher-led instruction, students take an active role in identifying problems, conducting research, collaborating with peers, and proposing solutions. Amanda et al. (2018), Attik et al. (2017), Bezanilla et al. (2019), Choi et al. (2014), and Dunne (2015) state that PBL encourages students to think critically by analyzing and evaluating information to develop problem-solving strategies. Students learn to question assumptions, gather evidence, and make decisions based on information, enhancing their critical thinking skills. El-Zein et al. (2016), Hidayat et al. (2019), Khoiriyah et al. (2018), and Sholihah et al. (2020) report that through PBL, students face complex and open-ended problems that require them to apply their knowledge and skills creatively. Students learn to break down problems into manageable parts, consider different perspectives, and develop innovative solutions.

Ersoy (2014), Hidayat et al. (2019), and Vahid et al. (2017) found that Problem-Based Learning (PBL) encourages students to think creatively and generate unique solutions to problems. By exploring various possibilities and considering different perspectives, students develop the ability to think outside the box and produce innovative approaches. PBL cultivates self-directed learning skills as students are responsible for their own learning process. Students develop research skills, independent thinking, and the ability to seek resources and information, which are valuable skills for problem-solving and lifelong learning. Developing and strengthening students' conceptions requires a conceptual approach. The collaboration of PBL and question mapping is expected to foster strong conceptions and reduce misconceptions when studying the structure of organic chemical molecules.

A question map is the process of connecting the questions posed with the prior knowledge possessed by students. In the context of reducing misconceptions, a question map helps students identify any incorrect or erroneous understandings they may have about a concept. By mapping the questions asked against students' knowledge, they can become aware of gaps in their understanding and seek more accurate solutions or comprehension (Aritia et al., 2019; Burrows & Mooring, 2015; Dohrn, & Dohn, 2018; Ghani et al., 2017; Holdbrook et al., 2006; Johnstone et al., 2006; Mohammed et al., 2020).

The fundamental concept in chemistry is the atom, which is the smallest unit composing elements, molecules, and chemical compounds that we observe today. Many students consider the atom as the smallest component of matter and believe it cannot be further divided. Most students are unaware of subatomic particles such as protons, neutrons, and electrons (Fitriza & Gazali, 2018; Tamungku et al., 2019; Zarkadis et al., 2021). Many students do not realize that these subatomic particles have the most significant influence on the characteristics of elements, molecules, and compounds to be formed. Poor understanding of atoms can lead to misconceptions about other chemical concepts. The characteristics of elements composing molecules affect their physical and chemical properties as well as the interactions between molecules. The complex structure of organic chemical molecules can be studied by examining the various atoms that make up the functional groups. Functional groups are the most active sites in organic chemical reactions. A deep understanding of these basic concepts is essential for comprehending the more complex structures of organic chemical molecules (Akkuzu et al., 2016; Tsaparlis et al., 2018). A conceptual-based learning model and a question map approach are solutions to address these issues.

Abstract nature of chemistry materials makes it difficult for students to comprehend (Kim et al., 2019). Multiple representations are required to construct a more comprehensive understanding of chemistry concepts (Abdurrahman et al., 2019; Baptista et al., 2019; Gautam et al., 2020; Harza et al., 2021). Alam (2020) states that computational skills and contextual knowledge are needed to build meaningful knowledge. Separation of macroscopic, microscopic, and symbolic concept levels can lead to misconceptions among students (Pikoli, 2020; Widarti et al., 2016). Chemistry explores the characteristics, properties, and arrangements at the atom, molecule, and macromolecule levels. If the foundational concepts at the atom level are weak, it can lead to a poor understanding of concepts at the molecule and macromolecule levels. Poor understanding of these basic concepts can result in misconceptions among students when examining more complex concepts in organic molecules.

Molecular modeling is needed to facilitate students' understanding of molecular structure and its characteristics. Molecular modeling is a method used to comprehend the behavior of molecules and their interactions. It involves creating 3D representations of molecules that can be manipulated to understand their function in various environments. This technique is highly efficient in predicting molecular behavior. Chemical representation is a crucial concept in the analysis of molecular structure. It is used to depict the arrangement of atoms in molecules and how they are connected. Harza et al. (2021) and Pikoli (2020) state that this representation can be broken down into three levels -molecular formula, structural formula, and Lewis structure. Each level provides different information about the molecule and can be used for different purposes. Chemical representation is a powerful tool for understanding molecular structure. By using different levels of chemical representation, scientists can visualize and interpret molecular structures in a more comprehensive way. This allows students to gain insight into the properties and reactivity of molecules, which is crucial for understanding how molecules behave in different environments. Computational technology is used to facilitate students' understanding of multiple chemical representations and can reduce misconceptions (Baptista et al., 2019; Harza et al., 2021; Tamungku et al., 2019; Tsaparlis et al., 2018). Understanding multiple chemical representations can foster higher-order thinking skills, which are in demand in 21st-century education and the 4th industrial revolution (Abdurrahman et al., 2019; Baptista et al., 2019).

Collaboration between problem-based learning models with a question map approach assisted by computational chemistry is crucial to meet the demands of independent learning curricula. Problem-based learning is an approach to education where students are actively engaged in solving real-world problems or situations that require critical thinking and problem-solving. This method emphasizes active, collaborative, and student-centered learning (Fadilla et al., 2021; Hidayat et al., 2019; Joseph et al., 2018; Khoiriyah et al., 2018). The problems presented are based on current social and environmental issues. Issues such as global warming, green technology, and green energy are examples of current social and environmental problems. Students then work independently or in groups to analyze these issues, identify the necessary sources of information, collect data, analyze information, and develop solutions or recommendations (Ahdhianto et al., 2020; Johnstone et al., 2006; Norman, 1988). Based on the above research, a PBL model with a question map approach assisted by computational chemistry is essential to be applied to reduce misconceptions in students' understanding of the structure of organic chemical molecules.

