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Research Artikel

# ANALYSIS OF STUDENTS' SCIENTIFIC ARGUMENTATION USING THE SOLO TAXONOMY ON HYDROCARBON MATERIAL THROUGH A SOCIO-SCIENTIFIC ISSUES (SSI) APPROACH

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***Abstract***

*This study aims to identify the argumentation profiles of students on the topic of carbon compounds using a socio-scientific issues (SSI) approach. The research was conducted at one of public senior high schools in Tangerang involving 32 twelfth-grade students. A mixed methods were employed. The research instruments included observation sheets, reflective journals, argumentation tests, student worksheets, and interviews. The results indicate that chemistry learning on carbon compounds through the socio-scientific issues (SSI) approach created a more engaging learning environment, as the discussions and problem topics were closely related to everyday life. The students' argumentation profiles generally demonstrated multi-structural abilities in the components of evidence and reasoning, with respective percentages of 81% and 50%. Meanwhile, the components of rebuttal and claim were still at pre-structural and unistructural levels, with a unistructural percentage of 50% and 72%, respectively. These findings suggest that although the Socio-scientific Issues (SSI) approach has been effective in developing students' abilities to provide evidence and reasoning, their skills in constructing strong claims and presenting appropriate rebuttals still require further improvement.*

***Keywords***: *Carbon compound; scientific argumentation; socio-scientific issues approach; SOLO taxonomy.*

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## INTRODUCTION

In today's era of globalization, education increasingly emphasizes the development of students' scientific argumentation skills, particularly their ability to identify and analyse scientific issues, evaluate the credibility of evidence, construct logical arguments, and make informed decisions regarding complex socio-scientific problems encountered in everyday life.

Through the Programme for International Student Assessment (PISA), established by the Organization for Economic Co-operation and Development (OECD, 2023), students around the world are encouraged not only to understand the learning process but also to apply their scientific knowledge to real-life situations. Moreover, PISA emphasizes that students should be able to utilize their understanding and skills to address real-world challenges in the modern era. PISA identifies three core competencies in science that students need to master: identifying scientific issues, explaining phenomena scientifically, and using scientific evidence to interpret data, solve problems, and make informed decisions related to science and technology. These three competencies are categorized under scientific literacy.

Within the framework of scientific literacy, scientific evidence represents a fundamental aspect of scientific argumentation. This ability involves constructing claims supported by relevant and reliable evidence. Thus, the capacity to use scientific evidence is closely connected to argumentative competence, as both focus on constructing and evaluating claims based on empirical data. Scientific argumentation itself is an essential skill that plays a critical role in fostering scientific reasoning and problem-solving abilities in modern science education (Altun & Ozsevgec, 2025). Consequently, many countries have recommended the development of argumentation skills as one of the key competencies required of 21st-century learners.

Scientific argumentation is a vital component of science learning, as it enhances students' conceptual understanding while cultivating their critical thinking abilities. Haruna & Nahadi, (2021)emphasize that argumentation skills are strongly correlated with students' critical thinking skills. Similarly, several studies have demonstrated that students' conceptual understanding in chemistry improves when instruction integrates argumentation-based learning (Aydeniz & Ozdilek, 2015); (Aydeniz & Dogan, 2016). These findings are supported by (Heng et al., 2014) and (Kaya, 2013), who revealed that engaging students in scientific argumentation deepens their understanding of scientific concepts. Furthermore, (Von Aufschnaiter et al., 2008) argue that involving students in argumentation enables them to use their prior knowledge and reconstruct it at higher levels of abstraction, thereby creating more meaningful learning experiences.

Chemistry, as a branch of science, focuses on the study of the composition, structure, properties, and transformations of matter and the energy associated with these processes (Gilbert et al., 2013). Understanding these concepts requires students not only to master scientific knowledge but also to develop scientific argumentation skills, enabling them to analyze evidence, explain chemical phenomena logically, and construct evidence-based arguments when addressing scientific and socio-scientific issues. However, many students perceive chemistry as a difficult subject (Johnstone, 2000). This difficulty arises primarily from the need to integrate three levels of chemical representation macroscopic, microscopic, and symbolic (Johnstone, 1991). One particularly challenging area of chemistry is organic chemistry, which examines compounds containing carbon (Solomons, 2011) . In Indonesia, organic chemistry is often considered one of the most difficult topics for students. Siregar et al. (2021) reported that students' mastery of hydrocarbon concepts remains low, particularly in analyzing carbon atom types based on their bonding structure. Similarly, other research found that functional group topics are often perceived as complex due to their broad conceptual scope. These difficulties are attributed to the multidimensional nature of organic chemistry (Ulfah et al., 2017). Supporting this view, Austin (Austin et al., 2018) emphasized that understanding organic chemistry requires various cognitive abilities, including memory, spatial reasoning, three-dimensional visualization, problem-solving, and conceptual understanding.

In learning organic chemistry, students' success is often linked to their ability to construct well-supported arguments (Lieber & Graulich, 2022). One major challenge lies in formulating sufficient and relevant evidence to support a claim. Students often rely on a single piece of evidence, whereas robust scientific argumentation requires multiple pieces of corroborating evidence. (Bodé et al., 2019) found that most students struggle to use relevant data when constructing scientific claims, resulting in weak argument quality. (Devi et al., 2019) also revealed that students' argumentation quality on buffer solution topics is generally limited to Level 1 (claims only) and Level 2 (claims with data). Similarly, Wahdan et al. (2017) found that the argumentation levels of high school, madrasah, and chemistry education students at Universitas Negeri Malang were predominantly at Level 2a, indicating a low level of argumentation skill.

Moreover, (Haruna & Nahadi, 2021) observed that students often face difficulties in identifying data relevant to their conclusions, which is reflected in the correlation between argumentation quality and critical thinking skills in the topic of chemical bonding. Students tend to participate actively in discussions but fail to align their claims with the supporting data and discussion topic, leading to weak, invalid, and irrelevant arguments. Similar weaknesses were noted by (Kulatunga et al., 2013), who found that students often present claims without supporting data. Further demonstrated that students struggle to utilize evidence effectively when constructing claims or rebuttals (Sampson et al., 2011a; Solomons, 2011).

Several strategies have been implemented to improve students' scientific argumentation skills in chemistry education, one of which is the integration of socio-scientific issues (SSI). According to (Sadler, 2004a), socio-scientific issues are controversial topics arising from the intersection of science and societal problems. Implementing SSI contexts can enhance students' scientific argumentation skills by encouraging them to relate scientific concepts to real-world phenomena (Acar et al., 2010). Inquiry-based learning using SSI significantly improves students' scientific explanation abilities (Mahanani et al., 2019). This approach aligns with PISA's three core science literacy competencies explaining phenomena scientifically, evaluating evidence, and interpreting data making learning more meaningful. In the context of organic chemistry, which is highly applicable to everyday life, integrating SSI particularly in topics such as carbon compounds can help students understand concepts more contextually and meaningfully.

