JPII 13 (3) (2024) 447-458

Jurnal Pendidikan IPA Indonesia

https://journal.unnes.ac.id/journals/jpii

IMPLEMENTATION OF STEM-BASED INQUIRY IN LEARNING FUNDAMENTAL LAWS OF CHEMISTRY: STUDENTS' PERCEPTION AND RESPONSE

L. A. Pohan[1*], R. D. Suyanti[2], A. W. Nugraha[3], D. Pebrianti[4], R. Panjaitan[5], S. H. Hasibuan[6]

[1]Universitas Islam Sumatera Utara, Indonesia
[2,3]Universitas Negeri Medan, Indonesia
[4,5]International Islamic Unversity Malaysia, Malaysia
[6]Universitas Muhammadiyah Sumatera Utara, Indonesia

DOI: 10.15294/jpii.v13i3.3431

Accepted: April 13th, 2024. Approved: August 29th, 2024. Published: August 29th 2024

ABSTRACT

This research aims to analyze students' perceptions and responses to STEM-based inquiry learning. This research used a quantitative and qualitative survey method. The subjects of this study were 25 first-semester students who took the General Chemistry course in the chemistry education study program. The research instruments used were questionnaires, interviews, and learning observation sheets. Meanwhile, the quantitative technique used is descriptive analysis. Quantitative data analysis found that 72% of students were actively involved in learning when formulating questions and investigations. STEM-based inquiry learning in observing, measuring, and analyzing data helped 72% of students understand the basic laws of chemistry. Most students benefit from STEM-based inquiry learning because this model triggers curiosity, the ability to formulate scientific questions, and the ability to evaluate and utilize information that helps determine experimental procedures. In conclusion, the learning experience using the STEM-based inquiry learning model on the basic laws of chemistry positively impacts students' perceptions and responses.

Keywords: perception, response, STEM-based inquiry learning, scientific literacy

INTRODUCTION

In a technology era where scientific literacy and higher-order thinking skills are increasingly necessary, STEM-based inquiry learning serves as a powerful tool to cultivate these competencies in students. The ability to critically analyze, experiment, and apply scientific concepts, especially in chemistry, directly aligns with the goals of modern education to prepare students for the demands of the 21st century. So far, the process of learning the basic laws of chemistry has focused on calculations. The focus on calculations in chemistry education often leaves students with a limited understanding of the broader applications of fundamental laws in real-world contexts. By integrating STEM-based inquiry learning, this research aims to bridge the gap between theoretical knowledge and practical application, particularly in the context of stoichiometry, a fundamental yet challenging concept in chemistry.

According to Roberts et al. (2018) and Rivera & Li (2020), STEM-based inquiry learning plays a significant role in training students' inquiry skills through active experimental activities. Where students not only understand scientific concepts but are also deeply involved in the scientific investigation process. In line with the study by Jeskova et al. (2022), they also emphasized that the STEM approach is able to trigger students' curiosity and ability to formulate relevant scientific questions.

*Correspondence Address
E-mail: lisa.ariyantipohan@fkip.uisu.ac.id

The researchers' efforts in developing inquiry-based strategies integrated with STEM have the potential to train students' inquiry skills well through active experiments to produce students who are interested in and have careers in STEM fields (Roberts et al., 2018; Rivera & Li, 2020). Job opportunities in STEM fields are predicted to grow and require empowered human resources (Langdon et al., 2011; Caprile et al., 2015; Hasim et al., 2022).

The STEM approach is experiential learning through problem analysis that applies knowledge and skills in projects (Bertrand & Namukasa, 2022). This approach also aims to develop skills in higher education and career readiness in STEM fields (Christensen & Knezek, 2017; Silin & David, 2017). The application of STEM learning in careers has many practical aspects that provide several benefits for individuals and organizations: 1) Problem-solving skills that begin with identification and analysis skills; 2) Technology skills; 3) Creation and innovation skills; 4) Collaboration skills (DeCoito & Richardson, 2016; Farwati et al.,2017; Suratno et al., 2020).

One of the central and important subjects in the chemistry curriculum is stoichiometry, a mathematical chemistry concept that requires a deep understanding of the quantitative ratios between reactants and products in a chemical reaction (Zumdahl, 2002; Brown et al., 2012). Applying inquiry learning in stoichiometry allows students to be actively involved in the learning process because there are activities to formulate problems and investigations that involve observation, measurement, and data analysis. This inquiry model is effective in involving students in learning activities and developing various competencies, knowledge, and skills (Kuhlthau et al., 2015; Izzatin & Nurmala, 2018; Kuo et al., 2019; Wen et al., 2020; Novitra et al., 2021).

The main goal of higher science education is not only to provide an understanding of basic concepts but also to develop students' higher-order thinking skills (HOTS) and scientific literacy (Budsankom et al., 2015; Schreglmann & Öztürk, 2018; Rahmawati et al., 2020; Purba et al., 2021; Khaeruddin et al., 2023). One important aspect of STEM is the application of inquiry learning methods, which encourage students to actively seek, explore, and understand scientific concepts (Kawalkar & Vijapurkar, 2013; Moore et al., 2014; Prajoko et al., 2023). By incorporating stoichiometry into STEM-based inquiry learning, students can also see how this concept relates to various fields of science and technology.

To improve learning outcomes and meet educational goals, lecturers need to be creative in determining pedagogical strategies that encourage students to be active in learning (Prachagool et. al., 2016).). Scientific literacy must also be trained for students in the digital era (Pratiwi et. al., 2019; Budiarti & Tanta, 2021; Lestari et al., 2021). Scientific literacy is an individual's ability to use scientific knowledge, identify questions, and draw conclusions based on existing evidence (OECD, 2016; Bonney et al., 2016).

