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Using Scaffolding to Improve Grade 10 Students' Argumentation Skills on Green Chemistry

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Abstract

This study aimed to assess the impact of scaffolding instruction on the argumentation skills of 10th-grade students regarding green chemistry. Conducted in May 2023 at a public high school in Jakarta, Indonesia, the study employed a quasi-experimental design involving 72 students from two intact classes. These classes were divided into experimental and control groups. Students in the experimental group were instructed using scaffold learning with the MHC-C operator, while those in the control group followed conventional methods. The evaluation utilized scientific concept and argumentation assessments to gauge students' argumentation skills and the quality of their arguments. Independent and paired t-tests were employed to analyze differences and improvements in posttest scores between the two groups. The results of the t-test [$t = 2.06$; $p = 0.043$] revealed a disparity in posttest scores, with the experimental group demonstrating higher scores. Consequently, the data analysis suggests that the implementation of scaffolding instruction is more effective than conventional learning in enhancing students' argumentation skills regarding green chemistry.

Keywords: *Scaffolding, Argumentation Skills, Green Chemistry, MHC-C Operator*

INTRODUCTION

The current emphasis on argumentation skills within the realm of education is primarily due to its recognized significance in fostering students' comprehension of fundamental concepts, particularly in the realm of chemistry. It is widely agreed that the quality of education is determined by the extent to which students engage in active learning experiences (Lazonder & Harmsen, 2016; OECD, 2018). Active learning entails students' active involvement in the learning process, thereby facilitating meaningful learning experiences and enhancing the effectiveness of learning. Incorporating argumentative activities, such as argumentation, is a means to achieve this (Belland, 2011). Argumentation, often defined as the process of justifying a claim with evidence and reasoning (Toulmin, 1958), is crucial in this context. Indonesia's ranking of 73rd out of 78 countries in argumentation skills, as per data from the Program for International Student Assessment (PISA, 2018), underscores the relatively low proficiency of Indonesian students in this area. A significant barrier to implementing argumentation is students' insufficient understanding of its principles. Toulmin (1958) outlined six elements of a realistic argument: claim, data, warrant, backing, qualifier, and rebuttal. However, students commonly perceive argumentation merely as an evaluative tool rather than as a means of constructing knowledge (Foutz, 2018). Consequently, the inadequacy of students' argumentation skills can significantly impact their abilities and learning habits.

LITERATURE REVIEW

Argumentation Skills

Argumentation involves the alignment of evidence and reasoning to bolster a claim, a skill deemed crucial for the functioning of a democratic society (Fancourt et al., 2021). Widely defined as the substantiation of claims through evidence and reasoning, argumentation is acknowledged as a fundamental skill to cultivate in schools, facilitating both personal growth and a comprehensive understanding of the scientific subjects studied (Monte-Sano, 2016).

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Toulmin's method (1958) delineates the framework of an argument, comprising various components such as claim, evidence, justification, qualification, and rebuttal. While argumentation is commonly understood as the process of substantiating claims with evidence and reasoning, it's acknowledged that constructing and evaluating arguments across different scientific disciplines necessitates slightly nuanced yet complementary argumentation skills (Osborne et al., 2016). These skills can be honed within school settings across various subjects where argumentation serves as a disciplinary practice (Wolfe, 2011). Janik et al. (1979) propose a pattern, known as the Toulmin Argumentation Pattern (PAT), to evaluate students' constructed arguments, which encompasses six elements: claim or statement, data as the foundation for the claim, warrant as the linkage between data and statements, backing as fundamental assumptions to reinforce the explanation, refutations to identify statements determining when a claim is false, and qualifications setting conditions under which the claim holds true.

Engaging students in argumentation processes, whether individually or collaboratively, offers valuable experience and insight into the theory development process. Ilya et al. (2003) assert that student-centered activities, such as argumentation, play a crucial role in fostering scientific knowledge. Argumentation is widely acknowledged as a critical skill for students to acquire in school, facilitating the cultivation of critical thinking and a profound comprehension of the subject matter under study (Monte & Sano, 2016).

