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Exploring Students' Scientific Explanation Skills on the Circulatory System Topic: A Preliminary Study

Ita Yuliastuti [a, 1], Aripin [a, 2, *], Liah Badriah [a, 3], Diana Hernawati [b, 4]

[a] Program Magister Pendidikan IPA, Pascasarjana, Universitas Siliwangi, Tasikmalaya-Indonesia
[b] Program Pendidikan Biologi, Fakultas Keguruan Ilmu dan Pendidikan, Universitas Siliwangi, Tasikmalaya-Indonesia
[1] yuliastutiita6@gmail.com; [2] aripin@unsil.ac.id; [3] liahbadriah@unsil.ac.id; [4] hernawatibiologi@ac.id
* Corresponding author: aripin@unsil.ac.id

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ABSTRACT

Scientific explanation skills are a key competency in science education that supports students' ability to construct evidence-based scientific explanations. However, various studies indicate that these skills have not yet developed optimally in biology education. This study aims to explore the preliminary profile of high school students' scientific explanation skills regarding the circulatory system. The study employed a descriptive quantitative approach involving 73 twelfth-grade students in two classes at a high school in Tasikmalaya. The research instrument consisted of a scientific explanation skills essay test developed based on the components of claim, evidence, reasoning, and rebuttal. Data were analyzed using quantitative descriptive analysis by calculating the percentage of achievement for each component. The results showed that students' scientific explanation skills were still in the "insufficient" category, with an average achievement score of 58.64 in the first class and 55.26 in the second class. The "evidence" and "claim" components showed relatively higher achievement levels than "reasoning" and "rebuttal." The low achievement levels in the "reasoning" and "rebuttal" components indicate that students still struggle to connect empirical evidence with scientific concepts logically and to evaluate alternative explanations critically. This study makes an initial contribution to describing the characteristics of students' scientific explanation skills in high school biology lessons on the circulatory system. It provides a foundation for developing learning strategies based on scientific activities and scientific argumentation. Further research is recommended to test the effectiveness of various inquiry-based, scientific argumentation, and technology-integrated learning approaches in improving students' scientific explanation skills.

Keywords: Scientific Explanation Skills, Biology Instruction, Circulatory System, Initial Profile

Introduction

Education is a vital pillar that facilitates Indonesia's journey toward a prosperous future (Izza & Andrijati., 2024). One aspect of education instilled in Indonesian students is science education. In line with Berland and Reiser (2009), the goal of science education is to encourage students' participation in scientific practice; therefore, our understanding of explanations must expand to include the process of constructing them. One way to strengthen science education is to implement science instruction in schools. The Natural Sciences (IPA) subject in schools equips students with science learning experiences. Broadly speaking, Natural Sciences is divided into three branches: biology, physics, and chemistry (Sholihat & Anwar, 2023). Biology, as one of the main branches of natural sciences, not only focuses on the study of life phenomena but also requires students to interpret and explain various natural processes scientifically (Hidayati & Nurmawati, 2025). Students' explanations are expected to be scientifically grounded.

A scientific explanation is an explanation based on scientific facts that explains a phenomenon (Osborne & Patterson, 2011). A scientific explanation describes the product of science by detailing the processes, causes, and reasons behind a phenomenon (McNeill & Krajcik, 2009). This aligns with research conducted by Nurmatin and Aini (2024), which explains that scientific reasoning is crucial to strengthen in schools. This perspective indicates that scientific explanations play a vital role in building a comprehensive scientific understanding, rather than merely memorizing facts. Science education researchers and curriculum developers acknowledge that constructing scientific explanations is one of the primary epistemic practices students need to master (Acebes & Keith, 2024). A scientific explanation is a description used to answer why an event occurs or what causes a phenomenon in science (Ningsi et al., 2019). Mastery of scientific explanation skills is expected not only to foster theoretical understanding of scientific concepts but also to enable students to relate those concepts to real-world phenomena, interpret data accurately, and construct valid, logical scientific arguments.