Scientific literacy is the ability to master concepts, collect scientific problems, evaluate, investigate scientifically, interpret data, and communicate skills about science (Dragos & Mih, 2015; OECD, 2016). Science literacy involves cognitive processes divided into Lower-order Thinking Skills (LOTS), consisting of knowledge, understanding, and application, and Higher-order Thinking Skills (HOTS), consisting of analysis, evaluation, and creation derived from Bloom's taxonomy. This ability is expected to address advancing knowledge, technology, and information challenges. More sophisticated technology does bring convenience, but negative impacts accompany it. Scientific literacy helps students resolve the adverse impacts accompanying knowledge and technology advancement (Hofstein et al., 2011; Fakhriyah et al., 2017).

Flexible, creative, active, and more challenging learning design is needed to train higher-order thinking, scientific literacy, and critical thinking skills. The STEM approach allows for various learning activities that provide more experience and thinking skills (Fan & Yu, 2015; Sari et al., 2018; Miller et al., 2018; Shahali et al., 2019; Onsee & Nuangchalerm, 2019). In addition, experiences from STEM learning will shape perceptions about STEM because perceptions are formed from an experienced event, which becomes information in memory and forms understanding (Kaymaz & Sungur, 2015; Pohan & Maulina, 2023). This learning also provides an experience of collaborating with others to solve problems in real everyday contexts (Lindeman et al., 2013).

STEM emphasizes problem-solving and inquiry activities (Baharin et al., 2018). STEM learning is related to inquiry activities, which involve formulating questions designed and solved through investigation (Kennedy & Odell, 2014). By implementing integrated STEM-based learning, students can discover and develop curiosity (Kim et al., 2016).

While significant research has highlighted the potential of STEM-based inquiry learning to enhance critical thinking, scientific literacy, and problem-solving skills in various scientific domains (Fan & Yu, 2015; Baharin et al., 2018; Shahali et al., 2019), there remains a gap in the exploration of how this method can be effectively applied specifically to stoichiometry, a key yet often challenging concept in chemistry. Most existing studies have focused on the general application of STEM in science education (Rivera & Li, 2020; Parmin et al., 2020), but few have thoroughly examined the impact of STEM-based inquiry learning on students' understanding of stoichiometric principles. Furthermore, previous research has primarily concentrated on teacher perspectives regarding the implementation of STEM in science education, with less attention paid to the students' viewpoint, particularly their perceptions of learning stoichiometry through an inquiry-based approach (Permanasari et al., 2021).

Although STEM and inquiry learning offer great potential to improve conceptual understanding, research on the needs of STEM-based inquiry learning in stoichiometry is still limited, especially from students' perspectives. Meanwhile, the use of an integrated STEM approach in science learning, including chemistry, is a demand for education in the technological era due to the high career demands for graduates today (Isozaki, 2018; Tan, 2018). Therefore, this study aims to analyze students' perceptions and responses to the development of STEM-based inquiry learning by considering lecturers' perspectives as learning facilitators and students' perspectives as active participants. This study is based on a holistic approach that combines the perspectives of lecturers and students to gain a comprehensive understanding of the effectiveness and challenges of this learning method. The results of this study are expected to contribute to the development of stoichiometry learning in higher education.

METHODS

This research used a quantitative and qualitative survey method (Creswell & Creswell, 2017). The subjects of this study were 25 first-semester students who took the General Chemistry course in the chemistry education study program. The research instruments used were questionnaires, interviews, and learning observation sheets. The questionnaire to assess students› perceptions of STEM-based inquiry learning in stoichiometry learning included 1) Students› responses to stoichiometry material regarding the level of difficulty, the majority of learning methods, and sub-topics that are difficult to understand; 2) Implementation of STEM-based inquiry learning regarding whether or not lecturers have used it, student involvement, and the impact of implementation; 3) Students› opinions on the skills needed to implement STEM-based inquiry learning; 4) Benefits and challenges in STEM-based inquiry learning (Saptarani et al., 2019).

The research was conducted in two classroom meetings and two experiments in the laboratory. In the first meeting, the concept of the basic laws of chemistry was presented. Furthermore, the stages of the STEM-based inquiry learning model activities were explained.

Students were given an activity sheet using STEM-based inquiry stages. Students formulated research questions and designed experiments. In the second meeting, students conducted the designed experiments. Experiment 1 contains the following activities: a) Proving that the mass of a substance before and after a reaction is the same in a closed system; b) Proving experimental data on the comparison of the masses of two elements that combine (Law of Definite Proportions); c) Proving experimental data on the law of volume comparison that, at the same temperature and pressure, the ratio of the volumes of the reacting gases and the gas products of the reaction is a ratio of integers and simple numbers. At the end of the learning, students› perceptions and responses were assessed using questionnaires and interviews. The example of a storyboard of STEM-based inquiry learning is presented in Table 1.

The student response questionnaire to STEM-based inquiry learning was described from each of the following learning syntaxes: 1) Orientation: delivery of learning objectives, reinforcement of concepts, inquiry questions, motivation to prepare for learning, and motivation to find answers to questions from the internet and books; 2) Formulating research questions: the ability to formulate research questions and formulate hypotheses assisted by lecturers; 3) Investigation: the ability to find, evaluate, and utilize information to determine experimental procedures, activeness in learning, involvement in learning, and the ability to collaborate with colleagues; 4) Drawing conclusions: analyzing discovery patterns to make conclusions, understanding learning materials, increasing interest, increasing responsibility in completing group assignments, and making learning more interesting and challenging; 5) Discussion/ Sharing: expressing opinions and ideas, exploring skills, activating thinking skills, and reflecting on learning outcomes. Interviews were conducted with students to gain a deeper understanding of their experiences during the learning process. Interviews included questions on several aspects: acceptance, attractiveness, benefits, challenges, and suggestions.

The data source in this research came from students in general chemistry courses on the material of basic laws of chemistry using STEM-based inquiry learning. The number of students involved was 25 people. Quantitative data from perception questionnaires, classroom observations, and student responses were analyzed using descriptive statistics. Qualitative data were analyzed using interview transcript content to analyze students› perspectives.