Scaffolding

Lantof and Thorne (2006) characterize scaffolding as a concept centered on both the student and teacher, serving as a support mechanism until the student attains the desired abilities relevant to the given task or problem. Guerrero and Villami (2000) define scaffolding in alignment with Vygotsky's notion, emphasizing how adults introduce children to cultural knowledge. This approach involves supportive actions by more knowledgeable individuals (teachers) during interactions with learners, thereby facilitating learning progress. Nguyen (2013) investigated the impact of expert colleagues' interaction with students in the learning process, highlighting how scaffolding can create a learning environment where expert colleagues provide support to students, guiding them until they achieve their competency objectives. This assistance aids students in overcoming various challenges encountered while completing assignments or problem-solving tasks. In summary, the scaffolding method guides students to accomplish assignments more effectively compared to independent work. Scaffolding teaching entails teacher guidance tailored to students' individual needs (Wood et al., 1976).

The aim of this method is to foster student independence in completing meaningful tasks. Zimmerman (1990) suggests that teachers should adopt an instructional approach when guiding students to become independent learners who have mastered the cognitive skills they aim to achieve. The underlying principle of scaffolding teaching is that as students progress in their learning, they become increasingly independent, enabling them to take responsibility for their own learning or assignments. However, it's important to note that scaffolding teaching varies depending on the context, students' abilities, and the cognitive objectives to be attained (Salmon, 2011). Students require guidance from scaffolding teaching to enhance the quality of their argumentation. This is because scaffolding teaching can train students to generate arguments based on their own thoughts, derived from constructing and interpreting collected data. Typically, in the argumentation process, students tend to echo existing arguments rather than formulate their own (Jimenez-Aleixandre, 2000). Additionally, scaffolding teaching aids in directing students' arguments towards the specified problem. Often, in the argumentation process, students rely on emotional arguments, leading to a "win-lose" debate scenario, where they attempt to refute opponents' arguments to demonstrate the superiority of their own, often by presenting overly broad issues that detract from the intended focus of the problem (Belland et al., 2015). Consequently, scaffolding teaching emerges as a learning method that effectively enhances students' argumentation skills (Weng et al., 2017).

Research Question

This research was conducted to determine the influence of scaffolded instructions on students' argumentation skills in chemistry subject. Therefore, the research question is: "Does the implementation of scaffolding teaching influence students' argumentation skills regarding the topic of green chemistry?".

METHODOLOGY

Research Design

This study employed a quantitative method utilizing a quasi-experimental design. A quasi-experimental design is a quantitative research approach wherein researchers test a hypothesis by manipulating independent variables to observe their effects on dependent variables (Creswell, 2002).

Research Sample

The research sample comprised 72 grade 10 students, approximately aged between 16 to 18 years old, consisting of 33 males and 39 females. These students were selected from the same school and grade level, specifically grade 10, at a state high school in Jakarta, Indonesia, during the 2022/2023 academic year. The sample was divided into two groups: the experimental group (EG), assigned from class X-7, and the control group (CG), assigned from class X-6.

Instruments

Scientific Concept Assessment (SCA)

A second-level multiple-choice diagnostic instrument, known as a two-tier test, was developed for this research. In this test, the first level presents a question with five answer choices, while the second level provides five reason choices that correspond to the answers in the first level. This instrument aimed to assess students' comprehension of concepts related to green chemistry topics. The SCA (Second-level Choice Assessment) includes 20 questions; however, one question was found to be invalid during the validity test. Therefore, only 19 questions were utilized in this study, covering theoretical concepts and hypotheses. Students received one point for each correct answer and corresponding reason. Thus, the highest achievable score for students is 19, while the lowest score is 0. The estimated processing time for completing the test is 45 minutes. Through reliability calculations, the SCA instrument yielded a Cronbach's alpha value of 0.84.

