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Bridging the Gap in Abstract Biology Concepts: A Needs Analysis for STEM-Integrated Argument-Driven Inquiry (ADI) Photosynthesis Learning

Fitriyani[1], Neni Hasnunidah[1*], Kartini Herlina[1], Chansanah Diawati[1], Noor Fadiawati[1]

[1] Postgraduate Program, Master of Science Education, University of Lampung, Lampung, Indonesia.

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Corresponding Author:
Neni Hasnunidah
nenihasnunidah@gmail.com

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Abstract: This study aims to analyze teachers' needs for the development of photosynthesis learning based on *Argument-Driven Inquiry* (ADI) integrated with *the Science, Technology, Engineering, and Mathematics* (STEM) approach as the basis for developing learning tools. The study was conducted at the needs analysis stage within the *Design-Based Research* (DBR) framework using a *mixed methods approach* with a *sequential explanatory design*. Quantitative data were obtained through a survey of 33 high school biology teachers in Lampung Province using a Guttman scale-based questionnaire, while qualitative data were obtained through in-depth interviews with three biology teachers. The results showed that 66.7% of teachers were not familiar with the ADI model and 54.5% had not implemented the STEM approach in learning. 90.9% of teachers had never used STEM-integrated ADI-based student worksheets, and 100% of teachers had never applied it to photosynthesis material. In addition, 75.7% of teachers had not measured critical thinking skills and 87.8% had not systematically measured collaboration skills. Interview results revealed that teachers still experience difficulties in understanding the implementation of ADI, integrating STEM in learning, developing appropriate learning tools, and facing obstacles such as the abstract nature of photosynthesis material, time constraints, and limited laboratory facilities. Based on these findings, it is recommended to develop a photosynthesis student worksheet based on STEM-integrated ADI equipped with critical thinking and collaboration assessment instruments to support more meaningful biology learning and oriented towards 21st-century skills.

Keywords: Collaboration skills; Critical thinking skills; Photosynthesis; STEM-integrated ADI

Introduction

21st-century science education requires students to master not only conceptual knowledge but also the ability to think critically, collaborate, communicate, and solve complex problems. These demands arise as a consequence of the increasingly rapid development of science and technology and the need for human resources capable of adapting to various global changes (UNESCO, 2024). The Organization for Economic Cooperation and Development (OECD), through the results of the Programme for International Student Assessment (PISA), confirms that the success of students in the modern era is largely determined by the ability to use knowledge to analyze, evaluate, and solve problems in real contexts, not simply memorize information (OECD, 2023).

In line with this, various studies have shown that strengthening higher-order thinking skills is a crucial indicator of successful 21st-century science learning (Bybee, 2013; Trilling & Fadel, 2009). However, PISA results indicate that Indonesian students' scientific literacy skills are still below the OECD average. This indicates that the science learning process still needs to

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be improved to optimally develop higher-order thinking skills. Therefore, science learning needs to be designed innovatively to encourage active student involvement in the knowledge construction process. According to the OECD (2023), student-centered learning is a crucial strategy for sustainably developing 21st-century competencies. Therefore, efforts to improve the quality of learning need to be directed at developing strong conceptual understanding through the context of science learning, including in biology.

In biology learning, conceptual mastery is an essential foundation for students to understand various life and environmental phenomena. As a branch of science that studies living things and their interactions with the environment, biology requires students to systematically understand interrelated concepts. One concept that plays a central role in biology learning is photosynthesis. Photosynthesis is a biological process that allows plants to convert light energy into chemical energy stored in the form of glucose through a series of complex reactions that occur in chloroplasts. This concept forms the basis for understanding other materials such as plant metabolism, energy flow in ecosystems, the carbon cycle, and global climate change.

According to Taiz et al. (2022), photosynthesis is the most fundamental biological process that supports almost all life on Earth because it is the primary source of energy for heterotrophic organisms. Furthermore, research shows that understanding photosynthesis contributes to students' ability to explain the relationship between organisms and the environment scientifically American Association for the Advancement of Science (AAAS, 2011). Therefore, a good understanding of photosynthesis is crucial for building a comprehensive understanding of biology. Therefore, successful photosynthesis learning is an important indicator in biology learning in schools, so it deserves special attention in the learning process.

Although own very important role , photosynthesis Still be one of draft the most difficult biology understood by participants educate . Difficulty the appear Because part large photosynthesis process taking place at the level microscopic and molecular so that No can observed in a way directly by the senses humans. Participants educate No can see in a way real How molecule carbon dioxide enter to leaves , how energy light captured by chlorophyll , how reaction bright produce ATP and NADPH, as well as How glucose formed through Calvin cycle . Conditions the cause participant educate experience difficulty in connect observed phenomena with actual biological processes occurred (Taiz et al., 2022).