Table 1. The Storyboard of STEM-based Inquiry Learning

No	Stage	Objective	Activity	STEM
1	Orientation	Identifying students' initial knowledge Helping students master concepts Stimulating students' interest and curiosity	- Based on the law of conservation of mass, if rust occurs, what do you think the mass of the iron is before and after rusting? Does rusting increase mass? - Burning paper will produce ash. In your opinion, if weighed, is the mass of the ash the same as the mass of the paper before it was burned? Is the reaction of burning wood accompanied by a reduction in the mass of the burned wood? - To answer these questions, watch the explanation in the following video: https://youtu.be/JrUhHybVJdA	Science: Law of conservation of mass (Lavoisier's law) Technology: A series of tools for reacting $BaCl_2$ and K_2SO_4 in a closed system Engineering: Applying procedures to prove Lavoisier's law Mathematics: Calculating mass before and after reaction
2	Formulating research questions	Identifying problems and formulating questions Determining hypotheses for scientific questions	- How to prove that the mass of iron before and after the reaction is the same? How to prove that burning wood produces the same mass before and after burning? - Can you distinguish between a chemical reaction and a normal mixture using the law of conservation of mass?	
3	Investigation	Conducting experiments through information search to determine experimental procedures Evaluating and using information that leads to deeper creation and learning-dan pembelajaran yang lebih dalam.	- Making a mass procedure before and after the reaction of rusty iron - Mass in the reaction between BaCl2 and K2SO4; - Mass in the mixture of water and sugar. Burned Mg ribbon	
4	Drawing conclusion	Building deeper understanding by summarizing, interpreting, and expanding information to draw multiple conclusions	- Answering questions related to the experiment.	
5	Discussion/ Sharing	Sharing the findings of the experiment	- Writing a report and sharing the findings with other groups.	

RESULTS AND DISCUSSION

Learning stoichiometry is an important part of learning chemistry. Stoichiometry studies the quantitative relationship between reactants and products in a chemical reaction (Brown et. al., 2012). In learning about stoichiometry (the fundamental laws of chemistry), the lecturer acts as a facilitator who guides students in developing their understanding of stoichiometry concepts and applying these concepts in real-life situations. The student responses to the stoichiometry material are as follows:

Table 2. Students Opinon Regarding Stoichiometry Learning

Question	Opinion (%)	Criteria
Students' opinions on the subject of stoichiometry	43,8	Very hard
	28,1	Hard
	15,6	Easy
	9,4	Very easy
Use of methods in learning stoichiometry	51,6	Lecture
	48,4	Apart from lectures

Nearly 44% of 25 students stated that stoichiometry was very difficult, 28% stated it was difficult, 15.6% stated it was easy, and 9.4% stated it was very easy. From these data, the majority stated that stoichiometry was a difficult subject. Students' difficulties were spread across several sub-topics of stoichiometry.

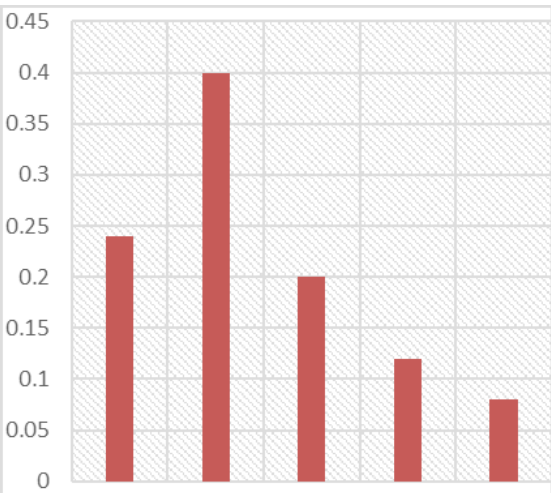

Figure 1. Students Understanding of Stoichiometry (a. Basic laws of chemistry; b. Chemical equations, c. Mole concept, d. Percent composition, e. Limiting reagent)

The students' difficulties in understanding stoichiometry are found in the subtopics of basic chemical laws (24%), chemical equations (writing chemical formulas) (40%), mole concept (20%), the percent composition and formula of compounds (12%), and limiting reagents (8%) of the 25 respondents who filled out the questionnaire.

The data show that most lecturers (72%) apply the STEM-based inquiry learning model in chemistry teaching. This shows that most lecturers know and try this approach in their learning. From the lecturers' perspectives, STEM-based inquiry learning in the basic laws of chemistry provides opportunities for students to develop critical thinking, problem-solving, and collaboration skills.

Table 3. Implementation of STEM-Based Inquiry Learning

Statements	(%)	Criteria
Lecturers have ever applied the STEM-based inquiry learning model in teaching chemistry.	72	Yes
	28	No
Student involvement in stoichiometry learning when using the STEM-based Inquiry Learning Model	12	Very involved
	72	Involved
	16	Neutral
Application of the STEM-based Inquiry Learning Model can help in understanding the concept of stoichiometry	8	Very helpful
	72	Helpful
	20	Neutral

Lecturers argue that this approach increases students' interest and motivation in learning the basic laws of chemistry because students are actively involved in scientific exploration and discovery. Lecturers realize that learning the basic laws of chemistry has only focused on calculations. Students are rarely invited to think more critically about applying the basic laws of chemistry to stoichiometric calculations and their applications in life. 28% of lecturers have never applied this model. The figures show that some lecturers are unfamiliar with this model and face obstacles in its application.

Most students (72%) feel involved in learning stoichiometry with the STEM-based inquiry learning model. This shows that this learning model has successfully attracted most students' interest and active participation. Only 12% of students feel very involved. Although the number is small, many students find this learning very interesting and may be highly interested. 16% of students who have a neutral opinion do not feel anything special about the learning.