Scientific Argumentation Assessment (SAA)

An open scenario-based instrument, termed the SAA (Scenario-based Argumentation Assessment), was created to evaluate students' proficiency in argumentation concerning green chemistry concepts. The SAA incorporates picture and scenario-based argumentation inquiries. This instrument comprises 6 hypothesis argumentation questions. An illustrative example is provided below:

> *"Since July 1, 2020, the DKI Jakarta Provincial Government has banned the use of single-use plastic bags. This prohibition is contained in Gubernatorial Regulation Number 142 of 2019 concerning the obligation to use environmentally friendly bags in shopping centers, supermarkets, and public markets. As an alternative, shops provide shopping bags such as tote bags and biodegradable plastic, but there are still many shops that provide conventional plastic because it is considered more practical." (https://megapolitan.kompas.com/)*
>
> *Based on the green chemistry that has been studied, if you were a consumer in a shop, which container would you choose (a) conventional plastic, (b) tote bag, or (c) biodegradable plastic? Give your argument according to Toulmin's argumentation pattern!"*

The researchers modified instruments developed by prior researchers, specifically those by Weng et al. (2017), to suit the SAA instrument. Consequently, the researchers also adopted the existing Cronbach's alpha value, which was reported as 0.92. Additionally, in the calculation of the Content Validity Index (CVI), a value of 1 was obtained, indicating high content validity for the instrument.

Argumentation Analysis Framework

In this research, an analytical framework is employed to evaluate both the quality and quantity of arguments produced for each question within the SAA (Scenario-based Argumentation Assessment). This framework serves as a structured approach to systematically assess the arguments put forth by students in response to the SAA questions.

MHC-C Operator

The MHC-C operator represents a form of teacher guidance provided to students. The instructions conveyed through this operator are tailored to align with the students' abilities and activities, which will subsequently be integrated into the assignments provided (Bernholt et al., 2016; Bernholt & Parchmann, 2011).

Table 1. MHC-C Operators (*Model of Hierarchical Complexity in Chemistry*)

Level	Operator	Level of Complexity
1	Everyday facts	Mention everyday problems
2	Name/Mention	Fact
3	Describe	Process description
4	Explain	Empirical univariate & multivariate and logical causality

Procedure

The research was conducted over the same duration for both the CG and EG. The research spanned 4 weeks of learning, with each week allocating 90 minutes for activities. The difference lay in the instructional approach: the EG utilized the scaffold method with MHC-C operators, while the CG employed the lecture method. Prior to commencing research activities, the teacher provided both groups with an explanation of the research's purpose and the planned activities. Furthermore, the researchers elucidated Toulmin's (1958) argumentation method and underscored the significance of problem comprehension. Specifically, students were introduced to the following aspects: (a) the definition of a claim, data, warrant, backing, qualifier, and rebuttal; (b) the interrelation between these components; and (c) the process of constructing a high-quality argument according to Toulmin's six elements (1958). Subsequently, a pretest was administered, followed by problem discussions, presentations, and concluding with a posttest.

Data Analysis

Data analysis involved statistical tests aimed at observing improvements in argumentation skills, preceded by prerequisite tests including the normality test using the Kolmogorov-Smirnov test and the homogeneity test using the Levene test. Since the assumption tests were met ($p > 0.05$), parametric statistics were employed for data analysis using the *t*-test through SPSS 25 software. The *t*-test was utilized to ascertain whether statistically significant differences existed between the average values of the two groups. Both independent *t*-tests and paired *t*-tests were conducted in this study. Additionally, Cohen's *d* effect size was calculated to assess the magnitude of the statistical impact of learning methods, with values > 0.20 indicating a small effect, > 0.50 indicating a medium effect, and > 0.8 indicating a large effect (Cohen, 2007).

RESULTS

Based on Table 2, the obtained significance value is 0.043, which is lower than the significance threshold of 0.05. This indicates a statistically significant difference in argumentation skills scores between students in the EG and CG after the treatment. Additionally, a paired sample *t*-test was conducted in this study to analyze whether there was an improvement observed after the treatment was administered in both groups.

Table 2. Independent sample *t*-test results

	Group	N	M	SD	*t*	*p*
Pretest	EG	36	5.17	3.238	0.35	0.973
	CG	36	5.14	3.571		
Posttest	EG	36	7.39	3.620	2.06	0.043
	CG	36	5.50	4.144		

According to Table 3, the significance value for both the pretest and posttest in the EG is 0.000. As this value is less than 0.05, it indicates a statistically significant increase in argumentation skills scores among students in the EG after employing scaffolding teaching. Additionally, the effect size calculated for the EG is 0.530, which signifies a medium effect size, indicating a substantial impact of scaffolding teaching on enhancing students' argumentation skills.