As a result , participants educate tend only memorize equality reaction photosynthesis without understand mechanism underlying scientific research . show that Lots participant educate Still experience misconceptions about source mass plants , function light sun , and relationships between carbon dioxide with formation glucose (Duda et al., 2023). Findings Hasnunidah (2022) also reported the same thing that concepts biological nature abstract often causes gap between understanding scientific and understanding possessed participant education . Research results the latest also shows that misconceptions about the material photosynthesis Still become problems found in various level education (Koba & Tweed, 2023; Zohar & Alboher, 2024). Conditions This show that photosynthesis is concepts that require more learning strategies innovative compared to learning conventional .

The low understanding conceptual participant educate to photosynthesis No only caused by characteristics abstract material , but also influenced by the approach learning implemented in schools . Many learning processes Still dominated by methods lectures and practicals verification that places participant educate as recipient information passive (UNESCO, 2024). In learning like this , participants educate generally only follow steps practical work that has been determined without given chance For formulate questions , composing argument , or evaluate proof scientific information obtained (Osborne, 2014). The knowledge transfer - oriented learning tend limit chance participant educate For develop ability think critical.

As a result , participants educate more focus on results end compared to the scientific process behind it . In fact , understanding deep conceptual only can formed if participant educate involved in a way active under investigation scientific (Osborne, 2014; Zohar & Alboher, 2024). Therefore, a learning model is needed that can transform students' roles from information recipients to knowledge builders. This need is increasingly important because today's science learning is not only oriented toward mastering concepts but also toward developing 21st-century skills.

This situation is increasingly becoming a concern because critical thinking skills are one of the key competencies students must possess in the 21st century. Ennis (2011) states that critical thinking is a reflective and rational thought process used to determine what to believe or do. Through critical thinking skills, students are able to analyze information, evaluate evidence, identify relationships between concepts, and make decisions based on logical reasoning (Paul & Elder, 2019).

These skills are crucial in biology learning because students are required to understand various life phenomena based on reliable scientific evidence. Therefore, biology learning needs to provide sufficient space for students to develop these skills through activities that require scientific analysis and reasoning. In addition to critical thinking skills, students also need to be equipped with the ability to collaborate to solve problems collectively.

In addition to critical thinking, collaboration skills are also a crucial competency in modern learning. Graesser et al. (2018) explain that collaboration is the ability of individuals to work together effectively to solve problems and achieve common goals. In science learning, collaboration allows students to exchange ideas, discuss observations, and build understanding through meaningful social interactions. Greenstein (2012) adds that effective collaboration can improve the quality of learning because students learn to appreciate multiple perspectives in solving problems. In addition to supporting improved conceptual understanding, collaboration also contributes to scientific communication skills and evidence-based decision-making. Therefore, biology learning needs to be designed in such a way that it can simultaneously develop critical thinking and collaboration skills. One alternative that can be used to achieve this goal is through the application of an argumentative inquiry-based learning model.

To address these challenges, a learning model is needed that integrates the scientific inquiry process with the development of critical thinking and collaboration skills. One model deemed suitable is Argument-Driven Inquiry (ADI). The ADI model places students at the center of learning through investigative activities, evidence collection, argument development, and data-driven scientific discussions (Sampson et al., 2011). Fakhriyah et al. (2021) explain that ADI can improve the quality of scientific argumentation and encourage students to construct knowledge through deeper thinking processes.

Recent research also shows that ADI implementation positively contributes to students' critical thinking skills, conceptual understanding, and scientific communication skills (Erduran & Kaya, 2024; Walker et al., 2023). However, argumentation-based learning requires a relevant context so students can connect scientific concepts to real-world situations. In this regard, a STEM approach can be a complementary and effective support for ADI implementation.

On the other hand, the Science, Technology, Engineering, and Mathematics (STEM) approach has developed as an approach capable of connecting scientific concepts with real-life contexts. The STEM approach provides students with opportunities to solve problems through integrated design, engineering, technology utilization, and the application of mathematical concepts (English, 2023). The STEM-based learning can improve students' higher-order thinking skills, creativity, and problem-solving skills.

Recent research findings indicate that the STEM approach can also increase student engagement in learning and help them understand abstract concepts through contextual learning experiences (Dare et al., 2023; Margot & Kettler, 2022). Therefore, STEM has great potential for application to photosynthesis, a topic often considered difficult for students to grasp. This potential will be even more optimal when integrated with a learning model that emphasizes the scientific argumentation process.

Theoretically, the integration of ADI and STEM holds enormous potential for addressing the challenges of photosynthesis learning. ADI provides a learning structure that enables students to construct and defend scientific arguments based on empirical evidence (Erduran & Kaya, 2024). Meanwhile, STEM provides the context and tools for visualizing abstract concepts through design and problem-solving activities (English, 2023).