In addition to Socio-Scientific Issues (SSI)-based learning, scaffolding has been widely recognized as an effective strategy for enhancing students' scientific argumentation skills. Luo (Luo et al., 2020a) demonstrated that reasoning-flow scaffolds can effectively assist students in constructing logical, coherent, and evidence-based arguments. To assess the quality of these arguments, a robust analytical framework is necessary, with the Structure of the Observed Learning Outcome (SOLO) taxonomy, originally developed by (Biggs & Collis, 2014), being one of the most widely applied frameworks in educational research. (Hodges & Harvey, 2003) reported that the SOLO taxonomy provides a practical and systematic framework for evaluating the complexity of students' arguments, while. In addition, Luo further confirmed its effectiveness in assessing the quality of scientific argumentation (Luo et al., 2020a).

Previous studies have examined the effectiveness of SSI-based learning in improving students' argumentation skills and have also explored the SOLO taxonomy as a framework for evaluating science learning outcomes; however, these studies have generally treated the two approaches separately. Moreover, limited research has integrated the analysis of scientific argumentation components, as proposed in Toulmin's Argumentation Pattern (TAP), with the hierarchical cognitive levels of the SOLO taxonomy within the context of socio-scientific issues, particularly in organic chemistry. Therefore, this study aims to address this gap by analyzing the quality of students' scientific argumentation on the topic of carbon compounds through an SSI-based learning approach grounded in the SOLO taxonomy. By integrating Toulmin's framework with the SOLO taxonomy, this research offers a more comprehensive understanding of students' argumentation profiles, reasoning processes, and cognitive development. Accordingly, the present study seeks to analyze students' scientific argumentation quality regarding carbon compounds using a socio-scientific issues approach based on the SOLO taxonomy.

## METHOD

The research methodology used in this study is mixed methods. According to (Creswell & Creswell, 2017), mixed methods is a research approach that combines quantitative and qualitative methods in a single study through the processes of data collection, analysis, and interpretation to obtain a more comprehensive understanding of a phenomenon. In line with this, (Tashakkori & Teddlie, 2021) as well as (Johnson et al., 2007) define mixed methods as a research design that integrates quantitative and qualitative approaches across various stages of the research in order to produce a deeper and more comprehensive understanding compared to using a single approach separately. This approach was chosen because the study does not only aim to identify students' levels of argumentation ability through quantitative data, but also to describe their argumentation characteristics in greater depth through qualitative data. Thus, the integration of both types of data is expected to provide a more complete picture of students' argumentation profiles on the topic of carbon compounds through a Socio-scientific Issues (SSI)-based learning approach.

The research was conducted in three stages. The first stage focused on preparation, which included developing learning materials and conducting initial interviews with teachers to explore students' understanding of carbon compounds, the implementation of the Socio-scientific Issues (SSI) approach in learning, and the quality of students' scientific argumentation. The implementation stage centered on the teaching and learning process using the SSI approach and the delivery of content related to scientific argumentation. The final stage involved processing and analyzing data obtained from various instruments and classroom activities. The data collected from these stages were then analyzed to determine the level of students' scientific argumentation ability.

The study was conducted at a Public secondary school in Tangerang that has implemented project-based and contextual learning approaches. The participants in this study consisted of 32 twelfth-grade science (MIPA) students. The selected students had previously studied the topic of carbon compounds and were actively engaged in learning activities utilizing the Socio-Scientific Issues (SSI) approach. Participant selection was carried out purposively, based on their involvement in SSI-based learning classes and the availability of complete data for analysis.

The argumentation skills test was developed by the researchers based on the learning objectives, basic competencies, and learning indicators of the hydrocarbon topic. To facilitate students' construction of scientific arguments, the test incorporated the Reasoning Flow Scaffold (RFS), an instructional framework adapted from Stephen Toulmin**'s** Argument Pattern (TAP) (Toulmin, 2003)**.** The RFS guides students through four essential components of scientific argumentation claim, evidence, reasoning, and rebuttal thereby supporting the development of logical, coherent, and evidence-based arguments.

Students' written responses were evaluated using the argumentation rubric developed by Luo et al., (2020a), which is based on the Structure of the Observed Learning Outcome (SOLO) Taxonomy. In this study, the RFS and the SOLO based rubric served complementary purposes: the RFS functioned as the instructional framework that guided students in constructing arguments, whereas the SOLO based rubric was used to assess the quality, coherence, and complexity of the arguments produced.

The argumentation test was situated within a socio-scientific context involving waste pollution in the Bengawan Solo River (Djoko Utomo et al., 2010). This context required students to apply their understanding of organic compounds to analyze an authentic environmental issue and construct scientifically justified arguments. During the assessment, students were instructed to use the

Reasoning Flow Scaffold that had been introduced during instructions to formulate their responses.

Prior to data collection, all research instruments including the argumentation skills test, student worksheets (LKPD), reflective journal prompts, interview protocols, observation sheets, the RFS framework, and the SOLO based scoring rubric underwent expert content validation by three validators, comprising two lecturers in organic chemistry and one lecturer in chemistry education from Universitas Negeri Jakarta. The validators evaluated the instruments for content relevance, conceptual accuracy, alignment with the learning objectives, clarity of language and instructions, and their suitability for measuring students' scientific argumentation skills. In addition, the alignment of the RFS with the intended argumentation components (claim, evidence, reasoning, and rebuttal) and the appropriateness of the SOLO based rubric for evaluating argument quality were specifically reviewed. Revisions were made based on the validators' recommendations to improve the wording, scaffolding sequence, and scoring criteria. Following these revisions, all instruments were considered valid and appropriate for use in the study.

The students' responses to the argumentation test were analysed using qualitative content analysis**.** Each response was first coded according to the four components of the Reasoning Flow Scaffold (RFS) claim, evidence, reasoning, and rebuttal to identify the completeness and quality of students' scientific arguments. The coding process examined the extent to which each argument contained a relevant claim, appropriate scientific evidence, logical reasoning linking the evidence to the claim, and a scientifically justified rebuttal.

Subsequently, the overall quality of each argument was classified according to the five levels of the Structure of the Observed Learning Outcome (SOLO) Taxonomy**:** Pre-structural, Uni-structural, Multi-structural, Relational, and Extended Abstract. The SOLO classification was used to evaluate the complexity and integration of students' scientific reasoning based on the relationships among the argument components identified through the RFS.

The classification criteria based on the SOLO Taxonomy are presented in Table 1(Toulmin, 2003). The distribution of students' argumentation levels was analyzed descriptively using frequencies and percentages, while qualitative analysis was conducted to identify patterns of students' reasoning and their ability to construct scientific arguments in response to the sociocentric issue.