Table 3. Paired sample *t*-test results

Group		N	M	SD	*t*	*p*	Cohen's *d*
EG	Pretest	36	5.17	3.238	-7.021	0.000	0.530
	Posttest	36	7.39	3.620			
CG	Pretest	36	5.14	3.571	-1.243	0.222	0.009
	Posttest	36	5.50	4.144			

DISCUSSION

This research aimed to enhance the argumentation skills of grade 10 students regarding green chemistry using scaffolding teaching. Based on the analyzed research data, there was no discernible difference in the average scores between the experimental group (M = 5.17; SD = 3.238) and the control group (M = 5.14; SD = 3.571) before the learning process commenced. Table 2 illustrates that there was no statistically significant difference in the pretest average scores between the experimental group and the control group [$t = 0.35$; $p = 0.973$]. This suggests that students from both classes possessed similar initial abilities before the treatment. Researchers observed that in the pretest responses, a majority of students tended to answer incorrectly on the second-level choices, specifically the reasons part corresponding to the first-level answers, resulting in zero points. This implies that while students understood the questions pertaining to green chemistry, they struggled with providing the underlying reasons for their chosen answers.

After the learning process, there was indeed a disparity in the average scores between the EG (M = 7.39; SD = 3.620) and the CG (M = 5.50; SD = 4.144). Both groups exhibited an increase in scores, but the EG demonstrated a more substantial increase (2.25 points) compared to the CG (0.36 points). Statistically, there is a significant difference in mean values between the EG and CG [$t = 2.06$; $p = 0.043$]. Moreover, besides the posttest scores, differences in the quality of argumentation were observed between the EG and CG, as assessed by the SAA instrument using the argumentation analysis framework.

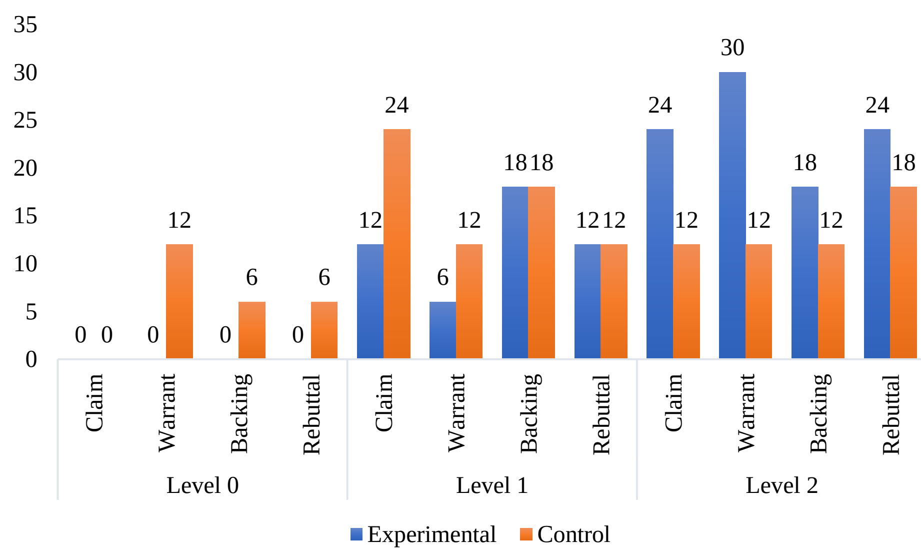

Figure 1. Quality of Student Argumentation

Based on Figure 1, discernible differences exist in the quality of arguments provided by students in the EG and CG. Students structured their arguments based on the Toulmin argumentation model, comprising six elements:

claim (c), data (d), warrant (w), backing (b), rebuttal (r), and qualifier (q). However, the researcher's evaluation focused solely on four elements: claim, warrant, backing, and rebuttal. The data elements were excluded from the assessment as they are considered supplementary information aimed at bolstering the argument's quality, while the qualifier elements represent conclusions drawn from other argumentation elements. Figure 1 elucidates the quality of students' arguments based on the assessment of each element of the Toulmin argumentation structure provided by students from both groups.