Method

This research is a qualitative descriptive study, aiming to depict and comprehend phenomena or events in detail and depth. The focus of this research is to gain a deeper understanding of students' abilities to examine and analyze the structures of organic chemical molecules. The study was conducted with fourthsemester students who were enrolled in the Basic Principles of Determining the Structure of Organic Compounds course. The population of this study consists of one class, and the sample was chosen purposively. Qualitative descriptive research employs qualitative methods, meaning that the researcher collects data in the form of words, narratives, pictures, or audio recordings, which are then analyzed in-depth. The research focuses on the students' ability to dissect questions structured within a question map.

Students' abilities to interpret reasons and describe problematic phenomena in the learning process are analyzed to provide an overview of their understanding level. The problems solved by students involve theoretical concepts examined critically and in-depth. Furthermore, these problems represent practical steps in synthesizing biodiesel, which is one of the solutions to current energy problems. In this research, data analysis is conducted inductively, where the researcher develops theories or findings based on the data collected, rather than relying on preconceived hypotheses (Doyle et al., 2020; Nilsson & Niedderer, 2014; Pratt & Yezierski, 2018). Figure 1 depicts the question map provided to students to explore their conceptions about charges on organic molecules in the synthesis of biodiesel from used cooking oil.

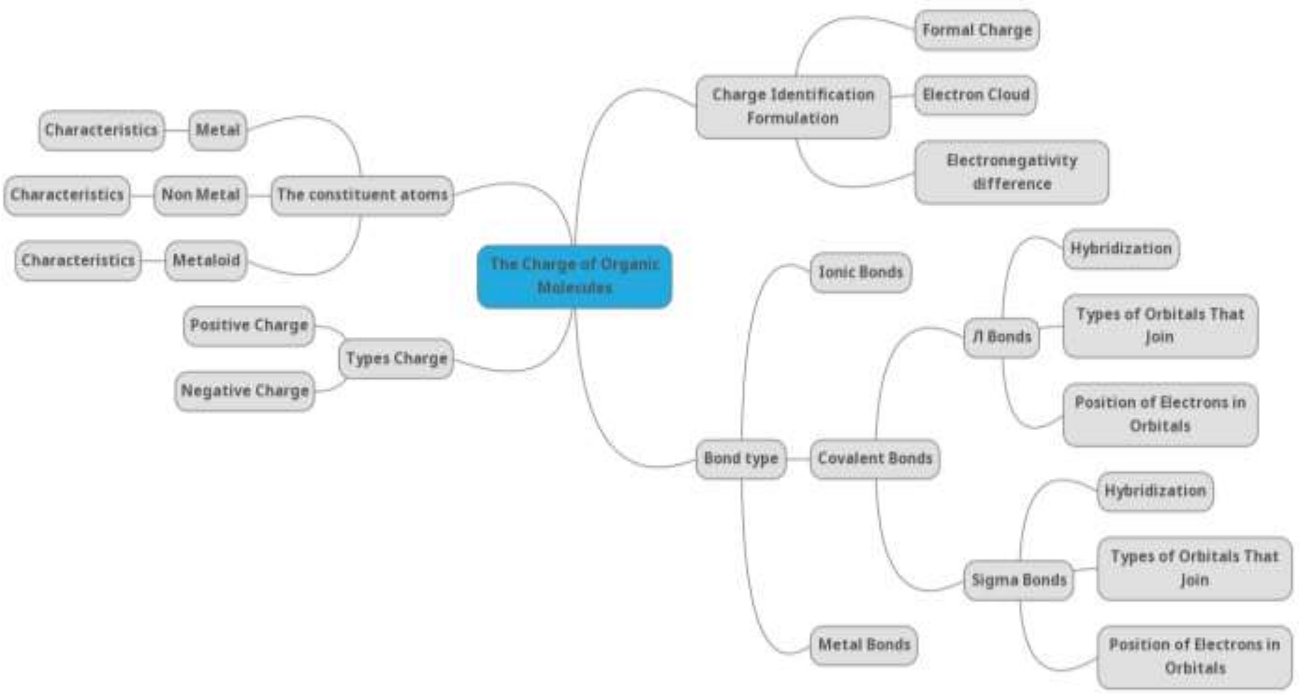

Figure 1. Model question map for assessing student conceptions

Result and Discussion

The preliminary research results indicate that students' understanding of molecular structure is still weak. In general, students can comprehend the types of organic molecule bonds, but a deeper study on the characteristics of constituent atoms, atomic orbitals, molecular orbitals, hybridization, the differences between sigma and pi bonds, polarity, and the positioning of electrons involved in bonding is understood by nearly 90% of the students. The preliminary research findings are shown in Figure 2.

The researcher's findings show that students are able to determine the types of bonds between atoms. However, students still lack a deep and comprehensive understanding of the molecular structure of organic compounds. The study on the molecular structure of triglycerides in organic compounds focuses on the carbonyl group, which is the most dominant group in the transesterification reaction of waste cooking oil in biodiesel synthesis (Awogbemi et al., 2019; Hulyadi et al., 2023; Li et al., 2020; Muanruksa, 2020). Students can identify the constituent atoms but have difficulty in examining the characteristics of these atoms. The characteristics of the constituent atoms include the type of atom, group, valence electrons, subatomic particles, and electronegativity. The complex nature of these constituent atoms in organic compounds makes it challenging for students to comprehend them fully. Students can only determine the type of atom, group, and valence electrons.