In this study, scientific explanation skills were constructed based on the scientific argumentation framework developed by McNeill and Krajcik, which is rooted in Toulmin's Argument Pattern (TAP) theory. This framework states that scientific explanation skills are built through the relationship between a claim as the main statement, evidence as supporting data, and reasoning as the logical link between the two (McNeill & Krajcik, 2008). Developing scientific explanation skills includes adding rebuttal: the ability to propose alternative explanations, supported by evidence and reasoning that show those explanations are inaccurate (Mcneill & Krajcik, 2012). Recent studies have linked arguments that challenge a claim to "counterarguments," while responses that challenge counterarguments are now considered "rebuttals" (Chuang & Yan, 2022). These four components work together to form a coherent and logical scientific explanation.

Students' skill development has not yet matched the urgency of mastering these four components. Various research findings indicate that students' scientific explanation skills remain unsatisfactory. Students still face various challenges, even in classroom learning contexts where scientific explanations have been explicitly presented (Mardhiyyah et al., 2022). Students often struggle to articulate and defend their knowledge claims; they frequently have trouble coordinating their claims with their evidence (Parnafes, 2012). Previous research indicates that students face the greatest difficulty in applying scientific principles to explain why the evidence they use supports their claims (McNeill et al., 2006). This aligns with earlier findings showing that most students struggle to connect empirical data to scientific concepts to construct logical arguments (Laksmi, 2021). This suggests that science education in schools emphasizes conceptual understanding and rote memorization more than developing deep scientific thinking skills. Findings from several similar studies show that the level of scientific explanation remains low, and students' reasoning still fails to provide concrete evidence from natural phenomena to support their claims (Widiana et al., 2024). Students tend to act as passive recipients of information, without actively engaging in formulating claims, identifying evidence, and developing reasoning that connects the two within a scientific conceptual framework (Tang & Putra, 2018).

This tendency indicates that the four components of scientific explanation skills have not developed in an integrated manner but remain partial and fragmented. The dominance of assessment focused on factual cognitive aspects further reinforces this condition, as it does not provide space for students to construct, test, and revise scientific explanations reflectively. According to Sandrika et al. (2025), assessment practices in Indonesia are still dominated by a cognitive approach that emphasizes written test results. This situation indicates a gap between the demands of science learning, which emphasizes scientific practice, and classroom instruction that remains oriented toward reproducing knowledge. This gap underscores the need for a learning approach that explicitly integrates the development of claims, evidence, reasoning, and rebuttals as a unified whole in constructing comprehensive scientific explanations.

Based on these considerations, this study aims to explore the preliminary profile of students' scientific explanation skills within the limited context of a specific high school biology topic. This study is not intended to make broad generalizations; rather, it provides an exploratory overview of the characteristics of students' scientific explanation skills in a specific context.

Methods

This study used a descriptive quantitative approach to assess students' initial scientific explanation skills. It was conducted at a high school in Tasikmalaya during the odd semester of the 2025/2026 academic year. The research subjects consisted of 12th-grade students. The researchers used purposive sampling, selecting students involved in learning activities that required scientific explanations. A total of 73 students served as research respondents. This study used a limited sample drawn from two classes; therefore, the results are contextual and not intended to generalize to a broader population. The research instrument consisted of a scientific explanation skills test developed based on four main components, according to Mcneill and Krajcik (2012): claim, evidence, reasoning, and rebuttal. The test consisted of 10 essay-type questions on the human circulatory system. The selection of the circulatory system as the subject matter was based on the material's characteristics, which allow exploration of relationships between concepts, phenomena, and scientific reasoning in a contextual manner. The rubric for assessing scientific explanation skills is based on the Claim, Evidence, Reasoning, Rebuttal (CERR) framework developed by Mcneill and Krajcik (2012), which has been widely used in science education research to evaluate the quality of students' scientific explanations. Each component is assessed based on achievement-level criteria that reflect the completeness and accuracy of the scientific explanation's structure. Experts in biology education validated the instrument to ensure that the content and measurement indicators align with the research objectives. Test results were analyzed using quantitative descriptive analysis by calculating the percentage of achievement for each component of scientific explanation skills. The percentage of achievement was then categorized according to McNeill et al. (2006) into the assessment criteria shown in Table 1.