The integration of these two approaches enables students not only to gain a deeper understanding of concepts but also to simultaneously develop critical thinking, collaboration, communication, and problem-solving skills (Dare et al., 2023; Margot & Kettler, 2022). Thus, the integration of ADI and STEM not only helps students understand the concept of photosynthesis more deeply but also fosters the development of 21st-century skills needed to face future challenges. However, this potential still requires broader empirical evidence in the context of biology learning.

However, the literature review indicates that research on ADI and STEM tends to be conducted separately. Fakhriyah et al. (2021) research focused more on the effectiveness of ADI in improving scientific argumentation skills, the application of STEM in developing 21st-century skills. Research specifically integrating these two approaches into photosynthesis is still very limited, particularly in the context of biology learning in secondary schools (Çetin-Dindar et al., 2023). Furthermore, most previous research focuses more on student learning outcomes than on the need for implementation at the school level (Shernoff et al., 2022). However, the success of a learning innovation is strongly influenced by teacher readiness, student characteristics, and the availability of appropriate learning tools (Thibaut et al., 2022). Therefore, there is still a research gap that requires further study, particularly regarding the need to implement ADI-based photosynthesis learning integrated with STEM in the context of biology learning in secondary schools.

Research gaps are also evident in the implementation aspect in the field. Most previous studies have focused on testing the effectiveness of learning models on student learning outcomes, while studies on teacher readiness and the need to develop Argument-Driven Inquiry (ADI) learning tools integrated with STEM are still relatively limited. In fact, the successful implementation of a learning innovation is greatly influenced by the readiness of teachers as the primary implementers of the learning process in the classroom. Initial analysis findings from various studies indicate that many teachers still experience difficulties in integrating STEM approaches into science learning and facilitating scientific argumentation through the ADI model. This situation indicates a need to identify barriers, perceptions, and teacher readiness as a basis for developing more comprehensive learning programs that are tailored to field needs.

Based on the description, the novelty of this research lies in its focus, which not only examines the effectiveness of learning models or abstract concepts of photosynthesis, but specifically analyzes the needs of teachers in implementing photosynthesis learning based on Argument-Driven Inquiry (ADI) integrated with STEM. This research also seeks to identify teacher readiness, implementation constraints, and the need for the development of learning tools as a foundation for developing more relevant and applicable programs.

The urgency of this research is further strengthened considering that critical thinking and collaboration skills are essential competencies in the 21st century, while photosynthesis remains a biological concept prone to misconceptions. Therefore, the research entitled "*Bridging the Gap in Abstract Biology Concepts: A Needs Analysis for Argument-Driven Inquiry (ADI)-Based Photosynthesis Learning Integrated with STEM*" was conducted to analyze teacher needs, identify implementation constraints, and provide an empirical basis for developing learning that can improve students' critical thinking and collaboration skills in biology learning.

Method

Data collection was conducted through a diagnostic survey involving 33 high school biology teachers in Lampung Province. The research instrument was a needs analysis questionnaire distributed online using Google Forms. The questionnaire was designed to identify teachers' initial conditions regarding the implementation of photosynthesis learning based on Argument-Driven Inquiry (ADI) integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach. The instrument used the Guttman scale with two answer options, namely "Yes" and "No", allowing researchers to obtain clear information regarding teachers' experiences, knowledge, and needs regarding the learning program to be developed. Before use, the instrument was first validated by experts to ensure the suitability of the indicators with the research objectives and the aspects being measured.

The questionnaire consists of seven questions grouped into seven main indicators, namely: (A1) teacher knowledge regarding the Argument-Driven Inquiry (ADI) learning model, (A2) teacher knowledge regarding the STEM approach, (A3) experience in implementing STEM-integrated ADI-based LKPD, (A4) experience in implementing STEM-integrated ADI-based LKPD on photosynthesis material, (A5) teacher experience in measuring students' critical thinking skills, (A6) teacher experience in measuring students' collaboration skills, and (A7) obstacles faced by teachers in learning photosynthesis material. These seven indicators were chosen because they represent important aspects needed in developing a STEM-integrated ADI-based photosynthesis learning program.

The quantitative data obtained from the questionnaire were analyzed using descriptive statistics in the form of percentages to illustrate the distribution of respondents' answers for each indicator. The percentage of "Yes" and "No" answers was used to identify teachers' levels of knowledge, implementation experience, and needs regarding the learning program to be developed. The results of the analysis were then presented in the form of diagrams and descriptive narratives to facilitate data interpretation. Although the number of respondents in this study was relatively limited, the findings obtained provide a contextual overview of the condition of biology learning in Lampung Province and can be used as a basis for the needs analysis stage of Design-Based Research (DBR) research.