**Table 1**. Criteria for Analysing Scientific Arguments Based on the SOLO Taxonomy

| **Level SOLO** | **Criteria Argumentation** |
|---|---|
| Pre-structural | Irrelevant, does not address the issue, no scientific claims or evidence |
| Uni-structural | Irrelevant, does not address the issue, no scientific claims or evidence |
| Multi-structural | Presenting several facts or claims, but not yet connected or integrated |
| Relational | The logical connection between claims, reasons, and evidence demonstrates understanding through arguments. |
| Extend abstract | Complex arguments, involving synthesis of concepts, reflective, and broad in scope |

## RESULTS AND DISCUSSIONS

This study examines students' scientific argumentation in socio-scientific issue (SSI)-based chemistry learning, analyzed through the lens of the SOLO Taxonomy framework develepoved by Biggs & Collis (Biggs & Collis, 2014). The research activities comprised the implementation of learning using an SSI approach, followed by instruction on argumentation and an argumentation test. These activities were conducted over four meetings: three meetings focused on teaching hydrocarbon topics using the SSI approach, and the fourth meeting covered argumentation instruction and testing. Data were collected through an argumentation skills test, reflective journals, interviews, student worksheets (LKPD), and observation sheets. The obtained data were divided into two main parts: (a) the implementation of the SSI approach in hydrocarbon learning, and (b) the analysis of students' scientific argumentation skills on hydrocarbon topics based on the SOLO taxonomy.

**The Implementation of the Socio-Scientific Issues Approach in Hydrocarbon Learning**

A socio-scientific issue (SSI) refers to a problem that generates disagreement or conflicting positions among stakeholders, bridging scientific knowledge and societal concerns (Sadler, 2004b). In this study, the SSI approach was employed to facilitate students' understanding of hydrocarbon concepts. The specific framework adopted was the socio-critical and problem-oriented model, which comprises five stages: (1) problem analysis, (2) clarification of the scientific background, (3) refocusing on the socio-scientific dilemma, (4) role-playing activities, and (5) a meta-reflective exercise (Marks & Eilks, 2009). The instructional implementation was conducted over four meetings, each consisting of four lesson hours, following the prepared lesson plans. The application of this five-stage approach is elaborated below."Problem Analysis.


Figure 1. Problem Analysis Activity

During the problem analysis stage, the researcher presents an issue related to the upcoming lesson, and the students listen to the teacher's introduction of the problem. At the start of each meeting, the researcher communicates the Basic Competencies and learning objectives, as informed by the observer's documented observations.

*"The teacher began the lesson effectively and introduced the learning outcomes and objectives for the lesson on alcohols and ethers".* (Observer 2, November 18, 2024)

*"The teacher began the lesson effectively and introduced the learning outcomes and objectives for the lesson on aldehydes and ketones".* (Observer 2, November 18, 2024)

*"The teacher began the lesson effectively and introduced the learning outcomes and objectives for the carboxylic acids and esters unit".* (Observer 2, November 25, 2024)

Following the introduction of learning objectives, the researcher presented problems related to the material to be taught and explicitly linked these problems to the content context. In each session, these connections were tailored to the specific topic, resulting in varied approaches for alcohols and ethers, aldehydes and ketones, and carboxylic acids and esters.

*"The teacher connected alcohols and ethers to a socio-scientific issue related to the current pandemic, highlighting that hand sanitizer production was being intensified due to high demand. The teacher explained that ethanol is the preferred ingredient for hand sanitizers because it is safer for both humans and the environment compared to methanol. However, some manufacturers still produce hand sanitizers using methanol, which is more hazardous to humans and the environment, due to its lower cost."*(Observer 1, November 18, 2024)

*"Next, the teacher presented a socio-scientific issue concerning formaldehyde: it is extremely dangerous if ingested, so it is untrue that formaldehyde (formalin) should be used as a food preservative. Nevertheless, because it is cheap and readily available, many food vendors or producers illegally use formalin to preserve their food products."*(Observer 1, November 25, 2024)

After that, the researcher gave students the opportunity to provide responses or ask questions related to the given problems. According to several students, the problems presented by the researcher were familiar and relevant to their daily lives, which enabled them to empathize with the issues. In addition, students also learned about the dangers associated with the presented problems.

*"I think this lesson was interesting because the case study discussed was quite familiar."* (Reflective Journal 2 – Student 10, November 18, 2024)

This finding aligns with Topcu (2010), who asserts that socio-scientific issues must be grounded in real-world community problems and should help students understand the associated dangers. Furthermore, Troy D. Sadler (2013) emphasizes that selected topics should be relevant and capable of capturing students' attention. In line with these criteria, three relevant and engaging issues were chosen for this study: the use of methanol in hand sanitizers, the use of formalin in food products, and detergent waste in rivers. All three topics satisfy the issue selection criteria proposed by Sadler (2013). Moreover, their integration into organic chemistry or carbon compound instruction is particularly appropriate given the nature of the subject matter, as they enable students to develop their chemical understanding across multiple dimensions of other scientific disciplines, consistent with the findings of Cha et al. (2020).

1. Clarification

At this stage, the researcher explains the material or concepts related to the given problem, and the students listen to the researcher's explanation. In the first session, the researcher first explains the concept of functional groups, followed by an explanation of various groups of carbon compounds. According to Solomons (Solomons, 2011), functional groups are arrangements of atoms within a carbon compound that confer predictability regarding a molecule's reactivity and properties. In the first session, the researcher provided a comprehensive explanation of alcohol and ether compound groups. Based on the results of this study, the students were able to distinguish between the alcohol and ether compound groups, as well as the hazards and uses of these compound groups, as shown in the students' responses below:

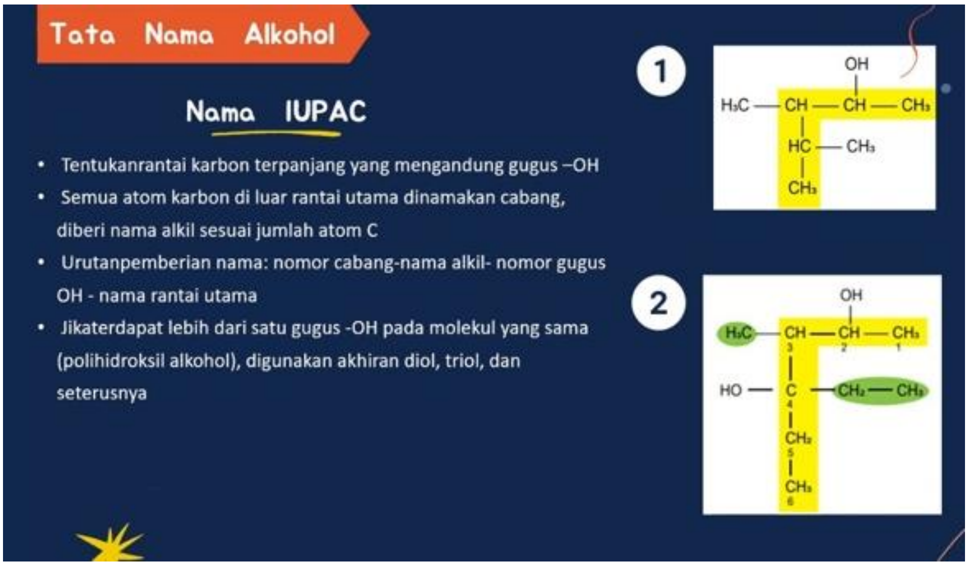

Figure 2. Clarification of the science Activity

*"They have different functional groups. In alcohol compounds, we find the –OH functional group. In ether compounds, we find the –O– functional group. Their names are also different: alcohol compounds end in –ol, and ether compounds end in –oxy/-ane."* (Reflective Journal 1—Student 14, November 18, 2024)

The students' responses align with the established characterization of carbon compounds: alcohols contain a hydroxyl (–OH) functional group, with one use in hand sanitizers, while ethers have the general formula R–O–R' (where R and R' are alkyl or aryl groups) (Wade, 2013). In the second session, the researcher explained aldehydes and ketones; students successfully distinguished between these groups and identified their hazards and uses. The same pattern held true for the third session on carboxylic acids and esters.