Table 1. Categories of scientific explanation skills

Percentage	**Description**
$85 < P \leq 100$	Excellent
$75 < P \leq 85$	Good
$59 < P \leq 75$	Fair
$54 < P \leq 59$	Poor
$P \leq 54$	Very Low

The formula used to calculate the average score for scientific explanation skills is as follows:

$$Average\ achievement\ score = \frac{score\ obtained}{maximum\ score} \times 100\%$$

The percentage scores for each component of scientific explanation skills (claim, evidence, reasoning, and rebuttal) were analyzed to identify patterns in students' skills. The results are presented in tables and bar charts to provide a more representative view of the skill distribution. Score categorization was used to clarify the level of mastery for each component, so that the data obtained could provide a concise and accurate initial overview of students' scientific explanation skills.

Results and Discussion

The analysis of students' percentage scores for scientific explanation skills was based on observations conducted in the class that was the subject of this study. The limited sample size means the results reflect the local conditions of the class under study; therefore, they must be interpreted with caution. Students' scores were categorized into several components of scientific explanation skills, namely the ability to present scientific claims, the use of supporting evidence, reasoning that links evidence to claims, and the ability to construct a complete scientific explanation. Figure 1 shows the percentage of achievement for each component and illustrates variation in students' proficiency across each aspect of scientific explanation skills.

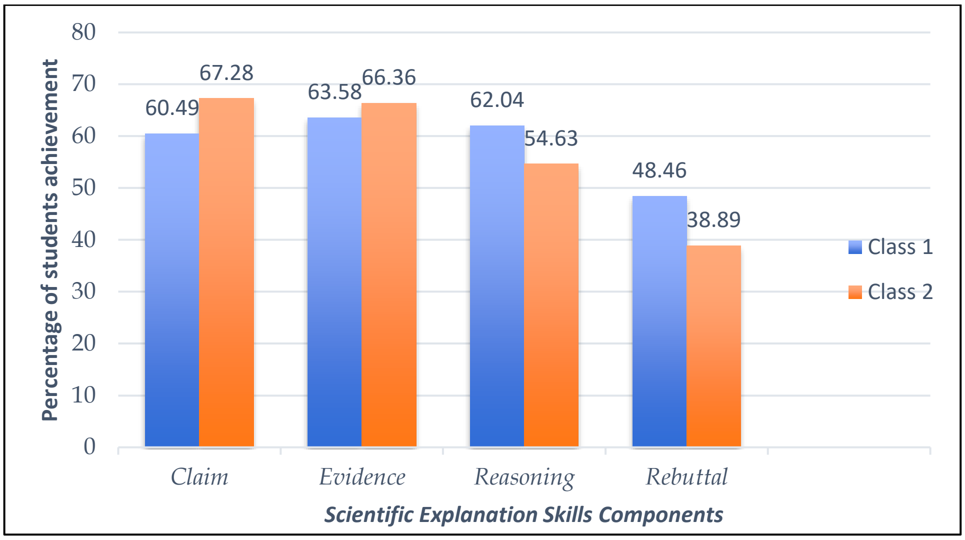

Figure 1. Analysis results of the percentage of achievement in scientific explanation skills

Based on the figure above, the scientific explanation skills in the two classes indicate that students' ability to construct scientific explanations remains in the low to insufficient category. The analysis results for the first class show an average scientific explanation skill score of 58.64, falling into the "inadequate" category. In contrast, the second class averaged 55.26, which also falls into the "inadequate" category. These findings indicate that most students still struggle to construct complete scientific explanations based on the components of claim, evidence, reasoning, and rebuttal.

Analysis of each component revealed differences in achievement patterns between the classes. In the first class, the highest achievement was in the evidence component (63.58%), followed by reasoning (62.04%) and claim (60.49%), while the lowest achievement was in the rebuttal component (48.46%). Meanwhile, in the second class, the "claim" component achieved the highest score at 65.47%, followed by "evidence" at 64.56%, while "reasoning" and "rebuttal" scored lower, at 53.15% and 37.84%, respectively. These results indicate that students are more capable of presenting initial statements and citing simple evidence than of developing scientific reasoning and constructing evidence-based rebuttals.