In addition to quantitative data, this study also collected qualitative data through interviews with three purposively selected biology teachers. The interviews were conducted to gain a deeper understanding of the teachers' barriers, needs, and expectations regarding the implementation of STEM-integrated ADI-based photosynthesis learning. The interview data were analyzed through data reduction, coding, theme grouping, and interpretation. Furthermore, the results of the quantitative and qualitative analyses were integrated to identify gaps between existing and desired learning conditions as a basis for developing learning programs in the next stage. The research flow at this stage analysis need in The Design-Based Research (DBR) framework is presented in Figure 1.

Figure 1 shows the research design schematic implemented during the needs analysis stage within the Design-Based Research (DBR) framework. The study employed a mixed methods approach with a sequential explanatory design, where quantitative data collection and analysis were conducted initially, followed by qualitative data collection and analysis to deepen and explain the findings obtained from the quantitative data (Creswell & Clark, 2017). Quantitative data were obtained through a diagnostic survey involving 33 high school biology teachers in Lampung Province, while qualitative data were obtained through in-depth interviews with three purposively selected biology teachers. The integration of these two types of data was used to gain a more comprehensive understanding of teacher needs in implementing Argument-Driven Inquiry (ADI)-based photosynthesis learning integrated with STEM.

Figure 1. Research Design Scheme

The questionnaire instrument used in this study was developed based on theoretical studies, literature study results, and research objectives at the needs identification stage within the Design-Based Research (DBR) framework (McKenney & Reeves, 2012). The questionnaire was compiled based on seven main indicators, including teacher knowledge of the ADI model, knowledge of the STEM approach, experience implementing STEM-integrated ADI-based student worksheets (LKPD), implementation on photosynthesis material, measuring critical thinking skills, measuring collaboration skills, and obstacles faced in photosynthesis learning. The instrument uses a Yes/No response format (Guttman scale) to obtain an initial overview of the conditions and needs of teachers related to the learning program to be developed.

Instrument validity was assessed through content validity using expert judgment involving biology education lecturers and biology learning practitioners. The validation process aimed to assess the suitability of each indicator to the research objectives, the clarity of the question wording, the relevance of the instrument content, and the representativeness of the constructs being measured. Suggestions and input from the experts served as the basis for revising and refining the instrument before use in data collection. This approach aligns with the principles of instrument development in educational research, which emphasize the appropriateness of instrument content to the measurement objectives and research context (Fraenkel et al., 2019).

Furthermore, the validity of the research data was strengthened through method triangulation, namely by integrating the results of quantitative surveys and qualitative interviews. Triangulation was carried out to increase the credibility of the findings and ensure that the identified needs were not only based on survey data, but also supported by in-depth explanations from interview respondents (Creswell & Creswell, 2018). Thus, the data obtained can provide a more complete picture of the conditions of photosynthesis learning and teacher needs as a basis for designing ADI-based photosynthesis student worksheets integrated with STEM in the next development stage.

Results and Discussion

The results and discussion of the data obtained in the form of a questionnaire related to the ADI-based photosynthesis material learning program integrated with STEM are presented in Figure 2.

Teacher Knowledge Regarding the Argument-Driven Inquiry (ADI) Learning Model

The needs analysis revealed that 66.7% of teachers were unfamiliar with the Argument-Driven Inquiry (ADI) learning model, while 33.3% were familiar with it. This finding suggests that teachers' understanding of learning models that emphasize scientific argumentation remains relatively low. This indicates that most teachers lack sufficient experience in implementing learning that encourages students to construct knowledge through scientific inquiry and evidence-based argumentation. Yet, the demands of 21st-century learning require students not only to master concepts but also to develop critical thinking skills, problem-solving skills, and scientific communication skills (OECD, 2023).

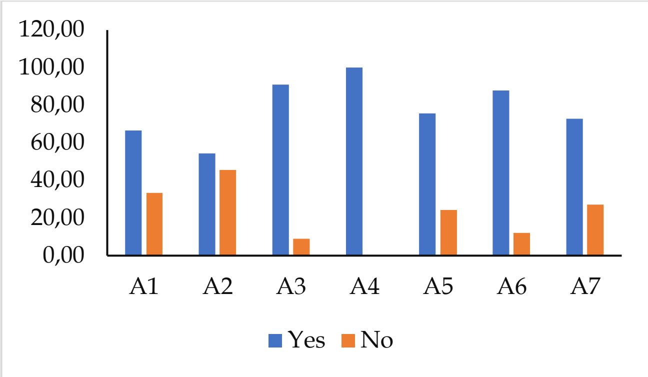

Figure 2. Results of Teacher Needs Analysis

Information:
A1 = Teacher knowledge regarding learning models (*Argument Driven Inquiry (ADI)).*
A2 = Teacher knowledge of STEM approach
A3 = Implementation of ADI-based LKPD integrated with STEM
A4 = Implementation of STEM-integrated ADI-based LKPD in learning photosynthesis material
A5 = Teacher experience in measuring students' critical thinking skills in learning .
A6 = Teacher experience in measuring students' collaboration skills in learning.
A7 = Teacher constraints in the process of learning photosynthesis material