Based on the students' answers, their conceptual understanding of the aldehyde–ketone compound groups is quite good. This is evidenced by their answers, which align with the concept that the difference between aldehyde and ketone compounds lies in the alkyl groups bonded to the carbonyl group (C=O): the aldehyde compound group has one alkyl group bonded to the carbonyl group, whereas the ketone compound group has two alkyl groups bonded to the carbonyl group (Wade, 2013). Additionally, the naming of aldehyde compounds include the suffix -al, whereas ketone compounds include the suffix -on. In terms of reactivity, aldehyde compounds are relatively more reactive than ketone compounds (Solomons, 2011). However, when these two groups are compared to hydrocarbons, both are significantly more reactive. Regarding boiling point comparisons between ketones and aldehydes, ketones have relatively higher boiling points due to having more electron-withdrawing groups compared to aldehydes (Solomons, 2011).

Students also demonstrated the ability to identify both the benefits and hazards of aldehyde and ketone compounds. Based on the responses of 27 students, one identified product of the aldehyde group is formalin, which is useful as a non-food preservative but hazardous if ingested. Students' conceptual understanding of carboxylic acids and esters was also quite good; they were able to distinguish between these two compound groups and articulate their respective benefits and hazards. This is evidenced by the following student response:

*"Formic acid can be used as an antibacterial chemical, a pesticide, and a tanning agent; however, formic acid can be corrosive at high concentrations and produce hazardous fumes. Methyl butyrate itself can function as a flavoring agent in food."* (Reflective Journal 3 – Student 30, November 18, 2024)

The distinction made by the student aligns with the concepts regarding nomenclature, carboxylic acids are named by prefixing the word "acid" followed by the alkyl group with the suffix "-ate"(Solomons, 2011). For esters, which are derivatives of carboxylic acids, the naming consists of two words: the first word denotes the alkyl or aryl group bonded to the oxygen atom, and the second word denotes the alkyl group bonded to the carbonyl group.

2. Refocus on the Socio-Scientific Dilemma

At this stage, the researcher conducted a recall, revisiting the issues introduced at the beginning of the lesson for students to discuss, in accordance with the socio-scientific issue framework (Marks & Eilks, 2009)The researcher presents each topic to be discussed at every meeting; the first meeting focuses on the dangers of methanol in hand sanitizer, which relates to the alcohol and ether compound groups; the second meeting addresses the dangers of formalin in food; and the third meeting covers the hazards of detergent waste in rivers. Next, the researcher gave students the opportunity to ask questions or provide feedback regarding the issues to be discussed in the worksheets. Some groups asked questions related to the issues presented, but there were several groups that did not ask questions because they already understood the issues presented, as noted by the researcher below:

*"Some groups asked questions about the problems presented in the LKPD, but there were still a few groups that did not ask any questions".* (Researcher's note, November 18, 2024)

After the students provided their responses and asked their questions, the researcher instructed them to begin a discussion within their respective groups.

3. Role-Playing Task

At this stage, the students engaged in discussions to address the problems presented. The researcher observed the progress of the discussions in each group by moving from one group to another. During the discussion process, some groups actively discussed the problems together, while others assigned tasks to individual group members to be completed on their own.

*"So, we divide up the tasks among ourselves when working on them. Like, for example, the real experts handle the harder parts, and the others handle the simpler ones."* (Interview with student 19, January 13, 2025)

The discussion process lasted 35 minutes. After the discussion activity concluded, the researcher invited a representative from each group to present their discussion results. Based on the discussion results from each group over the course of three sessions, the following answers were obtained:

*"Detergent waste can lower the pH of water because sodium alkanesulfonate detergents are produced by reacting sulphur with acyl chloride to form potassium salts of sulfonyl chloride or sulfonic acid, which are acidic; when sodium sulfonate detergents react with water through hydrolysis, they produce free fatty acids and sulfonate compounds. These free fatty acids produce H+ ions, making the water's pH acidic."* (LKPD 3-K3, November 25, 2024)

Based on the answers from several groups on each worksheet, the students' answers align with the answer key provided in the worksheet. This indicates that the socio-scientific issue approach has helped students understand the concepts of carbon compounds, particularly those related to socio-scientific issues. Students not only grasp the concepts but also apply them to real-life situations.

Discussion activities and the review of discussions are activities that students greatly enjoy. This is because the discussion process allows students to validate the accuracy of their group's discussion outcomes regarding the given problems.

*"What I like is that there is a discussion and evaluation of the worksheets after they are completed, so we know what is missing from the worksheets we have done".* (Journal Reflection 1-PD16, November 17, 2024)

In addition, the researcher's discussion of the results was thorough and helped to deepen the students' understanding.

4. Meta-Reflective Activity

At this stage, the researcher invites the students to ask questions and reflect on what they have learned. The researcher then summarizes the learning that has taken place.

Based on the learning activities conducted, the students felt that learning through a socio-scientific approach was enjoyable. This was because the lessons were not monotonous, encouraged student engagement, and fostered interaction among students. Additionally, the explanations provided by the researcher were easy to understand, making the learning experience enjoyable.

*"The learning process was enjoyable, not monotonous, involved discussion, and was quite active and interactive between the mentor and the students being taught".* (Journal Reflection 1-PD8, November 17, 2024)

In addition to making learning less monotonous and more interactive, discussion activities also make learning more enjoyable. This is because the discussion process breaks up the monotony of learning and gives every group member the opportunity to exchange ideas and share their opinions on a particular issue.

"*It's exciting it makes it easier to understand because after the explanation, we have to process the information in the references ourselves. Plus, there are group discussions, so we can exchange ideas with our classmates. What I like most is that the discussions and learning are based on real-world issues that relate to our own lives. It really makes it easier to understand".* (Reflective Journal 1-PD31, November17, 2024)

**Analysis of Students' Scientific Argumentation Sills on Hydrocarbon Topics Based on the SOLO Taxonomy**

An argument is a specific statement made by one person to another regarding a subject in response to a statement (Copi & Cohen, 2014; Emeren et al., 1996). According to the PISA data, scientific argumentation is the ability to explain a phenomenon using a scientific approach, interpret the data obtained scientifically, and draw conclusions from it (OECD, 2023). There are several components of argumentation that have been modified and adapted for this study, namely: claim, evidence, rebuttal, and evidence (Luo et al., 2020a).