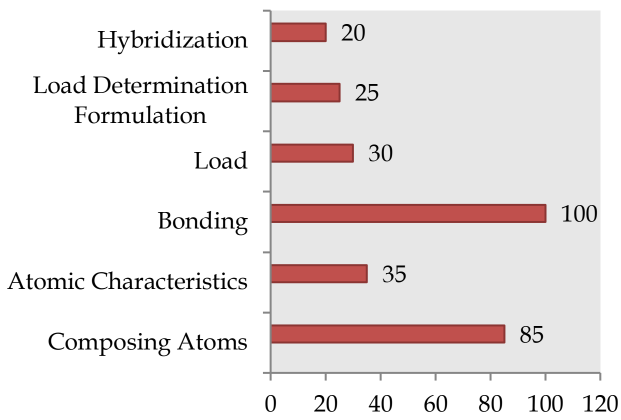

Figure 2. Preliminary concept testing results of students

The study of subatomic particles and electronegativity remains elusive for students. The abstract nature of subatomic materials poses a difficulty for students, impacting their understanding of atomic concepts. Visual modeling is required to represent atoms and their subatomic particles, making it easier for students to grasp the concept of atoms as a whole (Khaeruman et al., 2017; Perdana et al., 2020). The characteristics of organic molecules are highly influenced by the subatomic particles contained within the atoms that make up organic molecules. These subatomic particles play a critical role in the reaction patterns, reactivity, and physicochemical properties of organic compounds (Reyes et al., 2019; Seifert, 2023). Students must master the concepts of subatomic particles to analyze the behavior of organic molecules. Subatomic particles are components within atoms that are so small that they cannot be observed directly. Studies on the subatomic particles of atoms need to be presented more clearly to build a strong foundation in students. The use of technology like flash chemistry and computational chemistry is chosen to visualize the microscopic side of atoms that constitute organic molecules (Saunders, 2022; Seifert, 2023; Weiss & Hofer, 2013). Computational chemistry utilizes quantum chemistry, focusing on the interactions of subatomic particles. Subatomic particles are smaller components of atoms and are fundamental to matter. Simulating the interaction of subatomic particles is necessary to depict the abstract side of chemistry. These subatomic particles consist of various types, with the most important being electrons, protons, and neutrons. Students need to master the behaviors of these three subatomic components to construct a comprehensive concept of the characteristics of organic molecules. Furthermore, the use of simulations in learning not only enhances cognitive competence but also increases students' interest and motivation to learn (Rodríguez-Becerra et al., 2020). The following is a simulation used to build students' fundamental concept about subatomic particles in Figure 3.

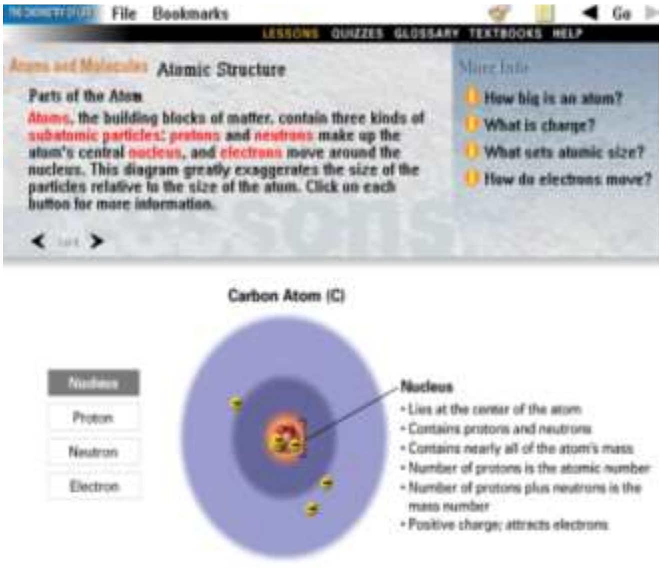

Figure 3. Simulations of subatomic particle interactions within an atom

This simulation is expected to build a strong understanding of atoms and enhance student motivation to learn. A strong comprehension of atomic concepts can serve as the foundation for understanding simple and more complex molecule conceptions. Figure 4 describes how electronegativity influences the movement of electrons within their orbitals, leading to the emergence of polarity in the bonds between oxygen and hydrogen atoms.

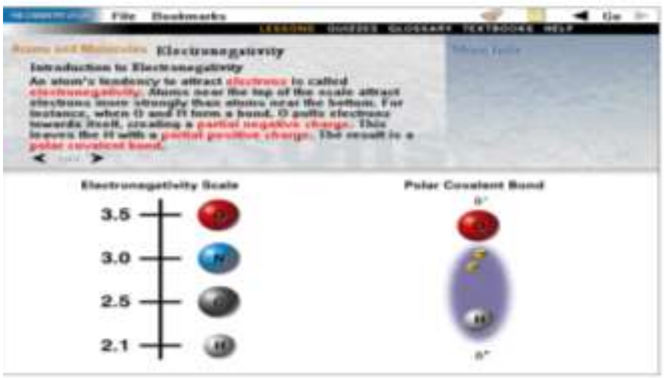

Figure 4. Simulation of the influence of different electronegativity values on the movement of electrons in its bonding orbitals

Simulation is used to build students' understanding of the formation of a dipole due to the differences in the electronegativity of the constituent atoms. This simulation is expected to provide an overview of how the nucleus's attraction affects the outermost electrons, which in turn impacts the atom's ability to attract electrons from other atoms used collectively. Based on the simulation, the influence of subatomic particles on electron attraction, known as electronegativity, can be analyzed. Häse et al. (2019), Houk et al. (2021), and Lin et al. (2021) reported that this simulation can stimulate students' curiosity and promote critical thinking skills. Building a strong concept requires the use of media because subatomic particles' reality cannot be observed directly. Computational chemistry can be a solution to concretize abstract chemical concepts.