Theoretically, ADI is a learning model that integrates the scientific inquiry process with evidence-based argumentation. According to Sampson et al. (2011), the ADI model is designed to engage students in investigative activities, data collection, claim formulation, use of evidence, and evaluation of arguments through scientific discussions (Sampson et al., 2011). Through these stages, students have the opportunity to understand how scientific knowledge is constructed and maintained based on empirical evidence. Therefore, ADI is seen as a model that can simultaneously develop critical thinking skills and scientific literacy.

The findings of this study align with those of Knight et al. (2022), which showed that many science teachers still lack a thorough understanding of the implementation of scientific argumentation-based learning. Research by Osborne (2014) also found that teachers' low understanding of argumentative learning models is a barrier to developing students' higher-order thinking skills. Based on these findings, more intensive training and mentoring are needed to ensure teachers have a sufficient understanding of the concepts, syntax, and implementation of ADI before the model is applied to STEM-based photosynthesis learning.

Teachers' Knowledge Regarding STEM Approaches

The needs analysis results show that 54.5% of teachers have not implemented the STEM approach in their learning, while 45.5% have. Although a significant percentage of teachers are familiar with STEM, these results indicate that the implementation of the STEM approach in biology learning remains uneven. This condition indicates that some teachers still experience difficulties in integrating aspects of science, technology, engineering, and mathematics into meaningful learning activities. As a result, learning tends to focus on mastering concepts without providing sufficient opportunities for students to apply these concepts in real-life contexts.

The STEM approach is a learning approach that integrates four disciplines science, technology, engineering, and mathematic to solve real-world problems. According to Kelley & Knowles (2016), STEM provides learning experiences that enable students to connect academic concepts with real-world needs through design, engineering, and problem-solving activities. This approach is not only oriented towards mastering concepts but also aims to develop critical thinking, creativity, collaboration, and communication skills needed in the 21st century.

The findings of this study are supported by research by El Nagdi et al. (2023), which showed that STEM implementation in schools still faces various obstacles, such as limited teacher understanding, lack of training, and a lack of examples of appropriate learning tools. Research by Park et al. (2022) also showed that teachers often experience difficulties integrating engineering and mathematics elements into science learning. Therefore, professional development programs are needed that can help teachers understand STEM concepts more comprehensively and be able to implement them in biology learning.

Implementation of Integrated STEM ADI-Based LKPD

The needs analysis results show that 90.9% of teachers have never used ADI-based student worksheets (LKPD) integrated with STEM in their learning, while only 9.1% have. This percentage indicates that the use of learning tools that integrate ADI and STEM is still very limited. This finding indicates that most teachers do not have experience in utilizing LKPDs designed to develop scientific argumentation skills as well as STEM-based problem-solving skills. As a result, learning activities still tend to use conventional LKPDs that focus on completing tasks without involving in-depth argumentation and investigation processes.

The STEM-integrated ADI-based Student Worksheet (LKPD) is a learning tool designed to facilitate students in conducting scientific investigations, constructing arguments based on evidence, and solving problems through a STEM approach. In this learning, students are not only asked to observe or answer questions, but also to develop solutions to a problem through the process of design, data collection, evidence analysis, and scientific discussion. According to Sampson et al. (2011), the use of learning tools that support scientific argumentation can help students build a deeper conceptual understanding. Meanwhile, the STEM approach allows students to connect the concepts learned with relevant real-life situations.

The findings of this study align with those of Herro et al. (2022), which showed that most teachers do not yet have learning tools that specifically integrate scientific argumentation and STEM into teaching and learning activities. Research by Aslam et al. (2023) also reported that the availability of STEM-based learning tools integrated with innovative learning models is still relatively limited in schools. Therefore, the results of this study reinforce the importance of developing STEM-integrated ADI-based photosynthesis worksheets as an alternative learning tool capable of optimally supporting the development of students' critical thinking and collaboration skills.

Implementation of Integrated STEM-Based ADI-Based Student Worksheets on Photosynthesis Material

The needs analysis results show that 100% of teachers have never implemented STEM-integrated ADI-based student worksheets (LKPD) on photosynthesis. This finding indicates that photosynthesis learning is still dominated by conventional approaches and does not utilize learning tools specifically designed to develop scientific argumentation and problem-solving skills. This condition indicates a gap between the demands of 21st-century learning and ongoing classroom learning practices. Photosynthesis is, however, an abstract biological concept that often leads to misconceptions among students.