With 84% of students showing a positive level of engagement (12% very engaged, 72% engaged), it is concluded that STEM-based inquiry learning effectively increases students' involvement in learning. This conclusion is supported by Alarcon et al. (2023) and Morris (2024), who state that the inquiry-based learning model is centered on students who are actively involved, engaging in constructing procedures, and experimenting can improve scientific reasoning, communicative focus, and critical attitudes towards science. Cognitive, operative, and affective engagement are obtained from the application of inquiry learning (Attard et al., 2021; Ogodo, 2024).

Most respondents (72%) feel helped, and 8% of respondents feel immensely helped in understanding the stoichiometry concept using the STEM-based inquiry learning model. These results indicate that this model is quite effective and has strong potential to provide a positive impact. Meanwhile, 20% of respondents are neutral, indicating room for further improvement or adaptation in this approach. Bakirci et al. (2021) state that STEM-supported inquiry learning can improve students' conceptual understanding of science learning.

This research applies the STEM-based inquiry learning model to the basic laws of chemistry. The student worksheet contains the stages of STEM-based inquiry.

1. Orientation (Proving that the mass of a substance before and after a reaction is the same in a closed system). Based on the law of conservation of mass, if rust occurs, what do you think the mass of the iron is before and after rusting? Does rusting increase mass?

Answer: From our previous thinking, there are two possibilities. First, the mass of the iron after rusting is greater than the mass of the nail before rusting because the rusting produces a brown solid substance that is brittle. Second, the mass of the iron before and after may still be the same, but the color of the iron changes.

From the learning videos and teaching material literature provided, Lavoisier's Law states, "In a closed system, the mass of the substance before the reaction (reactants) and after the reaction (products) are the same. In rusty iron, it appears as if the mass of the iron increases, but what happens is the reaction of iron with oxygen. The mass of rusty iron appears to increase because of the additional mass of oxygen bound to form iron oxide."

Burning paper will produce ash. In your opinion, if weighed, is the mass of the ash the same as the mass of the paper before it was burned? Is the reaction of burning wood accompanied by a reduction in the mass of the burned wood?

Answer: Based on our observation of paper burning, there is indeed a reduction in mass because the unburned paper is a solid substance with actual mass. After burning, the paper is powdered with reduced mass.

From the learning videos and teaching material literature, it can be concluded that Lavoisier's Law still applies because paper combustion occurs in an open system. The paper reacts with oxygen to produce ash, CO (carbon monoxide), and water vapor. If CO and water vapor are added to the ash, the result will remain the same as the mass before the reaction occurred. In combustion, it seems as if a mass is lost, but it is not. Because some of the mass of the reaction results in the form of gas being released, what is left is carbon.

2. Formulating research problems (Students formulate questions independently and create hypotheses): a) How to prove that the mass of iron before and after the reaction is the same? (b) How to prove that burning wood produces the same mass before and after burning? (3) Can you distinguish between a chemical reaction and a normal mixture using the law of conservation of mass?

Hypotheses: a) The mass of rusted iron will be greater than before rusting if it is in an open system and will be the same if it is in a closed system; b) Wood burned in an open system will experience a reduction in mass; c) There is a difference in the application of the law of conservation of mass in ordinary mixtures and chemical reactions.

3. Investigation (Create an experimental procedure to prove the law of conservation of mass based on the literature review and teaching materials provided).

Instructions: 1) Making a mass procedure before and after the reaction of rusty iron; 2) Mass in the reaction between $BaCl_2$ and K_2SO_4; 3) Mass in the mixture of water and sugar; 4) Burned Mg ribbon.

4. Drawing conclusion The essence of this law is that the system must be closed. If a chemical reaction occurs in an open system, the mass

before and after the reaction will not be the same.
5. Writing a report and sharing the findings with other groups

During the learning, the lecturer walked around the class, supported students in developing their ideas, and asked questions that stimulated critical thinking. The lecturer also suggested how to set up experiments so that the results could provide a deeper understanding of the concepts of basic laws of chemistry.

The discussion that took place was fascinating. Each group provided new insights into how the basic laws of chemistry can be understood through an experimental approach. This learning session provided a better understanding of the concepts of the basic laws of chemistry and developed critical thinking, collaboration, and problem-solving skills.

Most students (72%) state that the learning helps them understand the basic laws of chemistry for stoichiometric calculations. This is in line with Zhai (2019), who stated that inquiry learning is closely related to practice so that students actively discover concepts and principles through inquiry learning steps prepared in student activity sheets accompanied by exploration by reading, thinking, experimenting, observing, and discussing through examples and questions. This aligns with Roberts et al. (2018) and Huda et al. (2019), who state that students' perceptions of STEM learning can make them excel in mastering materials and provide a positive view of STEM-based inquiry learning. From the students' experience participating in STEM-based inquiry learning, they have opinions about the skills needed to apply STEM-based inquiry learning, as explained in Figure 2.

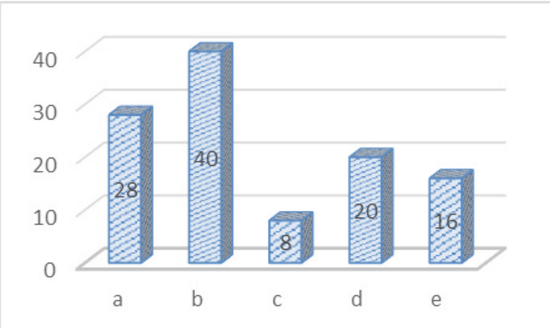

Figure 2. Students' responses on the needed skills (a. Basic understanding; b. Critical thinking readiness; c. Teamwork; d. Communication; e. Learning independence)

In applying STEM-based inquiry learning in stoichiometry, students are given tasks encouraging them to conduct discovery activities, collect data, analyze data, solve problems, and draw conclusions based on their findings (Aydin-Gunbatar et al., 2018; Karamustafaoglu & Pektas, 2022). In this process, students learn to connect the basic laws of chemistry and the concepts of stoichiometry calculations with their practical applications in everyday life.