Jäger et al. (2015), McArdle et al. (2020) and Qasim et al. (2007) reported that computational chemistry is an interdisciplinary field that combines chemical principles with computation to gain a deeper understanding of chemical processes. This includes using software and computational methods to design, simulate, and analyze molecular structures, chemical reactions, and chemical properties. In the development of strong concepts, computational chemistry plays several important roles. Computational chemistry enables scientists to model molecular structures and properties with a high level of precision, aiding in understanding interactions between atoms and molecules. El-Taib Heakal et al. (2017), Manly et al. (2001), and Wang et al. (2016) states that computational chemistry allows for a better understanding of chemical reactions, including reaction pathways, kinetics, and reaction mechanisms. This contributes to the development of more efficient chemical processes. Computational chemistry allows for the calculation of molecular energy and stability, which is crucial for understanding the thermal and thermochemical properties of chemical substances. Computational chemistry aids in the development of advanced chemical theories and predictions of molecular properties, contributing to a deeper understanding of chemistry. In other words, computational chemistry allows scientists to build strong concepts about chemical properties and chemical reactions with the help of computational tools, enabling more in-depth research and practical applications in various fields, including pharmaceuticals, materials science, environmental science, and more (El-Taib Heakal et al., 2017; Qasim et al., 2007; Wang et al., 2016).

The application of problem-based learning models assisted by computational chemistry has been proven to enhance students' understanding of concepts. Computational chemistry assistance helps students in making abstract chemical concepts more tangible (Dong et al., 2019; Gautam et al., 2020). The concept of chemistry becomes strong at the application level if the basic concept of atoms is mastered, especially regarding the characteristics of subatomic particles. Subatomic particles determine the character of atoms and organic chemical macromolecules (Garcia, 2020; Swanson, 2012). This is evident in the researchers' findings that there is an improvement in students' conception of understanding the structure of organic molecular competence after being assisted with chemistry applications that focus on subatomic particles. The description of students' conceptions can be seen in the figure 5 below.

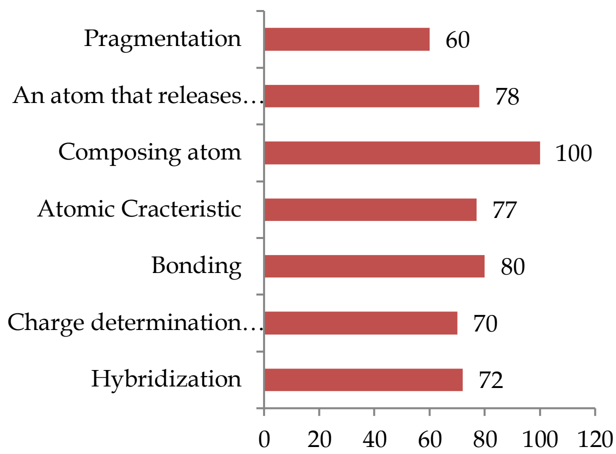

Figure 5. Student conception test results after being taught using the PBL model assisted by computational chemistry

In addition to computational chemistry, the question map approach has been shown to stimulate students' curiosity and critical thinking abilities. Questions structured in a specific way can lead students to engage in deeper learning and thinking. Rustanto et al. (2023) and Subramani et al. (2022) stated that questions play a crucial role in building one's concepts and thinking processes. Well-crafted questions can trigger creative thinking, aid in deeper comprehension, and encourage the exploration of new ideas. Challenging questions can foster critical thinking. When individuals are faced with questions that require them to consider various perspectives, analyze evidence, and construct arguments, it can contribute to the development of critical thinking.

Questions assist individuals in delving into specific topics or concepts. By asking relevant and profound questions, one can explore a topic more deeply, grasp its more complex aspects, and expand their knowledge. Creative questions can stimulate creative thinking. They can help individuals view problems or concepts from various angles, generate new ideas, and promote innovation. Questions are often used in education as a tool to guide students in understanding new concepts. Teachers can use questions to help students reflect on the material, make connections between concepts, and develop a deeper understanding. Constructive questions can build a comprehensive and in-depth understanding by connecting sub-concepts with each other, and these connections are established in a question map (Hulyadi et al., 2023; Raymond et al., 2020). Questions are also an essential tool in communication. They aid in obtaining additional information, clarifying ideas, and promoting meaningful dialogue among individuals or within groups. Questions can assist in problem-solving. By breaking down a problem into a series of smaller questions, one can more easily identify possible solutions and move toward resolution. Well-formulated questions can help strengthen one's memory. When someone attempts to answer questions, it can assist them in remembering information better.

Conclusion

The PBL model assisted by computational chemistry with a question map strategy has proven effective in reducing students' misconceptions when studying the structure of organic molecules. There is a weakness in students' ability to predict the fragmentation of macromolecules into smaller molecular ions, and a small portion of students still do not understand the molecular hybridization of biodiesel, especially in the carbonyl group that plays a central role in biodiesel synthesis reactions.

