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Development and Validation of ADI-STEM-Based Biotechnology e-Liveworksheets to Enhance Student Argumentation Skills

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Abstract: Development and Validation of ADI-STEM-Based Biotechnology e-Liveworksheets to Enhance Student Argumentation Skills. Objectives: Despite its enormous potential, ADI-STEM-based electronic worksheets are still rarely used. In the face of the challenge of integrating STEM, ADI-based worksheets should be centered on authentic engineering issues. Designing real-world, challenging, yet still solvable problems for students with digital tools (Technology & Math) and relevant Science concepts. The purpose of this study is to fill this gap by developing and validating a reliable teaching material called the ADI-STEM-Based Biotechnology e-Liveworksheets (ASBL), which is intended to train the argumentation skills of Indonesian junior high school students. **Methods:** The research employed a development method using the Thiagarajan 4-D model, which includes the stages of Define, Design, and Develop, without the Disseminate stage. The ASBL underwent rigorous validation by experts and field testing in junior high school students in Indonesia. The Sampson & Clark framework is used to measure students' argumentative skills. Two biology education experts reviewed the content to ensure its validity. Two media experts reviewed the content to ensure its validity, and a senior teacher assessed the feasibility and practicality of ASBL. Researchers got real-world data for descriptive-quantitative analysis from 30 9th-grade students at a junior high school in Lampung, Indonesia. This data demonstrates the practicality of teaching materials, as evidenced by the increase in the average value of argumentation skills between before and after learning, as well as the responses of educators and students to the learning process. Data were collected using validated questionnaires and written tests. **Findings:** The results of the study showed that the ASBL was stated as very high validity (93%) by material experts, high validity (87%) by media experts, very practical to uses in learning by students (98%), with in improving students' argumentation skills with N-gain in the high cateogry of claim (0,82), evidence (0,78), and reasoning (0,79). The majority of students (over 85%) found ASBL easy to use, engaging, and helpful in guiding their learning process. Teachers reported that the platform enabled efficient progress tracking and assessment of students' argument construction at each learning phase. **Conclusion:** This research develops valuable and valid teaching materials to train students' argumentation skills. As a teaching material that aligns with the Independent Curriculum, ASBL is quite useful for Indonesian teachers. This encourages a shift from memorizing things by rote to understanding them more deeply and learning how to conduct science. Future research could explore scaling this model across different science topics, educational levels, or through longitudinal studies to assess retention and transfer of argumentation skills.

Keywords: biotechnology, liveworksheets, argumentation, argument-driven inquiry, STEM.

▪ INTRODUCTION

The 21st century has brought about significant transformations in various aspects of life, including education, communication, and work. Life in the 21st century is characterized by three main characteristics, namely: the flood of information and disinformation, as well as the complexity of problems (socio-scientific issues) that are complex and do not have one correct answer, and the demands of new skills (Li & Guo, 2021). The world of work no longer requires fact memorizers but demands individuals

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who can think critically, communicate effectively, collaborate, and create (4Cs) to solve problems that have never existed before. In this complex situation, science education often falls short in imparting the necessary science knowledge to students. Students must be trained to apply their knowledge of science to take stands, make informed decisions, and persuade others logically (Osborne, 2013). This is the reason why argumentation skills are so important. Argumentation skills train students to demand evidence and assess the quality of reasoning behind a claim. It is the most effective cognitive vaccine to combat the surge of disinformation. Argumentation turns the (emotional) coachman debate into a productive (data-based) discussion. Students learn that in SSI, there is often no absolute correct answer; instead, the best decision can be made based on the available evidence (Williams Jr..

Argumentation skills are the mother of almost all 21st-century skills, namely: critical thinking, creativity, communication, and collaboration. Argumentation is a form of critical thinking that is expressed (Kuhn & Udell, 2003). Students must analyze the data, evaluate the weaknesses of the opponent's arguments, and identify hidden assumptions. Argumentation trains students to structure their thoughts logically, sequentially, and persuasively, both verbally and in writing. Scientific argumentation is a social process. Students work in groups to build claims, then argue with other groups to refine a common understanding. Students are challenged to find new ways of interpreting data or finding unique evidence to support their claims (Berland & Reiser, 2009; Berland & McNeill, 2010).

Argumentation is the way science works. Science is a social process complete with debate. A scientist makes a claim (hypothesis), presents evidence (experimental data), and provides reasoning (theory). The scientific community will then attack, test, and try to rebuttal these claims (Jiménez-Aleixandre & Erduran, 2007). The scientific knowledge we receive today (such as the theory of evolution or the theory of plate tectonics) is an argument that has won long debates because it is supported by the most substantial evidence and the most logical reasoning. By practicing argumentation skills, we not only teach students about science but also help them develop the critical thinking and problem-solving skills characteristic of scientists (Osborne, 2010).