In this study, the researcher analyzed the four components of argumentation among 12th-grade MIPA 1 students using the SOLO taxonomy proposed by Biggs and Collis in 1982 (Lucander et al., 2010a) ; (Luo et al., 2020b). This taxonomy can be used to measure an individual's conceptual understanding based on five levels: (1) pre-structural, (2) uni-structural, (3) multi-structural, (4) relational, and (5) extended abstract (Biggs & Collis, 1982). The SOLO taxonomy was used to assess the quality of each student's scientific argumentation across each argument component. To assist students in constructing an argument, a scaffolding tool called the Reasoning Flow Scaffold, adapted from the research by Luo et al (2020), is used.

To analyze the quality of scientific reasoning among 12th-grade MIPA 1 students, a reasoning test instrument was used that had been validated by two experts a chemistry lecturer at Jakarta State University. The instrument was found to be aligned with the SOLO taxonomy framework proposed by Biggs and Collis (1982) and was considered appropriate for measuring students' scientific argumentation skills. The test was conducted during the fourth meeting of the research process. The researcher first presented material related to argumentation and how to construct arguments using the Reasoning Flow Scaffold framework. Next, students were asked to complete the argumentation test instrument to assess the quality of their arguments. Based on the students' responses to the argumentation test, the data shown in Figure 3 was obtained.

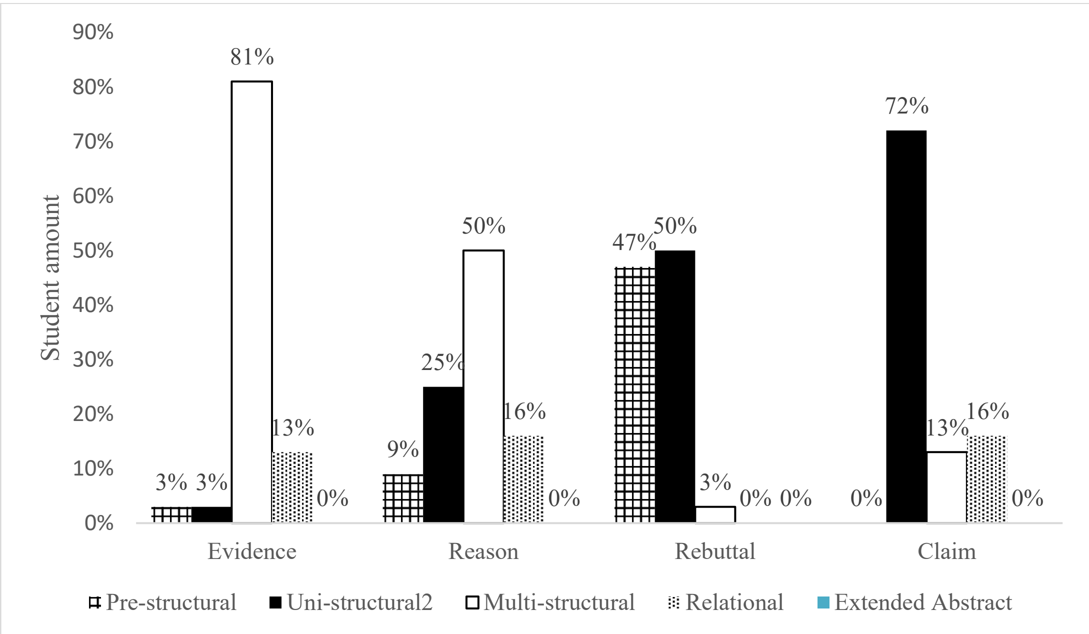


Figure 3. Scientific Argumentation Performance of Grade XII MIPA 1 Students

The analysis was conducted on 32 twelfth-grade students, and the classification results are presented in the percentage distribution of students' scientific argumentation components based on the SOLO taxonomy levels, as shown in Table 2. Based on Table 2, the percentage distribution indicates that most of the evidence components (81%) and reasoning components (50%) were categorized at the multi-structural level, while the claim components (72%) and rebuttal components (50%) were predominantly at the uni-structural level. No components were found to reach the extended abstract level (0%).


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Tabel 2. Distribution of Students' Scientific Argumentation Based on SOLO Taxonomy Levels

| Solo Level | Evidence | Reason | Rebuttal | Claim |
|---|---|---|---|---|
| Pre-structural | 3% | 9% | 47% | 0% |
| Uni-structural | 3% | 25% | 50% | 72% |
| Multi-structural | 81% | 50% | 3% | 13% |
| Relational | 13% | 16% | 0% | 16% |
| Extended abstract | 0% | 0% | 0% | 0% |

The analytical framework employed in this study integrates Toulmin's Argumentation Model (Toulmin, 2003) with the Structure of the Observed Learning Outcome (SOLO) Taxonomy developed by Biggs and Collis (1982). The integration of these frameworks is based on their complementary roles in assessing scientific argumentation. Toulmin's model provides a structural framework for identifying the essential components of an argument, namely claim, evidence, reasoning, and rebuttal, whereas the SOLO Taxonomy offers a hierarchical framework for evaluating the quality and cognitive complexity of each component. While Toulmin's model enables the identification of the elements that constitute an argument, it does not explicitly assess the depth of understanding reflected in those elements. Therefore, the SOLO Taxonomy was incorporated to evaluate how well students developed and connected their ideas within each argumentation component.

The analytical matrix was developed by mapping each Toulmin component onto the five SOLO levels: prestructural, unistructural, multistructural, relational, and extended abstract. This process was informed by the theoretical framework proposed by Biggs and Collis (Biggs & Collis, 1982) and adapted from previous studies that applied the SOLO Taxonomy to assess the quality of scientific reasoning and argumentation (Lucander et al., 2010b; Luo et al., 2020a). Within this matrix, each argumentation component was evaluated independently according to its level of cognitive complexity. Responses classified at the prestructural level contained irrelevant or absent ideas, whereas those at the unistructural and multistructural levels demonstrated one or multiple relevant ideas, respectively. Responses categorized as relational showed logical integration among ideas, while those at the extended abstract level reflected the ability to generalize, synthesize, and transfer understanding to broader contexts.

The integration of Toulmin's Argumentation Model and the SOLO Taxonomy provide a comprehensive approach to evaluating students' scientific argumentation by capturing both its structural and cognitive dimensions. Through this framework, students' arguments were analysed not only in terms of the presence of claim, evidence, reasoning, and rebuttal components but also in terms of the complexity, coherence, and sophistication of the ideas expressed within each component. Consequently, the analytical matrix enabled a more nuanced assessment of students' argumentation quality and provided a stronger basis for interpreting their levels of scientific reasoning.