Author Contributions

Conceptualization, methodology, validation, data analysis. H. M.; writing and review manuscrif, G.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

Abdurrahman, A., Setyaningsih, C. A., & Jalmo, T. (2019). Implementating Multiple Representation-Based Worksheet to Develop Critical Thinking Skills. *Journal of Turkish Science Education*, *16*(1). Retrieved from https://www.tused.org/index.php/tused/article/view/235

Ahdhianto, E., Marsigit, Haryanto, & Santi, N. N. (2020). The Effect of Metacognitive-Based Contextual Learning Model on Fifth-Grade Students' Problem-Solving And Mathematical Communication Skills. *European Journal of Educational Research*, *9*(2), 753–764. Retrieved from https://files.eric.ed.gov/fulltext/EJ1250376.pdf

Akkuzu, N., & Uyulgan, M. A. (2016). An Epistemological Inquiry into Organic Chemistry Education: Exploration Of Undergraduate Students' Conceptual Understanding Of Functional Groups. *Chemistry Education Research And Practice*, *17*(1), 36–57. https://doi.org/10.1039/c5rp00128e

Alam, A. (2020). What Is The "Philosophy of Chemistry Education"? Viewing Philosophy Behind Educational Ideas in Chemistry from John Dewey's Lens: the Curriculum and the Entitlement to Knowledge. *Palarch's Journal of Archaeology of Egypt /Egyptology*, *17*(9). Retrieved from https://archives.palarch.nl/index.php/jae/article/view/5303

Amanda, F., Rui, M.V., & Celina, T.V. (2018). Educating For Critical Thinking In University: The Criticality Of Critical Thinking In Education And Everyday Life. *ESSACHESS - Journal For Communication Studies*, *11*(22 (2)), 131–144. Retrieved from https://www.ceeol.com/search/article-detail?id=740444

Amin̈, S., Utaya, S., Bachri̇̈, S., Sumarmi̇̈, S., & Susi̇̈lo, S. (2020). Effect Of Problem Based Learning On Critical Thinking Skill And Enviromental Attitude. *Journal For The Education Of Gifted Young Scientists*, *8*(2). https://doi.org/10.17478/jegys.650344

Anzovino, M. E., & Bretz, S. L. (2016). Organic chemistry students' fragmented ideas about the structure and function of nucleophiles and electrophiles: A concept map analysis. *Chemistry Education Research and Practice, 17*(4), 1019-1029. Retrieved from https://pubs.rsc.org/en/content/articlelanding/2016/rp/c6rp00111d

Aritia, E., & Suyanto, S. (2019). The Effect Of Problem Based Learning Model And Concept Map Strategy For Problem Solving And Understanding Of The Ecosystem Concept Of High School Students. *Journal Of Physics: Conference Series*, *1233*(1), 012005. https://doi.org/10.1088/1742-6596/1233/1/012005

Attiq, S., Rasool, H., & Iqbal, S. (2017). The impact of supportive work environment, trust, and self-efficacy on organizational learning and its effectiveness: A stimulus-organism response approach. *Business & Economic Review, 9*(2), 73-100. Retrieved from https://www.bereview.pk/index.php/BER/article/view/151

Awogbemi, O., Onuh, E. I., & Inambao, F. L. (2019). Comparative study of properties and fatty acid composition of some neat vegetable oils and waste cooking oils. *International Journal of Low-Carbon Technologies, 14*(3), 417-425. Retrieved from