Students' perceptions of STEM-based inquiry learning are assessed from matters related to its application, the skills needed, the influence of learning on scientific literacy, and the benefits of learning. Based on students' responses, the benefits of STEM-based inquiry learning are explained in Figure 3.

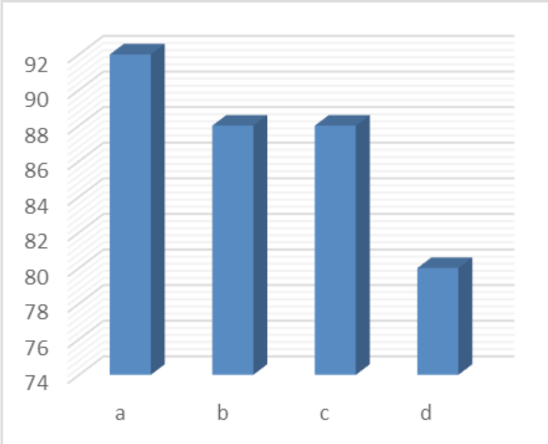

Figure 3. The Benefits of STEM-based Inquiry Learning (a. The inquiry stage triggers curiosity; b. The ability to ask questions solves scientific problems; c. The use of information helps determine experimental procedures; d. Learning activities increase curiosity)

From the lecturer's perspective, STEM-based inquiry learning in stoichiometry provides opportunities for students to develop critical thinking, problem-solving, and collaboration skills. This finding aligns with previous studies that convey the influence of planned inquiry-based STEM activities in out-of-school learning environments on improving students' creative problem-solving skills and STEM awareness (Karamustafaoglu & Pektas 2022).

So far, the learning process of basic laws of chemistry has focused on calculations. Students are not encouraged to think more critically about applying basic chemical laws to stoichiometric calculations and in life. Therefore, the application of STEM-based inquiry learning can improve students' LOTS and HOTS (Julianda et al., 2018; Izzatin & Nurmala, 2018; Puspita et al., 2022; Fadillah et al., 2022; Panggabean et al., 2023).

Implementing STEM-based inquiry learning benefits students. Most students (92%) state that thought-provoking questions trigger curiosity in the early stages of inquiry. The same percentage of students (88%, respectively) state that formulating scientific questions in the inquiry stage can solve scientific problems, and the ability to evaluate and utilize information can help determine experimental procedures. 80% state that learning activities that invite students to think and work to solve STEM-based stoichiometry problems increase curiosity. The following are some findings from interviews with students.

For several reasons, students' acceptance of implementing the STEM-based inquiry learning model is very positive. First, learning that directly applies concepts through experiments makes it easier for students to understand the materials. They can see and feel how the materials are applied in real situations, deepening their understanding. In addition, this learning model also helps students express their opinions. Active discussions and interactions during learning make students feel more comfortable and encouraged to speak and express their ideas. This model improves their communication skills and enriches the teaching and learning process with various perspectives.

The STEM-based inquiry learning model and communicative lecturer guidance also increase students' enthusiasm. Lecturers who can communicate well and provide clear and inspiring guidance make students feel more appreciated and motivated to learn. Positive interactions between lecturers and students create a conducive and enjoyable learning environment. Finally, students feel more involved in class learning. They are not just passive recipients of information but also take an active role in learning. With higher involvement, students are more motivated to learn and participate in class activities, ultimately improving the overall quality of learning.

Overall, the implementation of the STEM-based inquiry learning model was well accepted by students because it provided a more interactive, participatory, and real-life relevant learning experience. Students' acceptance of the implementation of the STEM-based inquiry learning model was due to several reasons: (1) Learning that directly applies concepts through experiments, (2) Learning that helps students express their opinions, (3) The STEM-based inquiry learning model combined with communicative lecturer guidance for students makes students enthusiastic about learning, (4) Students are more involved in learning in class.

The STEM-based inquiry learning model has several interesting aspects. First, it is active and student-centered learning, which involves asking questions, conducting experiments, and finding solutions to the problems presented. Second, students are invited to think critically, collaborate, solve problems in stoichiometry material, and try to find out the context for solving stoichiometry problems.

Students benefit from using the STEM-based inquiry learning model. First, this model emphasizes independent problem-solving, which requires students to think critically and creatively when finding solutions. This encourages students to think proactively when solving problems. Second, by implementing this model, students face situations where they must formulate their hypotheses before conducting experiments or analysis, thus training them to think analytically. Third, being actively involved in experiments and discoveries allows students to see firsthand how chemistry concepts work and deepen their understanding through practical experience. Fourth, applying basic laws of chemistry in stoichiometric calculations in everyday life helps students see the practical relevance of their learning, thereby increasing motivation and understanding. Fifth, learning through direct experience can strengthen understanding and retention of basic concepts. Sixth, this model encourages students to always ask questions and seek answers, which builds their curiosity and encourages continuous learning.

Students are comfortable learning because they are facilitated with learning resources, such as student activity sheets and teaching materials with links to complete STEM-based inquiry learning activities. The lecturer walks around, supervises, and directs students' discussions in groups. This makes students have a positive attitude towards STEM-based inquiry so that they are happy to be involved in inquiry activities, such as asking questions, formulating problems, finding ways to answer these questions, and increasing their capacity to provide conclusions based on evidence when they become active learners.

This is in line with Kuo et al. (2019), who state that students who implement inquiry learning are significantly superior to traditional learning in terms of self-confidence in learning science, science scores, achievement of learning objectives, and positive perceptions of inquiry. Positive attitudes towards inquiry are also obtained from previous studies. Involvement in asking and formulating questions can increase students' capacity to draw conclusions based on evidence when they become active learners in an inquiry learning environment (Wang et al., 2021). This aligns with the positive response to implementing STEM-based inquiry learning (Table 4).