1. Evidence

According to Toulmin (1958), as cited in (Erduran et al., 2004a), the evidence component refers to statements containing facts used to support a claim. The levels of students' argumentation for the evidence component in this study are presented in Figure 4.

Figure 4 illustrates the distribution of students' argumentation levels for the evidence component as follows: 3% of students were at the prestructural level, 3% at the unistructural level, 78% at the multistructural level, 16% at the relational level, and 0% at the extended abstract level.At the prestructural level, only 3% of students fell into this category. An example of a response is as follows:

*"Ethanol waste polluting the Bengawan Solo River can cause serious problems for the environment and human health."*. (Argumentation Test, Student 30)

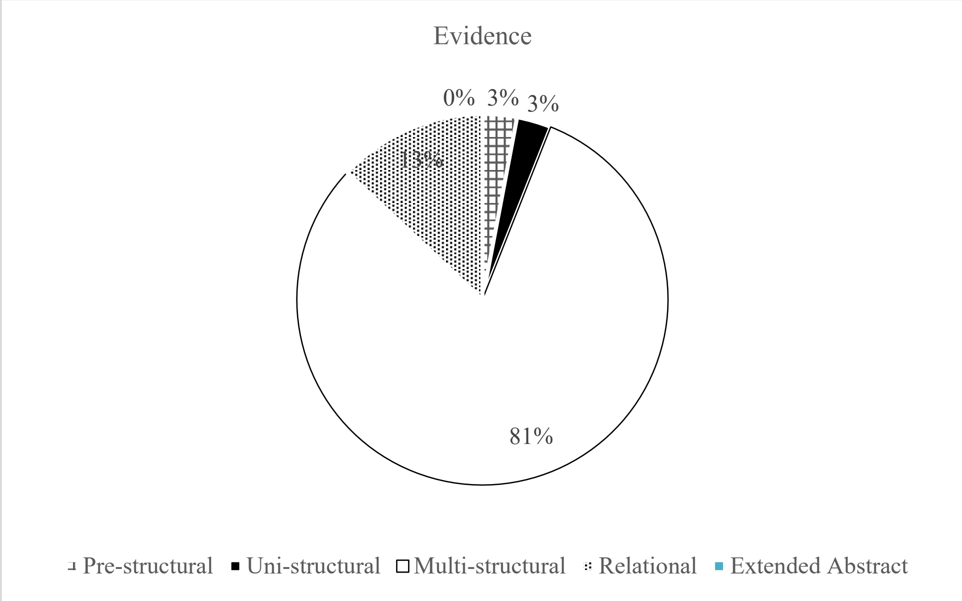


Figure 4. Distribution Chart of Students in the Evidence Component

The response provided by students 30 appears to be a claim rather than evidence, even though it is chemically accurate. According to Child et al. (2011), ethanol waste can indeed cause serious problems for both the environment and human health. Therefore, sudent's 30 answer is classified as prestructural because it is not relevant to the expected argument component (evidence). The percentage of responses at this level is slightly higher than that reported by Luo et al. (2020), which was 0%, indicating that most students in this study were already able to construct valid pieces of evidence within their arguments.

From a chemical standpoint, according to the New England Interstate Water Pollution Control Commission (2001), ethanol waste is toxic to living organisms and can cause acute poisoning in aquatic life, potentially leading to mass mortality events. This toxicity is not only due to the chemical nature of ethanol itself but also to the depletion of dissolved oxygen levels in water bodies, which further endangers aquatic ecosystems. Compared to Luo et al. (2020), where 41% of students reached higher levels of understanding, the results of this study indicate that only a few students were able to connect multiple chemical concepts to construct coherent and relevant pieces of evidence. Similarly, none of the students achieved the extended abstract level (0%), likely due to their limited depth of understanding of chemical concepts and insufficient ability to integrate interdisciplinary knowledge, resulting in difficulties connecting ideas across different scientific domains.

2. Reason

According to McNeill et al. (2006), as cited in Sampson et al. (2011), the reasoning component refers to statements that explain or justify a given piece of evidence. The distribution of students' argumentation levels for the reasoning component is presented in Figure 5.

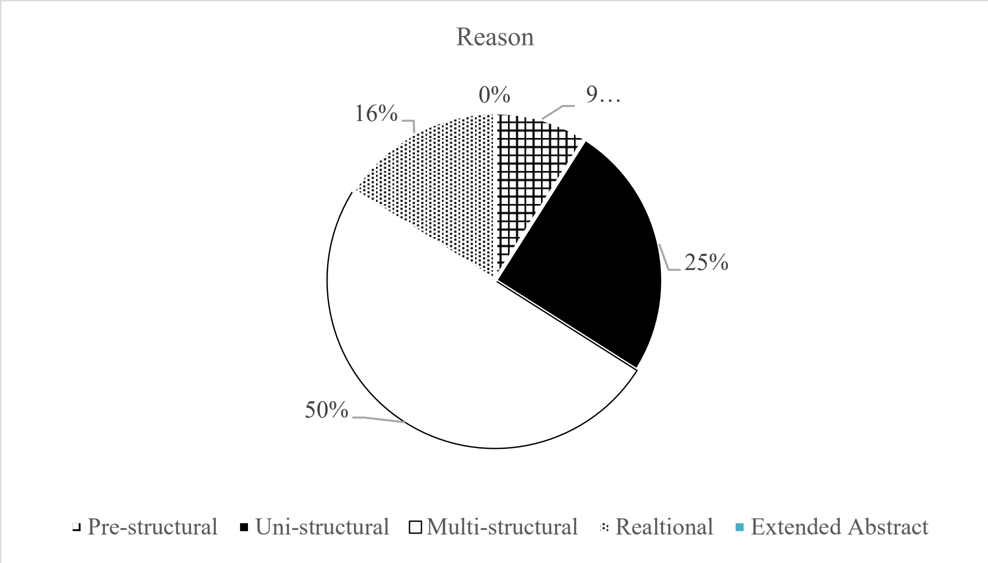


Figure 5. Distribution of The Reason

The diagram in Figure 5 shows the distribution of students' argumentation levels for the reasoning component as follows: 9% of students are at the pre-structural level, 25% at the uni-structural level, 50% at the multi-structural level, 13% at the relational level, and 0% at the extended abstract level. The highest percentage is found at the multi-structural level, with 50% of students. At the pre-structural level, only 9% of students are categorized in this group. The following is an example of a student's response at this level:

*"Ethanol is volatile and can dissolve easily when mixed with water."* (Argumentation Test, Student 12)

Conceptually, alcohols are volatile substances that can dissolve in water due to intermolecular interactions in the form of hydrogen bonding (Solomons, 2011). However, the response falls under the pre-structural level because the reasoning provided is not aligned with the evidence presented. The percentage of students at this level (9%) is slightly higher than that reported in Luo et al. (2020), which was only 2%. This small difference indicates that only a few students were unable to construct appropriate reasoning. At the uni-structural level, 25% of students reached this category, which is slightly higher than in Luo et al. (2020), where only 22% did. Meanwhile, 50% of students reached the multi-structural level, a higher proportion than the 42% reported by Luo et al. (2020). This suggests that the Reasoning Flow Scaffold framework effectively supported students in developing their reasoning skills, and that the XII MIPA 1 students demonstrated a solid ability to construct logical explanations.