https://academic.oup.com/ijlct/article/14/3/417/5527146
Baptista, M., Martins, I., Conceição, T., & Reis, P. (2019). Multiple Representations in the Development Of Students' Cognitive Structures About The Saponification Reaction. *Chemistry Education Research And Practice*, *20*(4), 760–771. https://doi.org/10.1039/c9rp00018f
Bezanilla, M. J., Fernández-Nogueira, D., Poblete, M., & Galindo-Domínguez, H. (2019). Methodologies For Teaching-Learning Critical Thinking In Higher Education: The Teacher's View. *Thinking Skills And Creativity*, *33*, 100584. https://doi.org/10.1016/j.tsc.2019.100584
Burrows, N. L., & Mooring, S. R. (2015). Using Concept Mapping To Uncover Students' Knowledge Structures Of Chemical Bonding Concepts. *Chemistry Education Research And Practice*, *16*(1), 53–66. https://doi.org/10.1039/c4rp00180j
Choi, E., Lindquist, R., & Song, Y. (2014). Effects Of Problem-Based Learning Vs. Traditional Lecture On Korean Nursing Students' Critical Thinking, Problem-Solving, And Self-Directed Learning. *Nurse Education Today*, *34*(1), 52–56. https://doi.org/10.1016/j.nedt.2013.02.012
Dohrn, S.W., & Dohn, N.B. (2018). The Role Of Teacher Questions In The Chemistry Classroom. *Chemistry Education Research And Practice*, *19*(1), 352–363. https://doi.org/10.1039/c7rp00196g
Dong, B. X., Nowak, C., Onorato, J. W., Strzalka, J., Escobedo, F. A., Luscombe, C. K., Nealey, P. F., & Patel, S. N. (2019). Influence Of Side-Chain Chemistry On Structure And Ionic Conduction Characteristics Of Polythiophene Derivatives: A Computational And Experimental Study. *Chemistry Of Materials*, *31*(4), 1418–1429. https://doi.org/10.1021/acs.chemmater.8b05257
Doyle, L., McCabe, C., Keogh, B., Brady, A., & McCann, M. (2020). An overview of the qualitative descriptive design within nursing research. *Journal of research in nursing, 25*(5), 443-455. Retrieved from https://journals.sagepub.com/doi/abs/10.1177/1744987119880234?journalcode=jrnb
Dunne, G. (2015). Beyond Critical Thinking To Critical Being: Criticality In Higher Education And Life. *International Journal Of Educational Research*, *71*, 86–99. https://doi.org/10.1016/j.ijer.2015.03.003
El-Taib Heakal, F., Attia, S. K., Rizk, S. A., Abou Essa, M. A., & Elkholy, A. E. (2017). Synthesis, Characterization And Computational Chemical Study Of Novel Pyrazole Derivatives As Anticorrosion And Antiscalant Agents. *Journal Of Molecular Structure*, *1147*, 714–724. https://doi.org/10.1016/j.molstruc.2017.07.006
El-Zein, A.H., & Hedemann, C. (2016). Beyond Problem Solving: Engineering And The Public Good In The 21st Century. *Journal Of Cleaner Production*, *137*, 692–700. https://doi.org/10.1016/j.jclepro.2016.07.129
Ersoy. (2014). The Effects Of Problem-Based Learning Method In Higher Education On Creative Thinking. *Procedia - Social And Behavioral Sciences*, *116*, 3494–3498. https://doi.org/10.1016/j.sbspro.2014.01.790
Fadilla, N., Nurlaela, L., Rijanto, T., Ariyanto, S. R., Rahmah, L., & Huda, S. (2021, March). Effect of problem-based learning on critical thinking skills. In *Journal of Physics: Conference Series* (Vol. 1810, No. 1, p. 012060). IOP Publishing. Retrieved from https://iopscience.iop.org/article/10.1088/1742-6596/1810/1/012060/pdf
Fitriza, Z., & Gazali, F. (2018). Diagnosing Students' Conception On Atomic Structure Using Open Ended Questions. *Journal Of Physics: Conference Series*, *1013*(1), 012097. https://doi.org/10.1088/1742-6596/1013/1/012097
Ghani, I. A., Ibrahim, N. H., Yahaya, N. A., & Surif, J. (2017). Enhancing students' HOTS in laboratory educational activity by using concept map as an alternative assessment tool. *Chemistry education research and practice, 18*(4), 849-874. Retrieved from https://pubs.rsc.org/en/content/articlelanding/2017/rp/c7rp00120g
Garcia, R. (2020). Nanomechanical Mapping Of Soft Materials With The Atomic Force Microscope: Methods, Theory And Applications. *Chemical Society Reviews*, *49*(16), 5850–5884. https://doi.org/10.1039/d0cs00318b
Gautam, A., Bortz, W., & Tatar, D. (2020, February). Abstraction through multiple representations in an integrated computational thinking environment. In *Proceedings of the 51st ACM Technical Symposium on Computer Science Education* (pp. 393-399). Retrieved from https://dl.acm.org/doi/abs/10.1145/3328778.3366892
Harza, A. E., Wiji, W., & Mulyani, S. (2021). Potency To Overcome Misconceptions By Using Multiple Representations On The Concept Of Chemical Equilibrium. *Journal Of Physics: Conference Series*, *1806*(1), 012197. https://doi.org/10.1088/1742-6596/1806/1/012197
Häse, F., Galván, I. F., Aspuru-Guzik, A., Lindh, R., & Vacher, M. (2019). How Machine Learning Can Assist The Interpretation Of Ab Initio Molecular Dynamics Simulations And Conceptual Understanding Of Chemistry. *Chemical Science*,

10(8), 2298–2307. https://doi.org/10.1039/c8sc04516j

Hidayat, R.N., Rukmini, D., & Bharati, D. A. L. (2019). Developing Problem-Solving Based Assessment To Stimulate Critical Thinking And Creativity Of Studentsâ€™ Writing Skill. *English Education Journal*, *9*(2). https://doi.org/10.15294/eej.v9i2.28919

Holbrook, A., Cho, Y. I., & Johnson, T. (2006). The impact of question and respondent characteristics on comprehension and mapping difficulties. *International Journal of Public Opinion Quarterly, 70*(4), 565-595. Retrieved from https://academic.oup.com/poq/article-abstract/70/4/565/1889113

Houk, K. N., Liu, F., Yang, Z., & Seeman, J. I. (2021). Evolution Of The Diels–Alder Reaction Mechanism Since The 1930s: Woodward, Houk With Woodward, And The Influence Of Computational Chemistry On Understanding Cycloadditions. *Angewandte Chemie International Edition*, *60*(23), 12660–12681. https://doi.org/10.1002/anie.202001654

Hulyadi, H., Bayani, F., Muhali, M., Khery, Y., & Gargazi, G. (2023). Correlation Profile Of Cognition Levels And Student Ability To Solve Problems In Biodiesel Synthesis. *Jurnal Penelitian Pendidikan IPA*, *9*(6). https://doi.org/10.29303/jppipa.v9i6.3130

Hulyadi, H., Muhali, M., & Fibonacci, A. (2023). Identification Of Student Conceptions On The Molecular Structure Of Organic Compounds Using Question. *Hydrogen: Jurnal Kependidikan Kimia*, *11*(3), 328–338. https://doi.org/10.33394/hjkk.v11i3.8135

Jäger, M., Freitag, L., & González, L. (2015). Using Computational Chemistry To Design Ru Photosensitizers With Directional Charge Transfer. *Coordination Chemistry Reviews*, *304–305*, 146–165. https://doi.org/10.1016/j.ccr.2015.03.019