Table 4. Category of Student Response

No	Syntax	(%)	Category
1	Orientation	81	Very positive
2	Formulating Research Questions	78	Positive
3	Investigation	84	Very positive
4	Drawing Conclusion	82	Very positive
5	Discussion/ Sharing	83	Very positive

Based on Table 4, most students appreciate the interactive and collaborative learning experience in STEM-based inquiry learning. They enjoy the freedom to explore and experiment with new concepts and feel involved in a more active and in-depth learning process. Discussing, explaining ideas, planning experiments, experimenting, and drawing conclusions are significantly related to students' enjoyment of learning chemistry (Wang et al., 2021)

While the responses are generally positive, some students identify challenges in STEM-based inquiry learning. Some mention difficulties in making connections between the basic laws of chemistry and their calculations in stoichiometry because the material is so broad and complex, while others feel a lack of support or guidance from lecturers. The learning stages are designed for independent learning and critical thinking, requiring seriousness to realize it and making it difficult for some students to adapt.

Limitations of the Study is the study may have been conducted with a limited number of students from specific educational institutions, potentially leading to sample bias. This limitation restricts the generalizability of the findings to a broader student population across different educational contexts and regions. Future studies should aim to include a larger and more diverse sample of students from various educational institutions and regions. This would enhance the generalizability of the findings and provide a more comprehensive understanding of student experiences in STEM-based inquiry learning.

CONCLUSION

Students' perceptions and responses to STEM-based inquiry learning are one of important reasons for developing and applying it to chemistry learning. Based on the findings from this research, the majority of students are involved in learning activities, which can help them understand the fundamental laws of chemistry. Positive student perceptions and responses to STEM-based inquiry learning can help them better master the material content. However, apart from that, they think that the application of this learning requires initial skills that must be possessed, namely a basic understanding of the material, critical thinking, group work skills, communication skills, and independence in learning. Then the students also identified several challenges they faced in learning, namely that there were still difficulties in making connections between the basic laws of chemistry and their calculations in stoichiometry because the material was very broad and complex.

REFERENCES

Alarcon, D.A.U., Mendoza, F.T., Paucar, F.H.R., Caceres, K.S.C., & Viza, R.M. (2023). Science and Inquiry-Based Teaching and Learning: A Systematic Review. *Frontiers in Education*, 8, 1-10.

Attard, C. Berger, N., & Mackenzie, E. (2021). The Positive Influence of Inquiry-Based Learning Teacher Professional Learning and Industry Partnerships on Student Engagement With STEM. *Frontiers in Education,* 6, 1- 14.

Aydin-Gunbatar, S., Ekiz-Kiran, B., & Oztay, E.S. (2020). Pre-service Chemistry Teachers' Pedagogical Content Knowledge for Integrated STEM Development with LESMeR Model. *Chemistry Education Research and Practice,* 21(4), 1063-1082.

Baharin, N., Kamarudin, N., & Manaf, U. K. A. (2018). Integrating STEM Education Approach in Enhancing Higher Order Thinking Skills. *International Journal of Academic Research in Business and Social Sciences,* 8(7), 810-821.

Bakirci, H., Kirici, M.G., & Kara, Y.(2022). The Effectiveness of STEM-Supported Inquiry-Based Learning Approach on Conceptual Understanding of 7th Graders: Force and Energy Unit. *Journal of Science Learning*. 5(3). 452-468.

Bertrand, M. G., & Namukasa, I. K. (2022). A Pedagogical Model for STEAM Education. *Journal of Research in Innovative Teaching & Learning*, 16(2), 169-191.

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can Citizen Science Enhance Public Understanding of Science?' *Public Understanding of Science*, 25(1), 2–16.

Brown, T.L., Lemay, H.E., Bursten, B.E., Murphy, C.J., & Woodward, P.M. (2012). *Chemistry The Central Science*. Twelfth Edition, Prentice Hall.

Budiarti, I. S., & Tanta, T. (2021). Analysis on Students' Scientific Literacy of Newton's Law and Motion System in Living Things. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, *9*(1), 36-51.

Budsankom, P., Sawangboon, T., Damrongpanit, S., & Chuensirimongkol. J. (2015). Factors Affecting Higher Order Thinking Skills of Students: A Meta-Analytic Structural Equation Modeling Study. *Educational Research and Reviews,* 10(19), 2639-2652.

Caprile, M.; Palmén, R.; Sanz, P.; Dente, G. (2015). Encouraging STEAM Studies for the Labour Market; European Parliament: Strasbourg, France.

Christensen, R. and Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science Environment and Health*, 3(1), 1-13.

Creswell, J. W., & Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications.

DeCoito, I., & Richardson, T. (2016). Using Technology to Enhance Science Literacy, Mathematics Literacy, or Technology Literacy: Focusing on Integrated STEM Concepts in a Digital Game. In *Improving K-12 STEM Education Outcomes Through Technological Integration* (pp. 1–22). IGI Global.

Dragos, V. & Mih, V. (2015). Scientific Literacy in School. *International conference "Education, Reflection, Development" ERD*. Procedia - Social and Behavioral Sciences 209: 167 – 172.

Fadillah, H. N., Ismail, & Mu'nisa, A. (2022). Pengaruh Model Pembelajaran Inkuiri Terhadap Kemampuan Berpikir Tingkat Tinggi Siswa Pada Materi Sistem Gerak Kelas XI SMA Negeri 3 Wajo. *Biogenerasi*, 7(1), 197–205.

Fakhriyah, F. Masfuah, S., Roysa, M., Rusilowati, A., & Rahayu, E.S. (2017). Student's Science Literacy In The Aspect of Content Science? *Jurnal Pendidikan IPA Indonesia*, 6(1): 81-87.

Fan, S., & Yu, K. (2015). How an integrative STEM curriculum can benefit students in engineering design practices. *International Journal of Technology and Design Education, 27*, 107–129

Farwati, R., Permanasari, A., Firman, H., & Suhery, T. (2017). Integrasi Problem Based Learning Dalam STEM Education Berorientasi Pada Aktualisasi Literasi Lingkungan dan Kreativitas. *Prosiding Seminar Nasional Pendidikan IPA*, 198–206.