Theoretically, learning photosynthesis requires strategies that can help students understand the processes that occur at the microscopic and molecular levels. The integration of ADI and STEM allows students not only to conduct scientific investigations but also to connect the concept of photosynthesis to real-world problems through design and problem-solving activities. Through this approach, students can build conceptual understanding based on evidence obtained during the investigation process, making learning more meaningful and contextual.

This finding aligns with research by Kaltakci-Gurel & Eryilmaz (2023), which showed that photosynthesis remains a difficult concept for students to grasp due to its abstract nature. Research by Karaarslan & Sungur (2024) also reported that photosynthesis learning in schools is still largely oriented toward verification practicums, which provide limited opportunities for students to develop critical thinking and scientific argumentation skills. Therefore, the development of STEM-integrated ADI-based photosynthesis worksheets is crucial to support more innovative and student-centered learning.

Teacher Experience in Measuring Critical Thinking Skills

The needs analysis results show that 75.7% of teachers have never measured students' critical thinking skills, while only 24.3% have done so. This finding suggests that the learning evaluation process still focuses more on conceptual mastery and cognitive learning outcomes than on higher-order thinking skills. This situation has the potential to result in students' critical thinking skills not developing optimally because they are not a measurable part of the learning process.

Critical thinking skills are one of the key competencies students must possess in the 21st century. According to Ennis (2011), critical thinking is a reflective and rational thought process used to determine what to believe or do. In the context of science learning, critical thinking skills include the ability to analyze information, evaluate evidence, draw conclusions, and provide logical reasons for decisions. Therefore, critical thinking skills need to be measured systematically so that teachers can determine the level of development of students' abilities and determine appropriate learning strategies.

The findings of this study are supported by research by Zohar & Alboher (2024), which showed that most teachers still experience difficulties in developing instruments to measure students' critical thinking skills. Another study conducted by Schildkamp et al. (2023) also found that learning assessments in schools are still dominated by questions that measure memory and conceptual understanding. Based on these conditions, the development of assessment instruments capable of measuring critical thinking skills more comprehensively, as well as training for teachers in developing assessments based on higher-order thinking skills, is needed.

Teacher Experience in Measuring Collaboration Skills

The needs analysis results show that 87.8% of teachers have never measured students' collaboration skills, while only 12.2% have conducted such measurements. This finding indicates that collaboration skills have not been a primary focus in the learning assessment process. However, collaboration is a crucial skill for students to master in facing the challenges of the 21st century. The low level of collaboration skills measurement indicates that teachers still need support in developing appropriate assessment instruments and strategies.

Conceptually, collaboration skills are an individual's ability to work together with others to achieve common goals through communication, accountability, and active participation in a group. Greenstein (2012) explains that collaboration is not only related to the ability to work in a group, but also the ability to respect differences of opinion, share tasks fairly, and resolve conflicts constructively. In science learning, collaboration skills play a crucial role because the process of scientific inquiry is often carried out through group work involving discussion and the exchange of ideas.

The results of this study align with the findings of Graesser et al. (2018), which showed that collaborative skills assessment is rarely implemented in science learning in schools. Fiore et al. (2023) research also reported that many teachers do not have adequate instruments to objectively evaluate students' collaboration skills. Therefore, it is necessary to develop learning tools that not only facilitate collaboration but also provide assessment instruments capable of measuring these skills validly and systematically.

Teacher Obstacles in Learning Photosynthesis

The results of the needs analysis indicate that most teachers still experience obstacles in teaching photosynthesis. These obstacles include limited learning facilities and infrastructure, difficulty explaining abstract concepts, and limited learning tools capable of facilitating active student engagement. These findings indicate that photosynthesis learning still faces various challenges that can impact the quality of student understanding of the concepts being studied.

Photosynthesis is a fundamental concept in biology that possesses a high level of complexity because it involves processes that cannot be directly observed. According to Taiz et al. (2022), understanding photosynthesis requires the ability to connect various concepts at the macroscopic, microscopic, and molecular levels simultaneously. Therefore, learning photosynthesis requires strategies and learning tools that can visualize abstract concepts to make them easier for students to understand.

The findings of this study are supported by research by (Tekkaya & Balcı, 2022), which states that abstract biological concepts often cause misconceptions in students. Research by Koseoglu & Efendioglu (2024) also shows that limited media and learning approaches used by teachers can hinder students' conceptual understanding of photosynthesis. Based on these findings, learning innovations are needed that can integrate scientific investigation, evidence-based argumentation, and real-life contexts so that photosynthesis learning becomes more meaningful and can develop students' critical thinking and collaboration skills.