The low achievement in the reasoning and rebuttal components suggests that students are not yet accustomed to logically linking empirical evidence with scientific concepts or critically evaluating alternative explanations. Most students' answers remain descriptive and rote-memorization-based, lacking comprehensive scientific arguments. This suggests that current biology instruction still tends to focus on mastering factual concepts, thereby failing to facilitate the development of scientific explanation skills optimally. Therefore, the results of this preliminary study provide an initial basis for understanding the importance of developing learning strategies based on scientific activities, evidence-based arguments, and practice in scientific reasoning in biology education.

This trend aligns with findings from various studies showing that students often fail to understand the core of phenomena and cannot integrate scientific concepts to construct coherent arguments. Research by McNeill and Krajcik (2008) shows that students tend to cite available empirical data but struggle to connect it to scientific concepts, resulting in poor reasoning skills. This explains why the "evidence" component may score higher, even though reasoning ability remains low.

Figure 2 presents a flowchart of the analysis results, illustrating the interrelationships among the components of scientific explanation skills and students' common weaknesses at each stage of constructing a scientific explanation.

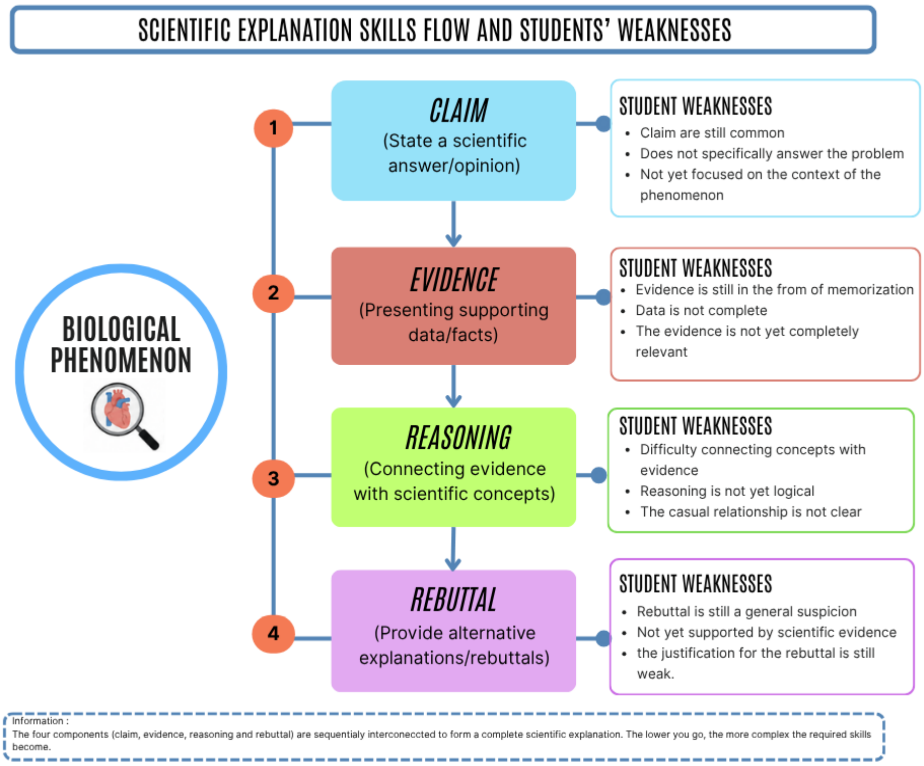

Figure 2. Flowchart of scientific explanation skills and students' weaknesses

The figure illustrates the relationships among the components of scientific explanation skills, including claims, evidence, reasoning, and rebuttals, along with the common weakness students exhibit at each stage. Based on the analysis, the most prominent weakness was found in the reasoning component: students were not yet able to logically connect evidence to biological concepts. Meanwhile, in the rebuttal component, students tended to offer only simple alternative answers without supporting them with strong scientific reasoning.

For one test item on the mechanism of blood circulation, most students described the flow of blood without conceptually linking it to the relationship between the heart's structure and its pumping function, reflecting limitations in the reasoning component. In the "claim" component, most students were not yet able to formulate specific scientific statements appropriate to the given problem (Widiana et al., 2024). Parnafes (2012) research confirms that students often fail to grasp the core of a scientific phenomenon, making it challenging for them to formulate an appropriate claim. Meanwhile, McNeill et al. (2006) found that reasoning is the aspect students most frequently struggle with because it requires the skill of logically connecting evidence to scientific concepts.