Hasim, S.M., Rosli, R., Halim, L., Capraro, M. M., & Capraro, R. M. (2022). STEM Professional Development Activities And Their Impact On Teacher Knowledge And Instructional Practices. *Mathematics, 10*(7), 1109.

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal Issues and Their Importance For Contemporary Science Education: A Pedagogical Justification and The State of The Art in Israel, Germany and the USA, *International Journal of Science and Mathematics Education,* 9 (6). 1459-1483.

Huda, M.N., Batlolona, J.R., Wartono. (2019). Science Literation Ability and Physics Concept Understanding In The Topic of Work and Energy With Inquiry-STEM. *International Conference on Science and Applied Science (ICSAS)*. 2202 (020063), 1-11.

Isozaki, T. (2018). Science Teacher Education in Japan: Past, Present, and Future, *Asia-Pacific Science Education*, 4(10), 1–14.

Isdianti, M.F., Erman, & Nasrudin, H. (2021). The Development of STEM (Science, Technology, Engineering, and Mathematics) Based Inquiry Learning Packages to Train Students' Critical Thinking Skill. *JPPS (Jurnal Penelitian Pendidikan Sains*), 10 (2): 1949-1959.

Izzatin, M., & Nurmala, R. (2018). Pembelajaran Berbasis Inquiry Untuk Melatih Higher Order Thinking Skills (HOTS) Mahasiswa Pendidikan Matematika pada mata kuliah metode numerik. *Edukasia*, 5(2), 72–81.

Jeskova, Z., Lukac, S., Snajder, L., Gunnis, J., Klein, D., & Kires, M. (2020). Active Learning in STEM Education with Regard to The Development of Inquiry Skills, *Education Sciences,* 12, 686.

Julianda, Widiati, U., & Djatmika, E. T. (2018). Pengaruh Strategi Pembelajaran Inkuiri Berbasis Keterampilan Multiliterasi Terhadap Kemampuan Berpikir Kritis Siswa. *Jurnal Pendidikan: Teori, Penelitian dan Pengembangan,* 3(4), 460–467.

Karamustafaoglu, O., & Pektas, H.M. (2022). Developing Students' Creative Problem-Solving Skills With Inquiry-Based STEM Activity in an Out-of-School Learning Environment. *Education and Information Technologies*. 28, 7651-766.

Kaymaz, M. L., & Sungur, M. (2015). The Effects of Knowledge Acquisition Levels on Perception in Art Education, *Anadolu Journal of Educational Sciences International*, 266-281.

Kawalkar, A., & Vijapurkar, J. (2013). Scaffolding Science Talk: The Role of Teachers' Questions in the Inquiry Classroom. *International Journal of Science Education,* 35(12), 2004–2027.

Kennedy, T. J & Odell M.R.L. (2014). Engaging students in STEM education, *Science Education International,* 25 (3), 246–258.

Khaeruddin, K., Indarwati, S., Sukmawati, S., Hasriana, H. & Afifah, F. (2023). An Analysis of Students' Higher Order Thinking Skills Through the Project-Based Learning Model on Science Subject. *Jurnal Penelitian dan Pembelajaran IPA*, 5 (2), 47-54.

Kim, M. K., Roh, I. S., & Cho, M. K. (2016). Creativity of gifted students in an integrated math-science instruction, *Thinking Skills and Creativity*, 19, 38-48.

Kuhlthau, C.C.; Maniotes, L.K.; Caspari, A.K. (2015). Guided Inquiry: Learning in the 21st Century; ABC-CLIO, LLC: Santa Barbara, CA, USA; ISBN 978-1-4408-3381-6.

Kuo, Y.-R., Tuan, H.-L., & Chin, C.-C. (2019). Examining low and non-low achievers' motivation towards science learning under inquiry-based instruction. *International Journal of Science and Mathematics Education*, 17(5), 845–862.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011). STEM: good jobs now and for the future (Report #03–11)'. Washington, DC: US Department of Commerce.

Lestari, H., Rahmawati, I., Siskandar, R., & Dafenta, H. (2021). Implementation of Blended Learning with a STEM Approach to Improve Student Scientific Literacy Skills During The COVID-19 Pandemic. *Journal of Research in Science Education, 7*(2), 224-231.

Lindeman, K.W.; Jabot, M.; Berkley, M.T. (2013). The Role of STEM (or STEAM) in the Early Childhood Setting. In Learning Across the Early Childhood Curriculum, *Emerald Group Publishing* Limited: Bentley, UK, 17, 95–114.

Moore, T.; Stohlmann, M.; Wang, H.; Tank, K.; Glancy, A.; Roehrig, G. (2014). Implementation and Integration of Engineering in K-12 STEM Education. In Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices; Purzer, S., Strobel, J., Cardella, M., Eds.; Purdue University Press: West Lafayette, ID, USA, 35–60.

Morris, D.L. (2024). Reflections of a First-Year Chemistry Teacher: Intersecting PCK, Responsiveness, and Inquiry Instruction. *Educ. Sci.* 14 (93). 1–19.

Miller, K., Sonnert, G., & Sadler, P. (2018). The Influence of Students' Participation in STEM Competitions on their Interest in STEM Careers. *International Journal of Science Education, Part B,* 8(2), 95-114.

Novitra, F., Festiyed., Yohandri., & Asrizal. (2021). Development of Online-Based Inquiry Learning Model to Improve 21st-Century Skills of Physics Students in Senior High School. *EURASIA Journal of Mathematics, Science and Technology Education*, 17(9), 2-20

OECD, (2016). Assessing Scientific, Reading and Mathematical Literacy A Framework for PISA 2015, Paris: OECD Publishing.

Ogodo, J.A. (2024). Culturally Responsive Pedagogical Knowledge: An Integrative Teacher Knowledge Base for Diversified STEM Classrooms. *Educ. Sci*. 14 (124), 1–13.