Based on findings from various studies in Indonesia, a general portrait of students' argumentation skills, both at the junior high and high school levels, reveals that these skills are still in the low to medium category and have not been adequately developed. Students are generally able to make claims, but tend to be weak in incorporating the more complex components that are at the heart of scientific arguments, such as data, warrants, and rebuttals. Research by Zairina & Hidayati (2022) on junior high school students in Surabaya found that 93.33% of students were only able to reach Level 2, and 6.6% were at Level 1. No student (0%) is able to reach Level 3, 4, or 5. This shows that the student failed to build an argument that included a rebuttal. Similar findings were also reported by Bahri et al. (2021) in high school students, who found that the quality of students' arguments remained relatively low. A study by Amielia et al. (2018) in Surakarta showed that although 44.08% of students were able to make claims, only 22.88% were able to include data, and only 20.43% were able to include warrants. This indicates a leap of logic where students jump to conclusions without being able to scientifically justify them. Similarly, research by Sadler & Donnelly (2006) shows that concept mastery significantly affects the quality of arguments, where Indonesian students with low concept mastery (as reflected in PISA scores) tend to have difficulty in arguing.

The facts indicate a significant gap between the global demand for scientific argumentation and the quality of graduates produced by Indonesia's education system. This competency deficit is clearly confirmed through international benchmarks. Data from the Programme for International Student Assessment (PISA) shows that Indonesian students' ability in scientific literacy, which includes the ability to understand, evaluate, and communicate scientific findings, is still relatively low, well below the Organisation for Economic Co-operation and Development (OECD) average. The trend of science literacy scores has continued to decline, from 403 points in 2015 to 396 points in 2018, and further to 383 points in the 2022 survey (Know & Do, 2019; OECD, 2024; PISA, 2023). Low scientific argumentation skills are a primary manifestation of weak science literacy. If a student has low argumentation skills, for example, they may only make claims without evidence or easily believe hoaxes without refutation. Their level of science literacy or ability to apply science in life is also weak. In contrast, students who are skilled in argumentation understand that science is about building the strongest arguments based on available evidence, which is at the heart of functional science literacy (Cavagnetto, 2010; Fakhriyah et al., 2022).

Based on a synthesis of various educational research studies in Indonesia, the low argumentation skills of students are attributed to traditional learning practices that have not yet adapted to meet the demands of 21st-century skills (Herlanti et al., 2019). The most fundamental weakness is the teacher-centered learning model. It serves as the sole source of truth. Learning is filled with teachers explaining and students taking notes. There is no room for students to question, refute, or argue (Jonassen & Kim, 2010). Argumentation skills require students who are actively building knowledge. However, in the lecture method, students are positioned as passive receivers of information. Teachers more often transfer "what" (facts) than practice "why" (reasoning) and "how do you know?" (evidence) (Shi, 2020).

Science learning in Indonesia is often treated as a product (a collection of facts) that must be memorized, not as a process (a way of thinking and investigating). The scientific concept is taught as a final fact that must be accepted, not as the best argument that scientists build on evidence (Fischer et al., 2014; Kuhn, 1993). A preliminary study conducted by researchers involving 20 junior high school science teachers in the city of Bandar Lampung revealed some alarming facts: 57.9% of teachers reported that they had not received training in specific argumentation skills, particularly in biotechnology-related materials. In addition, 78.9% of teachers stated that students did not dare to argue or answer questions, which, according to 94.7% of teachers, was attributed to students' low confidence in expressing their opinions. Even if there are students who dare to express their opinions, the ideas expressed are often not supported by relevant facts (89.5%), or their arguments are limited to self-statements (claims) without supporting data or facts. In addition, students are rarely faced with complex real-world problems and do not have a single correct answer; they also do not encounter socio-scientific issues.

Biotechnology materials should be taught through socioscientific issues. Using socio-scientific issues changes the focus of learning from "what is biotechnology?" (memorization) becomes "should we do it?" (analysis and evaluation). The socio-scientific issues are ill-structured and do not have one correct answer. The issue of biotechnology is the perfect "training arena" (gymnasium) for practicing debate. To engage in debate, students cannot rely solely on opinions. They must build arguments (claims) that are supported by evidence (data) and guarantees (scientific/ethical principles), and be able to rebuttal (the opponent's arguments). It is a direct practice of scientific argumentation skills (Noris et al., 2025; Nurtamara et al., 2019).