This aligns with findings from previous studies indicating that students tend to struggle to link scientific concepts to empirical data when explaining scientific phenomena (McNeill & Krajcik, 2008). These findings suggest that biology instruction in schools still places greater emphasis on cognitive aspects of memorization and conceptual understanding than fully developing comprehensive scientific thinking skills. The low level of scientific explanation skills indicates that students are not yet accustomed to using an evidence-based approach in constructing scientific arguments.

This indicates that they still lack a thorough understanding of the core of the phenomenon being analyzed (Hsu et al., 2015). Regarding the "evidence" component, although it had the highest score among the three components, students generally only cited evidence in general terms without clearly linking it to the claim. According to Pakpahan et al. (2021) evidence can take several forms: numerical data, background information, observational data, and facts revealed through reading and discussion. The reasoning component indicates that students struggle to connect evidence with relevant scientific concepts to construct logical reasoning (Nurmatin & Aini, 2024). The presence of rebuttals indicates that students have begun to think critically by considering exceptions (Aisyah et al., 2025). This low level of achievement may be caused by several factors, including a teacher-centered learning process, a lack of laboratory activities, and limited opportunities for students to explore phenomena independently. According to Harefa (2025), limited practical learning facilities result in low student engagement in the learning process, which ultimately affects their overall learning outcomes. Laksmi (2021) states that scientific explanation skills develop when students are actively engaged in scientific activities that require evidence-based reasoning. These conditions highlight the need for a paradigm shift in biology education toward a greater emphasis on the scientific thinking process. Teachers need to encourage students to construct explanations through data-driven observation, experimentation, and discussion.

According to Susilowati (2023), in classroom teaching practice, teachers rarely implement these methods due to time constraints during the teaching-learning process. Learning approaches such as inquiry-based learning, problem-based learning, computational thinking, or the integration of technology into the biology learning process are expected to serve as effective alternatives for improving students' scientific explanation skills. Thus, students not only understand concepts theoretically but can also use them to explain scientific phenomena logically and based on evidence. These findings suggest that the learning process should focus on scientific activities that encourage students to construct arguments, analyze data, and connect concepts with phenomena. Support through inquiry-based approaches, problem-solving, argument-driven inquiry, and the integration of computational thinking and virtual laboratories has the potential to improve the quality of students' scientific explanation skills in the circulatory system and other biology topics. These results show that students still face difficulties in establishing logical connections between scientific statements, empirical evidence, and the reasoning underlying the relationships between concepts.

The findings of this study make an important contribution to the development of biology education in schools. The data indicate that students' skills in constructing scientific explanations still need strengthening, particularly in linking evidence to claims and providing appropriate justifications. This information can serve as a foundation for teachers and researchers to design learning strategies that focus more on developing scientific explanation skills, thereby not only improving students' understanding of biological concepts but also fostering the growth of science literacy as a key 21st-century competency.

Conclusion

The results of the study indicate that the scientific explanation skills of students at a high school in Tasikmalaya remain in the low category across all components of claim, evidence, reasoning, and rebuttal as reflected in their limited ability to link empirical evidence with biological concepts to construct logical and structured scientific arguments. This suggests that biology instruction is still dominated by rote memorization rather than conceptual understanding, failing to provide learning experiences that foster scientific thinking skills, particularly in topics like the circulatory system, which require deeper analysis of biological phenomena. Based on the findings of this study, it is recommended that future research develop and test scientific activity-based learning approaches, such as inquiry-based and argument-driven inquiry, that provide students with broader opportunities to explore, observe, interpret data, and construct evidence-based arguments. This study has limitations regarding the sample size and scope; therefore, further research with a larger, more representative sample is needed. Further research should also consider integrating technology into biology education, such as computational thinking and virtual laboratories, as innovative approaches that can facilitate simulations of biological processes and support independent, data-driven problem-solving. Developing and testing these learning strategies is expected to further inform the design of interactive, relevant biology instruction, thereby more effectively enhancing students' scientific explanation skills and science literacy.

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Generative AI Disclosure

Not applicable.

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