Johnstone, A. H., & Otis, K. H. (2006). Concept mapping in problem based learning: a cautionary tale. *Chemistry Education Research and Practice, 7*(2), 84-95. Retrieved from https://pubs.rsc.org/en/content/articlelanding/2006/rp/b5rp90017d

Kashani-Vahid, L., Afrooz, G., Shokoohi-Yekta, M., Kharrazi, K., & Ghobari, B. (2017). Can a creative interpersonal problem solving program improve creative thinking in gifted elementary students?. *Thinking skills and creativity, 24*, 175-185. https://doi.org/10.1016/j.tsc.2017.02.011

Khaeruman, K., Darmatasyah, D., & Hulyadi, H. (2017). The Development Of Chemistry Virtual Laboratory On Colloidal System To Improve Generic Science Skills. *Hydrogen: Jurnal Kependidikan Kimia*, *5*(2), 84–93. https://doi.org/10.33394/hjkk.v5i2.1593

Khoiriyah, A.N & Husamah, & Husamah, H. (2018). Problem-Based Learning: Creative Thinking Skills, Problem-Solving Skills, And Learning Outcome Of Seventh Grade Students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *4*(2). https://doi.org/10.22219/jpbi.v4i2.5804

Kim, J.Y., & Lim, K.Y. (2019). Promoting Learning In Online, Ill-Structured Problem Solving: The Effects Of Scaffolding Type And Metacognition Level. *Computers & Education*, *138*, 116–129. https://doi.org/10.1016/j.compedu.2019.05.001

Li, R., Bahadori, A., Xin, J., Zhang, K., Muhunthan, B., & Zhang, J. (2020). Characteristics of bioepoxy based on waste cooking oil and lignin and its effects on asphalt binder. *Construction and Building Materials, 251*, 118926. https://doi.org/10.1016/j.conbuildmat.2020.118926

Lin, C.-Y., & Wu, H.-K. (2021). Effects Of Different Ways Of Using Visualizations On High School Students' Electrochemistry Conceptual Understanding And Motivation Towards Chemistry Learning. *Chemistry Education Research And Practice*, *22*(3), 786–801. https://doi.org/10.1039/d0rp00308e

Manly, C. J., Louise-May, S., & Hammer, J. D. (2001). The Impact Of Informatics And Computational Chemistry On Synthesis And Screening. *Drug Discovery Today*, *6*(21), 1101–1110. https://doi.org/10.1016/s1359-6446(01)01990-0

Mcardle, S., Endo, S., Aspuru-Guzik, A., Benjamin, S. C., & Yuan, X. (2020). Quantum Computational Chemistry. *Reviews Of Modern Physics*, *92*(1), 015003. https://doi.org/10.1103/revmodphys.92.015003

Mohammed, M., & Omar, N. (2020). Question Classification Based On Bloom's Taxonomy Cognitive Domain Using Modified TF-IDF And Word2vec. *PLOS ONE*, *15*(3), E0230442. https://doi.org/10.1371/journal.pone.0230442

Muanruksa. (2020). Combination Of Fatty Acids Extraction And Enzymatic Esterification For Biodiesel Production Using Sludge Palm Oil As A Low-Cost Substrate. *Renewable Energy*, *146*, 901–906. https://doi.org/10.1016/j.renene.2019.07.027

Nadeak, B., & Naibaho, L. (2020). The Effectiveness Of Problem-Based Learning On Students'critical Thinking. *Jurnal Dinamika Pendidikan, 13*(1), 1-7. Retrieved from https://ejournal.uki.ac.id/index.php/jdp/article/view/1393

Ng, W. (2022). Brief History Of Electronic Structure Calculations In Computational Chemistry. *Journal Of Nanotechnology Research*, *4*(1), 10–20. Retrieved from https://fortunepublish.com/articles/10.26502.jnr.2688-85210027.pdf

Nilsson, T., & Niedderer, H. (2014). Undergraduate Students' Conceptions Of Enthalpy, Enthalpy Change And Related Concepts. *Chemistry Education Research And Practice*, *15*(3), 336–353. https://doi.org/10.1039/c2rp20135f

Norman, G. R. (1988). Problem-solving skills, solving problems and problem-based learning. *Medical education, 22*(4), 279-286. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2923.1988.tb00754.x

Perdana, R., Jumadi, J., Rosana, D., & Riwayani, R. (2020). The Online Laboratory Simulation With Concept Mapping And Problem Based Learning (OLS-CMPBL): Is It Effective In Improving Students' Digital Literacy Skills? *Jurnal Cakrawala Pendidikan*, *39*(2). https://doi.org/10.21831/cp.v39i2.31491

Pikoli, M. (2020). Using Guided Inquiry Learning With Multiple Representations To Reduce Misconceptions Of Chemistry Teacher Candidates On Acid-Base Concept. *International Journal Of Active Learning*, *5*(1), 1–10. Retrieved from https://www.learntechlib.org/p/216682/

Pratt, J. M., & Yezierski, E. J. (2018). A Novel Qualitative Method To Improve Access, Elicitation, And Sample Diversification For Enhanced Transferability Applied To Studying Chemistry Outreach. *Chemistry Education Research And Practice*, *19*(2), 410–430. https://doi.org/10.1039/c7rp00200a

Qasim, M. M., Moore, B., Taylor, L., Gorb, L., Leszczynski, J., & Honea, P. (2007). Structural Characteristics And Reactivity Relationships Of Nitroaromatic And Nitramine Explosives – A Review Of Our Computational Chemistry And Spectroscopic Research. *International Journal Of Molecular Sciences*, *8*(12). https://doi.org/10.3390/i8121234