The following are the results of interviews conducted with three teachers regarding learning programs that implement the STEM-integrated ADI model to improve students' critical thinking and collaboration skills. These interviews aimed to obtain more in-depth information regarding school practices related to learning programs that implement the STEM-integrated ADI model to improve students' critical thinking and collaboration skills , both those that have been implemented and those that have not. The data obtained has been summarized in Table 1 for ease of understanding and analysis.

Table 1. Results of Teacher Interviews as Supporters Analysis Need

Question	Teacher A	Teacher B	Teacher C
What do you know? about the ADI learning model?	I have heard of ADI and know that this model emphasizes investigative activities and evidence-based scientific argumentation.	I have not understand in a way details regarding the ADI model and not yet Once follow training related to the model.	I just Once hear the term ADI, but Not yet know syntax and method its implementation in learning.
What do you know? about STEM approach?	STEM is an approach that integrates science, technology, engineering, and mathematics to solve real-world problems.	I know STEM in general, but still have difficulty applying it in biology learning.	I have not understand How integrate element technology, engineering, and mathematics in material biology.
Have you ever developed a STEM-integrated ADI-based student worksheet? Explain why.	Never, because I Not yet own example of LKPD that integrates ADI and STEM.	Never before, because I'm still having trouble integrating the STEM approach into the ADI syntax	Never before, due to limited facilities and lack of training regarding the development of ADI-STEM based LKPD.

Question	Teacher A	Teacher B	Teacher C
you ever used STEM-integrated ADI- based LKPD on the material? photosynthesis?	Never	Never	Never
How do you measure students' critical thinking skills?	I use question essay HOTS and question based analytical at the time discussion	I usually only evaluate results end assignments and not yet own instrument special for measure think critical	I have never done a specific measurement of critical thinking skills
How do you measure students' collaboration skills?	I observed student cooperation and participation during group activities	I don't have a specific instrument to assess students' collaboration skills yet	Collaboration assessment has never been carried out systematically because it focuses more on the results of group assignments.
What obstacles do you experience in teaching photosynthesis material?	Photosynthesis material nature abstract so that student difficult understand the process that is not can observed in a way direct	Learning and practical time often No sufficient for explain the process of photosynthesis in a way deep	Limited tools, practical materials, and learning media are obstacles in learning photosynthesis

Based on results interviews in Table 1, it can be seen that Teachers' understanding of the Argument-Driven Inquiry (ADI) learning model is still relatively limited. Of the three teachers interviewed , only Teacher A had own description regarding ADI as a learning model that emphasizes activity investigation and argumentation based evidence . Meanwhile that , Teacher B and Teacher C admitted Not yet understand syntax and implementation of ADI in learning . Findings This in line with results questionnaire that shows that part big teacher yet getting to know the ADI learning model . Conditions the indicates that learning based argumentation scientific Still Not yet Lots introduced in practice learning biology in schools . In fact , ADI provides chance to participant educate For build knowledge through the process of investigation , data analysis , and compilation supported arguments proof empirical (Sampson et al., 2011). Findings This is also supported by research by Knight et al. (2022) which shows that many science teachers Still experience difficulty in understand and apply learning based argumentation scientific research in the classroom. Research Erduran & Kaya (2024) also confirm that limitations teacher's understanding of argumentation scientific be one of inhibiting factors implementation development - oriented learning ability think critical participant. Teachers' low level of understanding of this model indicates the need for mentoring and training to ensure optimal implementation of ADI .

Interview results also indicated that teachers were generally familiar with the STEM approach but still experienced difficulties in applying it to biology lessons. Teachers B and C revealed that they did not yet understand how to integrate elements of technology, engineering, and mathematics into the material being taught. This situation became even more evident when all teachers stated that they had never developed or used STEM-integrated ADI-based student worksheets, including for photosynthesis. Various reasons were given, ranging from limited examples of learning tools, difficulties integrating STEM into ADI syntax, to limited supporting facilities. This finding reinforces the questionnaire results which showed that the use of STEM-integrated ADI-based student worksheets is still very low. According to Kelley & Knowles (2016), STEM implementation requires learning designs that are able to connect academic concepts with real-world problem solving. Therefore, the availability of appropriate learning tools is a critical factor in supporting the successful implementation of STEM in the classroom.

In terms of assessment, interview results indicate that critical thinking and collaboration skills are still not being measured optimally. Teacher A stated that critical thinking assessments were conducted through HOTS-based essay questions and observations during class discussions. However, Teachers B and C admitted to not having specific instruments to assess these skills. A similar situation was found for collaboration skills assessments, which were generally conducted only through simple observations of group activities. This finding aligns with the questionnaire results, which showed that most teachers have not systematically measured critical thinking and collaboration skills. Yet, both skills are essential competencies needed by students to face the challenges of the 21st century (OECD, 2023). The limited instruments and teachers' experience in conducting assessments indicate that the development of learning tools needs to be accompanied by the provision of assessment instruments that can be used practically in the classroom.