The quality of arguments in the EG surpassed that of the CG. Through calculations, the EG obtained a higher argument quality score of 6.67 compared to the CG's score of 4.83. The rationale behind the higher argument quality score in the EG can be observed in Figure 1. In the EG, a greater number of samples provided arguments conforming to the Toulmin structure at a high level compared to the CG. At level 2, the EG exhibited more dominant numbers of students in elements such as claim (c = 24), warrant (w = 30), backing (b = 18), and rebuttal (r = 24), whereas the CG showed lower numbers (c = 12, w = 12, b = 12, r = 18). Conversely, at level 1, the CG demonstrated a more dominant presence in the claim and warrant elements (c = 24, w = 12, b = 18, r = 12) compared to the EG (c = 12, w = 6, b = 18, r = 12).

Through data analysis, the influence of learning methods is evident from Table 3, particularly the significance value of the paired sample *t*-test for comparing pretest and posttest scores in the EG ($p = 0.000$). This value signifies a significant increase in argumentation skills within the experimental group. Therefore, it can be concluded that the application of scaffolding teaching has a substantial impact on students' argumentation skills. Additionally, based on calculations using Cohen's *d* formula, the effect size value derived from applying scaffolding teaching is 0.530, indicating a medium effect size. This further underscores the efficacy of scaffolding teaching in enhancing students' argumentation skills.

The disparities in argumentation skills between the EG and the CG may stem from differences in student activity levels during the learning process. Throughout the learning process, the experimental group typically exhibits higher levels of engagement compared to the control group. This contrast in activity levels becomes apparent during both the learning and argumentation phases. Specifically, the variation in student activity during the argumentation process is evident from the escalating number of arguments in the experimental group. For instance, in group 1, there was one argument, which then increased to two arguments in groups 2 and 3. Subsequently, the number of arguments surged to four in group 4, and peaked at six in groups 5 and 6. Conversely, in the control group, the number of arguments tends to remain stagnant, with only one or two students providing arguments in each group. There was even one group in the control group where no arguments were presented at all. Hence, it can be inferred that there are notable distinctions in the learning atmosphere between the two classes. In the experimental group, active learning prevails, whereas in the control group, passive learning predominates.

Active learning fosters greater student engagement in the learning process, leading to the acquisition of meaningful learning experiences and ultimately enhancing the effectiveness of learning (Belland, 2011). In the EG, increased student activity may be attributed to the influence of scaffold guidance provided by researchers. This guidance likely instills confidence in students, enabling them to feel assured when formulating and presenting arguments. The sense of self-assurance among students is known to have a positive influence on the quality of arguments they provide (Angeli & Valanides, 2014).

Students' self-confidence in the EG may have been established from the outset of scaffold learning implementation. At the beginning of the lesson, researchers presented several videos addressing common environmental issues encountered in daily life. Students were prompted to articulate their arguments regarding these environmental problems. Researchers employed MHC-C operators to guide students through the argumentation process at appropriate stages, progressing sequentially from Level 1 to Level 4. Notably, not all students reached Level 4, as evidenced by a decline in the number of students responding at each level. During the initial learning phase, the majority of students were able to provide responses up to Level 2. Consequently, students in the EG required additional guidance to attain Levels 3 and 4. However, even in this initial stage, student activity was evident, with the majority of students engaging at Levels 1 and 2. This heightened activity can be attributed not only to scaffold guidance but also to the influence of the environmental problem videos presented. The environmental issues depicted in the videos resonated with students' daily lives, enabling them to draw upon personal experiences or prior knowledge when formulating arguments.

The scaffold guidance process extends into the discussion phase when tackling open problems presented in the SAA instrument. Open problems are tasks that students often find challenging because they require a structured approach and step-by-step completion, rather than mere theoretical memorization of facts (Parish, 2014). During these discussions, researchers continue to guide each group using the MHC-C operator. Notably, students' self-confidence tends to increase significantly during these discussions compared to the initial meeting. This is evident from the majority of group members actively attempting to respond to questions posed by the MHC-C operator provided by the researchers. Based on these observations, it can be inferred that the application of the scaffold method contributes to an increase in students' self-confidence, thereby enhancing their argumentation skills. This enhancement stems from students' perception that they can effectively tackle challenging problems through the structured stages (MHC-C operators) provided by researchers (Bernholt et al., 2018).