Healthy argumentation actually thrives on differences of opinion, or "cognitive conflicts" (confusion or conflict of ideas), which encourage students to think more deeply (Potvin, 2023). Class culture in Indonesia often avoids this. Scientific debate activities are often considered "a waste of time", "noisy", or "rude" if students refute their teacher or friend. Group discussions are often ineffective. The dominant interactions are teacher-to-student (asking) and student-to-teacher (answering). Student-to-student interaction for constructive criticism of each other's ideas is minimal. A total of 20 junior high school teachers in Bandar Lampung stated that the existing learning process tends to limit opportunities for expressing opinions, allowing only teacher-initiated questions and answers or standard presentation sessions. Students rarely engage in rebuttal sessions against their peers' opinions, so they tend to be passive and agree with other opinions without defending their own ideas. Middle school students are naturally interested in controversy, justice, and issues relevant to their future (Öztürk & Okumus, 2022). When students feel their voices and values are heard in an authentic dilemma, their motivation and engagement in learning the underlying scientific concepts will increase dramatically. By discussing these issues in class, students are trained to evaluate claims based on the quality of the evidence. They learn to distinguish between scientific evidence, pseudoscientific claims, and value considerations. They become more critical consumers of information (Jiménez-Aleixandre & Erduran, 2007).

To address this complex problem, an innovative pedagogical intervention is needed, namely by adopting a learning model that explicitly demands evidence-based reasoning and a high level of cognitive engagement. The Argument-Driven Inquiry (ADI) learning model, which integrates STEM (Science, Technology, Engineering, and Mathematics), can be a highly effective solution because it fundamentally changes the way students learn science and explicitly trains the components of argumentation that have been missing in traditional learning. If traditional learning is a passive approach (accepting facts), ADI-STEM is an active model (building and defending arguments) that is grounded in real-world problems. ADI is designed as a pedagogical framework to help students learn to participate in scientific arguments (oral and written). This model explicitly scaffolds students to construct coherent and evidence-based arguments (Walker et al., 2011). Argumentation sessions in ADI help students understand the essence of science, which is that science is not a collection of facts, but rather a social process that involves criticism, evaluation, and revision. This process is at the heart of rebuttal exercises (Walker & Sampson, 2013). The integration of STEM methods in the ADI model enhances the depth and relevance of learning by situating argumentation in real-world, real-life scenarios (Duggan, 2022; Suganda et al., 2023). For instance, scientific thinking (Science) is applied in formulating research questions and hypotheses; engineering concepts (Engineering) are applied in crafting investigations or designs; mathematical ability (Mathematics) is applied in analyzing and interpreting data; and technologies (Technology) are applied in experimentation and dissemination. Such intermingling not only strengthens conceptualization but also enhances transferable skills, such as problem-solving, teamwork, and reflective thinking (Purnomo et al., 2023). Additionally, the Claim–Evidence–Reasoning (CER) framework and the Toulmin Argumentation Pattern (TAP) are scaffolded structures that enable students to build coherent and valid scientific arguments. It is this authentic context that provides "fuel" for students to make inquiries and argue about which solution is the most feasible. Thus, ADI-STEM becomes a bridge to train engineering practices (designing solutions) and science practices (arguing from evidence) simultaneously (Grooms et al., 2015).

The scientific literature indicates that the ADI-STEM synergy has a positive influence. Research by Hikmah et al. (2023) found that STEM-integrated ADI has a significant effect on improving critical thinking skills. Purnomo et al. (2023) also found that ADI-STEM is effective in improving science literacy. Specifically, the ADI model, when integrated with the STEM approach, has also been shown to have a significant influence on written argumentation skills. However, another challenge in implementing ADI is the aspect of learning media. Andriani et al. (2022) noted that although the ADI model has been widely implemented, some implementations still utilize electronic teaching materials, such as electronic learner worksheets. In fact, the use of electronic learner worksheets is an important implementation of technological advances and the demands of 21st-century learning. Electronic learner worksheets offer significant advantages over conventional learner worksheets, including interactivity, time and space effectiveness, and flexible accessibility (Liu et al., 2024). This interactive teaching material can integrate text, images, sounds, animations, and videos. One of the popular platforms used to create electronic learner worksheets is e-Liveworksheets. The platform provides a variety of interactive features (such as drag and drop, listening, and drop-down) and allows educators to monitor learners' progress directly. Studies have shown that e-Liveworksheets have proven to be valid, practical, and effective in improving learning outcomes (Prastika & Masniladevi, 2021). Studies that combined ADI with electronic learner worksheets (without STEM) were also reported to be effective in improving argumentation skills. Based on this review, it can be stated that although the effectiveness of ADI-STEM and the effectiveness of ADI-based e-Liveworksheets have been studied separately, there is still limited research that combines the three components of the ADI model, the STEM approach, and the e-Liveworksheets in an integrated manner to improve argumentation skills on complex science materials. This research aims to fill this gap by developing and testing products in the form of the ADI-STEM-Based Biotechnology e-Liveworksheets (ASBL). Specifically, the purpose of this study is to describe how the features in the ASBL facilitate the construction of the components of students' scientific arguments.