At the relational level, 16% of students achieved this category, which is slightly lower than the 24% found in Luo et al. (2020). The relatively small number of students at the relational level and the absence of any reaching the extended abstract level may be attributed to students limited theoretical knowledge, as proposed by (Driver et al., 2000). Students may lack a deep conceptual understanding of carbon compounds and the interdisciplinary connections required for higher-level reasoning. Both the relational and extended abstract levels demand the integration of multiple concepts in organic chemistry as well as connections to other scientific disciplines. Additionally, carbon compound material is considered challenging because it requires multiple cognitive dimensions, such as memorization, visualization, problem-solving, and conceptual understanding (Austin et al., 2018). This also explains why none of the students reached the extended abstract level.

3. Rebuttal

According to Toulmin (1958), the rebuttal component refers to a counterstatement aimed at weakening or challenging an argument (Erduran et al., 2004b). Based on the findings of this study, the distribution of students' rebuttal responses in class XII MIPA 1 is presented in Figure 6 below:

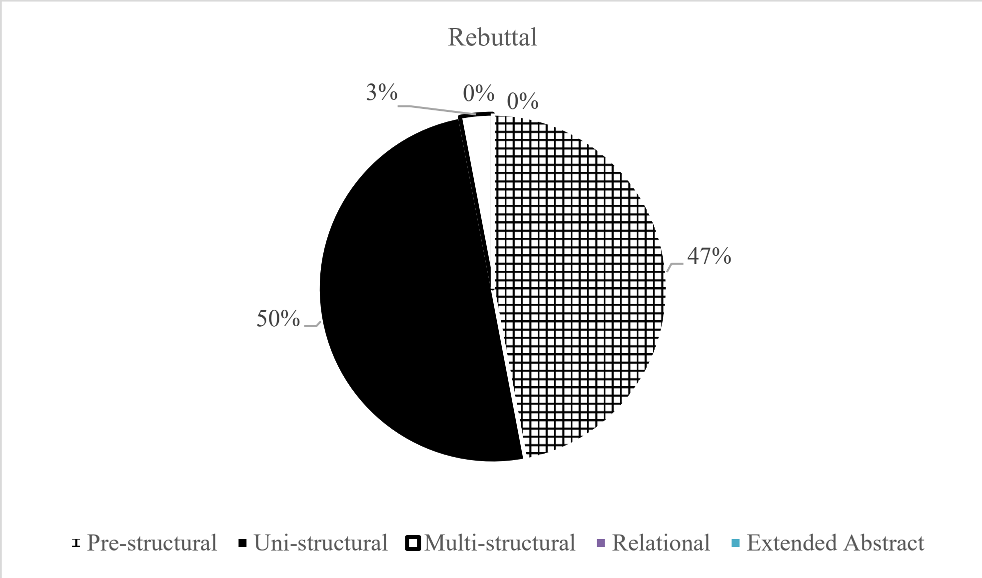


Figure 6. Distribution of Rebuttal

Based on the diagram in Figure 6, the interpretation of the argumentation levels demonstrated by students in Class XII MIPA 1 is as follows: 47% of students reached the prestructural level, 50% reached the unistructural level, 3% reached the multistructural level, and 0% reached both the relational and extended abstract levels. At the prestructural level, 47% of students fell into this category for the rebuttal component, which is significantly higher compared to Luo et al. (2020), where only 24% of students were at this level.The following is an example of a rebuttal response provided by one of the students:

*"Ethanol has antiseptic properties, meaning it can kill bacteria, fungi, and microorganisms. However, if used excessively, it can be harmful to the body, and if ethanol mixes with river water, it can cause aquatic organisms to be poisoned and die."* (Argumentation Test, Student 3)

The large number of students at this level occurred because the rebuttal component was considered the most difficult by the participants. This finding is supported by studies from (Clark & Sampson, 2007), (Katchevich et al., 2013), and (Yeh & She, 2010), which revealed that constructing rebuttals is even more challenging than formulating claims and supporting arguments without guidance. This is further reinforced by students' responses during interviews, where they expressed that developing rebuttals was particularly difficult.

*"Actually, finding claims and evidence is quite easy. But when it comes to finding the rebuttal, I get really confused. Like, from all the narratives in the worksheet, I don't really know which part could be the rebuttal."* (Interview with Student 1, January 7, 2025)

4. Claim

According to Toulmin (1958), a claim is a statement or assertion that represents an individual's position on a particular issue and serves as the central component of an argument(Erduran et al., 2004b). Further explain that a claim may take the form of an explanation, conclusion, or hypothesis that addresses a specific question or problem (McNeill et al., 2006; Sampson et al., 2011b). In scientific argumentation, claims reflect students' ability to formulate and communicate scientifically justifiable ideas. Therefore, analyzing the claim component provides valuable insights into students' scientific reasoning and argumentation skills. The distribution of students' responses for the claim component is presented in Figure 7.

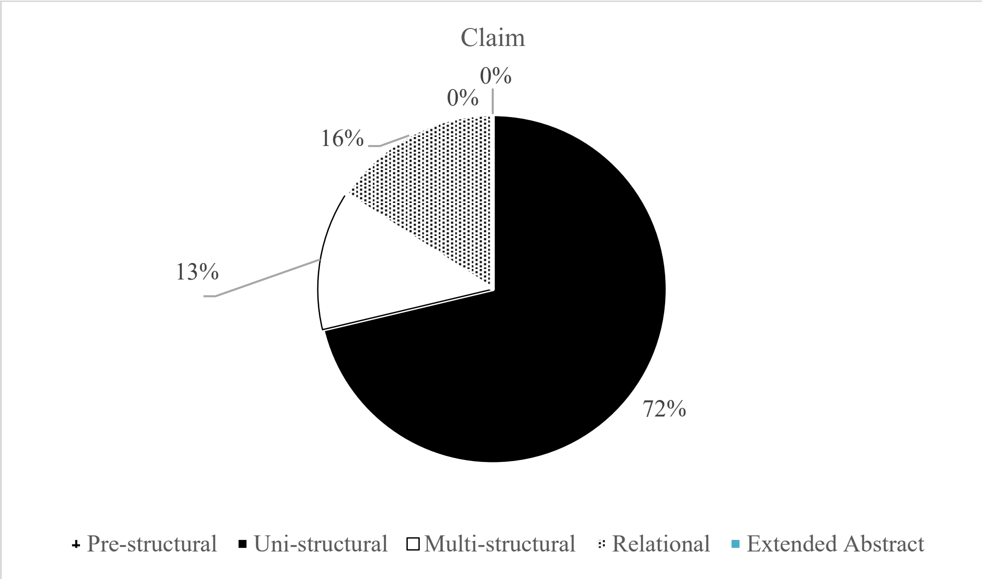


Figure 7. Distribution of Claim

Based on Figure 7, 0% of students reached the pre-structural level, 72% reached the unistructural level, 13% reached the multistructural level, 16% reached the relational level, and 0% reached the extended abstract level. These results indicate that the majority of students were at the unistructural level, suggesting that most of them still experienced difficulties in constructing well-developed claims.The following is an example of a student's response:

*"Human demand for ethanol-based products creates economic opportunities in the ethanol processing industry. However, waste generated from ethanol production can have serious consequences, as it may pollute the surrounding environment and cause significant harm. Therefore, both the community and the government must pay attention to this issue and develop effective waste management systems to minimize the risk of ethanol pollution."* (Argumentation Test, Student 10)

The response is categorized at the unistructural level, as the claim presented is singular but conceptually accurate and consistent with the supporting evidence, reasoning, and rebuttal. This finding is consistent with previous studies reporting that waste generated from ethanol-processing industries can adversely affect aquatic ecosystems and surrounding environments. According to the New England Interstate Water Pollution Control Commission (2001), excessive concentrations of ethanol in water bodies may reduce dissolved oxygen levels and contribute to fish mortality. Similarly, Nugroho et al. (2014) found that although ethanol is biodegradable, its accumulation in aquatic environments can negatively affect living organisms. Therefore, while ethanol waste may cause mass fish deaths, certain species, such as sucker fish, may exhibit greater tolerance and remain capable of surviving under such conditions. These scientific considerations support the student's claim and demonstrate a basic yet scientifically valid understanding of the environmental impacts of ethanol waste.

The relatively high number of unistructural responses indicates that students were only able to construct simple claims. This aligns with (Novak, 2002), who noted that it is difficult for individuals to change their perspectives or generate new claims within a short period of time. Similarly, Chang and Chiu (2008), who applied Lakatos' framework to evaluate students' written arguments on socio-scientific issues, found that it was challenging for students to alter their hard core that is, their initial claim over time. The findings of this study are consistent with these previous results, suggesting that strategies for helping students modify their claims require further exploration in future research (Chang & Chiu, 2008).

Based on the interpretation of students' argumentation quality across the four components, the majority were able to construct evidence and reasoning effectively, as indicated by their placement at the multistructural level. This success can be attributed to the use of the Reasoning Flow Scaffold (RFS), which supported students in developing coherent evidence and reasoning. However, for the rebuttal and claim components, most students were still at lower levels pre-structural for rebuttals and unistructural for claims. The difficulty in constructing rebuttals stemmed from students' limited ability to identify and formulate opposing arguments based on the test scenario or their own conceptual understanding. The low performance in the claim component is likely due to the extended time required to help individuals develop well-founded claims.

Nonetheless, none of the students achieved the extended abstract level across the four components. This may be due to a lack of deep conceptual understanding of carbon chemistry and related interdisciplinary knowledge. This finding supports (Austin et al., 2018), who argued that organic chemistry is a challenging subject because it demands multiple cognitive dimensions, including memorization, visualization, problem-solving, and conceptual understanding. Furthermore, the limited practice opportunities provided to students in constructing arguments using the RFS framework may have contributed to their difficulties in formulating claims and rebuttals. In this study, the argumentation session was conducted only once, giving students minimal experience in applying the RFS framework. This contrasts with Luo et al. (2020), whose study included four argumentation sessions one introducing the concept of argumentation and the RFS framework, and three practice sessions involving argumentation tasks. The higher frequency of practice in Luo et al.'s study gave students more experience in constructing arguments, resulting in a higher overall argumentation level compared to the present study.

To support students in achieving the extended abstract level within the SOLO taxonomy on hydrocarbon topics, teachers should implement continuous and structured learning activities that explicitly foster scientific argumentation skills through socio-scientific issues (SSI)-based instruction. Students should be regularly engaged in analysing authentic scientific issues related to hydrocarbons, such as fossil fuel consumption, plastic waste, environmental pollution, and sustainable energy, in order to encourage them to evaluate evidence critically, connect multiple scientific concepts, and construct well-reasoned arguments supported by scientific data. The integration of scaffolding strategies, including reasoning-flow scaffolds, argument mapping, guided inquiry questions, and collaborative discussions, can further assist students in developing more coherent, logical, and reflective arguments. Research by Luo et al. (2020) demonstrated that reasoning-flow scaffolds effectively improve students' scientific argumentation quality by supporting the development of claims, evidence, reasoning, and rebuttals within the SOLO taxonomy framework. Furthermore, recent studies have highlighted that sustained SSI-based learning promotes higher-order thinking, scientific literacy, and deeper conceptual understanding by enabling students to relate chemistry concepts to real-world contexts and evaluate issues from multiple perspectives. Through continuous argumentation practice, reflective writing, classroom debates, and scaffolded discussions conducted over several learning sessions, students are more likely to progress toward the extended abstract level, where they can generalize concepts, synthesize information across contexts, and formulate comprehensive scientific arguments independently.

## CONCLUSION

Based on the results of the argumentation test, the analysis revealed that most students were able to construct evidence and reasons effectively, as indicated by the majority reaching the multistructural level in these two components. This finding demonstrates that students were capable of presenting relevant evidence and logical reasoning concerning the environmental impact of ethanol waste and its effects on living organisms in polluted water ecosystems. Moreover, these results indicate that students had begun to integrate their understanding of hydrocarbon material with the socio-scientific issues discussed during instruction. However, students still encountered challenges in constructing claims and rebuttals. The majority were only able to formulate a single appropriate claim or rebuttal, placing them at the unistructural level according to the SOLO taxonomy. This difficulty in developing rebuttals stemmed from students' limited ability to identify and articulate opposing arguments. Similarly, the low performance on the claim component aligns with Novak and Treagust (2018), who explain that generating new claims or altering one's viewpoint within a short period of time can be inherently challenging.

The limitation of this study is the relatively low attainment observed in several components of students' scientific argumentation, particularly at the extended abstract level of the SOLO taxonomy. This finding may be influenced by the limited duration of the intervention, which was conducted in only a single instructional session. In contrast, previous studies have generally implemented SSI-based argumentation interventions across multiple and continuous learning sessions, allowing students more opportunities to develop higher-order reasoning, integrate scientific concepts, and construct more sophisticated evidence-based arguments. The development of advanced argumentation skills requires sustained practice, reflection, and repeated engagement with complex socio-scientific issues. Therefore, future research is recommended to implement continuous and structured argumentation practice through socio-scientific issues (SSI)-based learning over longer instructional periods to better support students in achieving the extended abstract level of the SOLO taxonomy.

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