Furthermore, interviews revealed various obstacles faced by teachers in teaching photosynthesis. Teacher A highlighted the abstract nature of the material, which often makes it difficult for students to understand processes that cannot be directly observed. Teacher B emphasized the limited time available for teaching and practical work, while Teacher C highlighted the limited tools, materials, and learning media available at the school. These various obstacles indicate that the problems in learning photosynthesis are not only related to the characteristics of the material but are also influenced by supporting learning factors. This finding aligns with the opinion of Urry et al. (2023) who stated that photosynthesis is a complex biological process because it involves the interconnectedness of various concepts at the organismal, cellular, and molecular levels that must be understood in an integrated manner. This difficulty was also reported by Kaltakci-Gurel & Eryilmaz (2023), who explained that abstract and non-directly observable biological concepts often lead to learning difficulties and misconceptions in students.

Overall, the interview results provide a consistent picture with the questionnaire findings and indicate that teachers still face various limitations in understanding ADI, implementing STEM, developing appropriate student worksheets (LKPD), and assessing 21st-century skills. On the other hand, photosynthesis material is still considered difficult to teach due to its abstract nature and the need for appropriate media support and learning strategies. Therefore, the development of a photosynthesis student worksheet based on ADI integrated with STEM is a relevant need to address these challenges. The developed learning tools are expected to not only help teachers convey the concept of photosynthesis more concretely but also facilitate the development of critical thinking skills and student collaboration skills simultaneously.

Conclusion

This preliminary study revealed that biology teachers still face various limitations in implementing photosynthesis learning based on Argument-Driven Inquiry (ADI) integrated with STEM. The questionnaire results showed that 66.7% of teachers were not familiar with the ADI learning model and 54.5% of teachers had not applied the STEM approach in their learning. In addition, 90.9% of teachers had never used STEM-integrated ADI-based student worksheets (LKPD), and 100% of teachers had never applied it to photosynthesis material. These findings were reinforced by interview results, which showed that only Teacher A had a general understanding of ADI and STEM, while Teachers B and C admitted to not having a deep understanding of ADI syntax or how to integrate STEM in biology learning. The three teachers also stated that they had never developed or used STEM-integrated ADI-based student worksheets due to limited experience, a lack of examples of learning tools, and limited facilities available at their schools. This condition indicates that the development of learning tools that integrate ADI and STEM is still very much needed to support the implementation of more innovative and student-centered learning. The study also showed that 21st-century skills assessments have not been implemented optimally. As many as 75.7% of teachers have never systematically measured critical thinking skills and 87.8% of teachers have never systematically measured students' collaboration skills. This finding is in line with the interview results, which showed that only Teacher A conducted critical thinking assessments through HOTS questions and observations of class discussions, while Teachers B and C did not have specific instruments to measure it. In terms of collaboration, the three teachers generally still relied on simple observations of group activities without using structured assessment instruments. Furthermore, the interviews also revealed that teachers faced various obstacles in learning photosynthesis, such as the abstract nature of the material, limited time for practicums, and limited tools, materials, and learning media. Therefore, the development of STEM-integrated ADI-based photosynthesis worksheets is needed not only to help visualize abstract concepts, but also to facilitate scientific investigation activities, evidence-based argumentation, and the development of students' critical thinking and collaboration skills. The findings of this study can serve as an empirical basis for developing learning tools that are appropriate to teacher needs and the characteristics of biology learning in schools.

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Author Contribution

Conceptualization, Fitriyani and Neni Hasnunidah; methodology, Fitriyani, Neni Hasnunidah, Kartini Herlina, Chansanah Diawati, and Noor Fadiawati; investigation, Fitriyani; data collection, Fitriyani; formal analysis, Fitriyani and Neni Hasnunidah; validation, Neni Hasnunidah, Kartini Herlina, Chansanah Diawati, and Noor Fadiawati; resources, Neni Hasnunidah, Kartini Herlina, Chansanah Diawati, and Noor Fadiawati; writing—original draft, Fitriyani; writing—review and editing, Neni Hasnunidah, Kartini Herlina, Chansanah Diawati, and Noor Fadiawati; visualization, Fitriyani; supervision, Neni Hasnunidah, Kartini Herlina,

Chansanah Diawati, and Noor Fadiawati; project administration, Fitriyani; funding acquisition, Fitriyani. All authors have read and approved the final version of the published manuscript.

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There is no conflict of interest.

Reference

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