Quattrucci, J. G. (2018). Problem-Based approach to teaching advanced chemistry laboratories and developing students' critical thinking skills. *Journal of Chemical Education, 95*(2), 259-266. https://doi.org/10.1021/acs.jchemed.7b00558

Raymond, C., Horton, R. M., Zscheischler, J., Martius, O., Aghakouchak, A., Balch, J., Bowen, S. G., Camargo, S. J., Hess, J., Kornhuber, K., Oppenheimer, M., Ruane, A. C., Wahl, T., & White, K. (2020). Understanding And Managing Connected Extreme Events. *Nature Climate Change*, *10*(7), Article 7. https://doi.org/10.1038/s41558-020-0790-4

Reyes, A., Moncada, F., & Charry, J. (2019). The Any Particle Molecular Orbital Approach: A Short Review Of The Theory And Applications. *International Journal Of Quantum Chemistry*, *119*(2), E25705. https://doi.org/10.1002/qua.25705

Rodríguez-Becerra, J., Cáceres-Jensen, L., Díaz, T., Druker, S., Padilla, V. B., Pernaa, J., & Aksela, M. (2020). Developing Technological Pedagogical Science Knowledge Through Educational Computational Chemistry: A Case Study Of Pre-Service Chemistry Teachers' Perceptions. *Chemistry Education Research And Practice*, *21*(2), 638–654. https://doi.org/10.1039/c9rp00273a

Rustanto, P. C. R., Suciati, & Prayitno, B. A. (2023). Developing Complex Multiple-Choice Test To Empower Students Higher Order Thinking Skill About Excression System. *AIP Conference Proceedings*, *2540*(1), 020008. https://doi.org/10.1063/5.0107968

Saunders. F. (2022). *Chemistry At The Quantum Level*. American Scientist. Retrieved from https://www.americanscientist.org/article/chemistry-at-the-quantum-level

Seifert, V. A. (2023). The Chemical Bond Is A Real Pattern. *Philosophy Of Science*, *90*(2), 269–287. https://doi.org/10.1017/psa.2022.17

Sholihah, T. M, & Lastariwati, B. (2020). Problem Based Learning To Increase Competence Of Critical Thinking And Problem Solving. *Journal Of Education And Learning (Edulearn)*, *14*(1), 148–154. https://doi.org/10.11591/edulearn.v14i1.13772

Subramani, S., & Radhakrishnan, J. (2022). Advances In Superhydrophobic Surfaces: Biology To Biomimetic. In *Advanced Engineering Of Materials Through Lasers* (Pp. 171–195). Springer International Publishing. https://doi.org/10.1007/978-3-031-03830-3_8

Swanson, D. (2012). Finding Subatomic Particles And Nanoscopic Gold With Open, Shared Computing. *Merrill Series On The Research Mission Of Public Universities*, 61–65. https://doi.org/10.17161/merrill.2012.7862

Talbert, L.C., L. E., Bonner, J., Mortezaei, K., Guregyan, C., Henbest, G., & Eichler, J. F. (2020). Revisiting The Use Of Concept Maps In A Large Enrollment General Chemistry Course: Implementation And Assessment. *Chemistry Education Research And Practice*, *21*(1), 37–50. https://doi.org/10.1039/c9rp00059c

Tamungku, R., R., Tani, D., & Tuerah, J. (2019). Analysis Of Students' Misconceptions Using Two-Tier

Multiple Choice Diagnostic Tests On Atomic Structure Material In Remboken State High School 1. *Oxygenius Journal Of Chemistry Education*, *1*(2). https://doi.org/10.37033/ojce.v1i2.109

Tsaparlis, G., Pappa, E. T., & Byers, B. (2018). Teaching And Learning Chemical Bonding: Research-Based Evidence For Misconceptions And Conceptual Difficulties Experienced By Students In Upper Secondary Schools And The Effect Of An Enriched Text. *Chemistry Education Research And Practice*, *19*(4), 1253–1269. https://doi.org/10.1039/c8rp00035b

Turan-Oluk, N., & Ekmekci, G. (2018). The Effect Of Concept Maps, As An Individual Learning Tool, On The Success Of Learning The Concepts Related To Gravimetric Analysis. *Chemistry Education Research And Practice*, *19*(3), 819–833. https://doi.org/10.1039/c8rp00079d

Wang, G., Chen, Z., Xu, Z., Wang, J., Yang, Y., Cai, T., Shi, J., & Zhu, W. (2016). Stability And Characteristics Of The Halogen Bonding Interaction In An Anion–Anion Complex: A Computational Chemistry Study. *The Journal Of Physical Chemistry B*, *120*(4), 610–620. https://doi.org/10.1021/acs.jpcb.5b08139

Weiss, A. K. H., & Hofer, T. S. (2013). Exploiting The Capabilities Of Quantum Chemical Simulations To Characterise The Hydration Of Molecular Compounds. *RSC Advances*, *3*(6), 1606–1635. https://doi.org/10.1039/c2ra21873a

Widarti, H. R., Permanasari, A., & Mulyani, S. (2016). Student Misconception On Redox Titration (A Challenge On The Course Implementation Through Cognitive Dissonance Based On The Multiple Representations). *Jurnal Pendidikan IPA Indonesia*, *5*(1). https://doi.org/10.15294/jpii.v5i1.5790

Zarkadis, N., Stamovlasis, D., & Papageogiou, G. (2021). Studying the coherence of students' portrayed representations of the atomic structure-Connections with conceptions and misconceptions. *Science Education International, 32*(2), 164-171. Retrieved from https://icaseonline.net/journal/index.php/sei/article/view/308