Onsee, P, & Nuangchalerm, P. (2019). Developing Critical Thinking of Grade 10 Students Through Inquiry-Based STEM Learning, *Jurnal Penelitian dan Pembelajaran IPA*, 2 (2), 132-141.

Parmin, P., Saregar, A., Deta, U.A., & El Islami, R.A.Z. (2020). Indonesian science teachers' views on attitude, knowledge, and application of STEM, *Journal for the Education of Gifted Young Scientists*, 8 (1), 17-31.

Panggabean, F. T. M., Silitonga, P. M., Sutiani, A., Purba, J., & Gultom, R. (2023). Inquiry-Based Learning STEM Teaching Materials to Improve Students' Thinking Skills in Stoichiometry. *JTK: Jurnal Tadris Kimiya,* 8 (2): 157-164.

Permanasari, A., Rubini, B., & Nugroho, O. F. (2021). STEM Education in Indonesia: Science Teachers' and Students' Perspectives, *Journal of Innovation in Educational and Cultural Research*, 2 (1), 7-16.

Pohan, L.A., & Maulina, J. (2023). Blended Learning Integrated With Project-Based Learning: Its Effect on Learning Outcomes, Perception, and Self-Regulated Learning. *Jurnal Pendidikan Kimia Indonesia*, 6 (2), 97-106.

Prachagool, V, Nuangchalerm, P, Subramaniam, G & Dostál, J. (2016). Pedagogical Decision Making Through the Lens of Teacher Preparation Program, *Journal for the Education of Gifted Young Scientists*, 4 (1), 41-52.

Prajoko, S., Sukmawati, I., Maris, A.F., & Wulanjani, A.N. (2023). Project Based Learning (PjBL) Model with STEM Approach on Students' Conceptual Understanding and Creativity. *Jurnal Pendidikan IPA Indonesia,* 12(4), 526-537.

Pratiwi, S.N, Cari C, Aminah, N.S. (2019). Pembelajaran IPA Abad 21 dengan Literasi Sains Siswa, *Jurnal Materi dan Pembelajaran Fisika.* 9 (1), 34-42.

Purba, J., Panggabean, F. T. M., & Widarma, A. (2021). Development of General Chemical Teaching Materials (Stoichiometry) in an Integrated Network of Media-Based Higher-Order Thinking Skills. *Proceedings of the 6th Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL)*, 591, 949–954.

Puspita, H., Marlina, D., & Hadi, F. R. (2022). Pengaruh Model Inquiry Terhadap HOTS Siswa SD. *Prosiding Konferensi Ilmiah Dasar*, 3,19–24.

Rahmawati, Y., Andanswari, F., Ridwan, A., Gillies, R., & Taylor, P. (2020). STEM Project-Based Learning in Chemistry: Opportunities and Challenges to Enhance Students' Chemical Literacy. *International Journal of Innovation, Creativity, and Change, 13*(7), 1673–1694.

Rivera, H., & Li, J.T. (2020). Potential Factors to Enhance Students' STEM College Learning and Career Orientation, *The Journal Frontiers in Education*, 5(25), 1 – 10.

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., Schroeder, D., Delaney, A., Putnam, L., & Cremeans, C. (2018). Students' Perceptions of STEM Learning After Participating in a Summer Informal Learning Experience, *International Journal of STEM Education*, 5(35), 1 – 14.

Sari, U., Alici, M., & Sen, OF (2018), The effect of STEM Instruction on Attitude, Career Perception and Career Interest in a Problem-Based Learning Environment and Student Opinions", *Electronic Journal of Science Education*, Vol. 22 No. 1, pp. 1–21.

Saptarani, D., Widodo, A., Purwianingsih, W. (2019). Biology Teachers and High School Students Perceptions About STEM Learning. *International Conference on Mathematics and Science Edu-*

cation (ICMScE). 1157 (042007), 1-6.

Schreglmann, S., & Öztürk, F. K. (2018). An Evaluation of Gifted Students' Perceptions on Critical Thinking Skills', *Journal for the Education of Gifted Young Scientists*, 6 (1), 1-16.

Shahali, E.H.M., Halim, L., Rasul, M.S., Osman, K., & Mohamad-Arsad, N. (2019). Students' Interest Towards STEM: A Longitudinal Study. *Research in Science & Technological Education,* 37(1), 71-89.

Silin, Y & David, K. (2017). A study of Students' Attitudes Towards Using ICT in a Social Constructivist Environment. *Australasian Journal of Educational Technology*, **33**(5), 50–62.

Suratno, S., Wahono, B., Chang, C. Y., Retnowati, A., & Yushardi, Y. (2020). Exploring a Direct Relationship Between Students' Problem-Solving Abilities and Academic Achievement: A STEM Education at a Coffee Plantation Area. *Journal of Turkish Science Education*, *17* (2), 211–224.

Tan, A. L. (2018). Journey of Science Teacher Education in Singapore: Past, Present and Future', *Asia-Pacific Science Education*, 4 (1), 1-16

Wang, H., Lin, H, Chen, Y., Pan, Y., & Hong, Z. (2021). Modelling Relationships Among Students' Inquiry-Related Learning Activities, Enjoyment of Learning, and Their Intended Choice of a Future STEM Career, *International Journal of Science Education*, 43 (1), 157-178.

Wen, C.-T., Liu, C.-C., Chang, H.-Y., Chang, C.-J., Chang, M.-H., Chiang, S.-H. F., Yang, C.-W., & Hwang, F.-K. (2020). Students' guided inquiry with simulation and its relation to school science achievement and scientific literacy. Computers & Education, 149, Article 103830.

Zhai, L. (2019). An Inquiry Teaching Mode Based on STEM, *International Journal of Emerging Technologies in Learning,* 14 (17), 44 - 58

Zumdahl, S. (2002). *Chemistry*. Boston, MA: Houghton Mifflin.