The argumentation process is fundamentally a socially constructed activity, wherein students collaborate in groups to construct, clarify, and negotiate their understanding of the discussed issues (Weng et al., 2017). The combination of students' high self-confidence and the gradual guidance provided by scaffolding teaching likely contributes to the high quality of argumentation observed in the EG. The continuous provision of scaffold guidance is crucial in nurturing students' ability to generate high-quality arguments. Students feel empowered and motivated when they can navigate through each stage of the scaffold, progressing from lower to higher levels of proficiency (Belland, 2011; Sherin, 2004).

On the contrary, the lack of student activity in the learning process within the CG resulted in no observable improvement in argumentation skills. Consequently, the learning process became passive for the control group. It's widely acknowledged that the learning methods employed significantly influence student activity levels (Sjostedt, 2015). In the case of the conventional method, typically characterized by lectures, the emphasis is placed on one-directional activity, primarily from the teacher's perspective (teacher-centered). In this scenario, students predominantly receive information passively, merely listening to the teacher's explanations and assuming their correctness. Consequently, students may lack curiosity and the inclination to ask questions. This passive learning environment can lead to a decrease in students' self-confidence, as they may not feel adequately supported (Cecil et al., 2021).

The passive learning atmosphere observed in the CG can be attributed to the absence of gradual guidance provided by researchers, specifically through the use of the MHC-C operator in the problem-solving process. In contrast to the experimental group, where scaffold guidance was implemented, the control group received instructional guidance focusing solely on the green chemistry material. This traditional instructional approach primarily emphasizes rote memorization of scientific facts, which may hinder students' ability to effectively tackle open-ended problems (Hong et al., 2013). Consequently, there was no observed improvement in argumentation skills among the control group sample. This elucidation underscores the effectiveness of scaffold teaching, particularly through the provision of MHC-C operators, in bolstering students' confidence in solving challenging problems, such as open-ended arguments. Thus, it can be inferred that scaffold teaching is indeed effective in enhancing the argumentation skills of grade 10 students.

CONCLUSION AND SUGGESTION

Based on the research findings and discussions, it is concluded that scaffolding teaching significantly impacts the argumentation skills of 10th-grade students at a public school in Jakarta, Indonesia, when compared to conventional learning methods. Scaffolding teaching plays a crucial role in enhancing students' self-confidence during the learning process, thereby fostering an active learning environment. By providing MHC-C operators, scaffolding teaching encourages student engagement, leading to increased confidence in answering questions and a heightened curiosity to achieve higher levels of proficiency. Active participation in class allows students to express their ideas through argumentation, thereby improving their argumentation skills. Furthermore, scaffolding teaching guides students in generating high-quality arguments, aligning with Toulmin's argumentation structure. The impact of scaffolding teaching in the EG is evident from the significant increase in average scores, rising from 5.17 in the pretest to 7.39 in the posttest. Additionally, the quality of arguments in the EG surpasses that of the CG, with the EG obtaining an argumentation quality score of 6.67 compared to 4.48 in the CG. These results underscore the efficacy of scaffolding teaching in enhancing students' argumentation skills and promoting active engagement in the learning process.

This research encountered several limitations that warrant consideration. Firstly, time constraints restricted the research process to a duration of only 4 weeks. It is recommended that future researchers extend the research period to obtain more comprehensive results. Additionally, the data collected in this study solely comprised student grades, which may not fully capture the nuances of students' learning experiences. Future research endeavors could benefit from incorporating qualitative data, such as interview results, by adopting a mixed-methods approach. This would offer a more thorough understanding of the impact of scaffolding teaching on students' argumentation skills. Furthermore, this study focused exclusively on the effects of scaffolding teaching on students' argumentation skills within the context of green chemistry topics. Future researchers are encouraged to explore the applicability of scaffolding teaching across a broader spectrum of chemistry learning topics or other academic domains. By diversifying the scope of the investigation, researchers can gain insights into the generalizability and efficacy of scaffolding teaching methods. Addressing these limitations will contribute to the advancement of knowledge in the field of education and instructional practices.

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