▪ METHOD

Participants

The population of this study consists of all ninth-grade students of SMPN 1 Tanjung Bintang, totaling 266 individuals, divided into seven classes. Sampling from this population is carried out using purposive sampling, which involves selecting participants from existing classes. Purposive sampling is a non-probability method chosen because the subject meets certain criteria and is specifically available for research (Creswell & Creswell, 2017). In the context of this design, the researcher objectively (purposively) selected one class that best suited the treatment criteria, namely, students with high academic ability compared to students in other classes. Based on this technique, students from Class IX A (n = 30) were selected as the research sample.

This study used a one-group pretest-posttest design. In this design, the confounding variable of the students' heterogeneous academic abilities can obscure the actual effectiveness of the treatment. Therefore, the sample (n = 30) was selected using purposive sampling with specific criteria to create a homogeneous sample. By selecting classes with high academic ability (which was objectively measured), researchers controlled for the variability in students' initial abilities. The criterion of high academic abilities is defined as students in grade IX A who have the highest average score in the Biology subject in the previous semester, compared to other parallel classes.

Research Design and Procedure

This study employed a developmental research method aimed at producing ADI-STEM biotechnology e-Liveworksheets. The development model used is the 4-D model (four D), proposed by Thiagarajan (1974), which encompasses four main stages: Define, Design, Develop, and Disseminate (Figure 1).

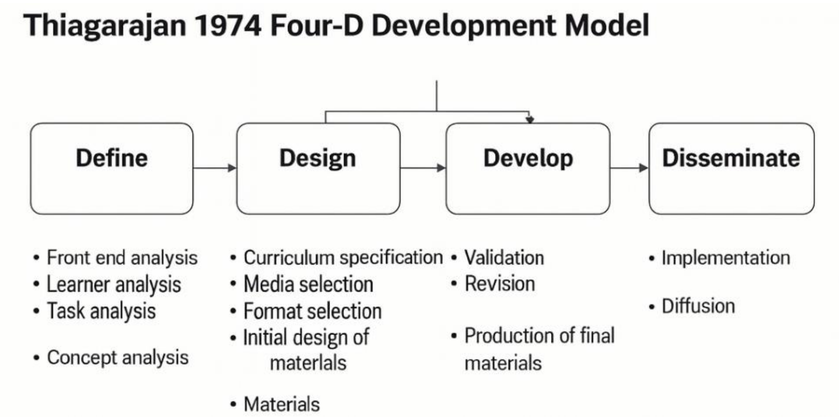

Figure 1. Developmental research model with thiagarajan (1974)

This development model was chosen to ensure a systematic and tested development of the learning product, guaranteeing that the resulting ASBL is valid and practical in achieving the predetermined learning objectives. In other words, this developmental research enables the refinement of educational products through user testing and feedback.

The Define stages began with an initial analysis to identify challenges faced by educators in teaching biotechnology. This analysis involved distributing questionnaires to 20 junior high school science teachers in Lampung Province to investigate issues such as pedagogical difficulties, inconsistencies between teaching materials and learning models, and other factors contributing to students' weak argumentation skills. Subsequently, a student analysis was conducted by administering questionnaires to 20 students to obtain information about their characteristics, including academic ability, learning motivation, and pre-existing argumentation skills. A task analysis was then conducted to systematically break down the content into specific learning steps and required behaviours. A concept analysis complemented this analysis, organizing the learning material into a logical and coherent structure. The define stage culminated in the formulation of clear, measurable, and achievable learning objectives to guide subsequent development stages.

The Design stage serves to produce the ASBL blueprint for the instructional materials, translating the conceptual framework from the Define stage into a concrete plan. Key activities include selecting appropriate assessment instruments, such as tests, performance tasks, and rubrics, to evaluate students' argumentation skills. Decisions regarding media and format are also finalized at this stage, considering the most effective content delivery methods, including text, visuals, audio, and interactive components. The final output of this stage is a preliminary draft of the ASBL, which integrates all planned argumentation content, activities, and assessment tools.

The Development stage began with validation by subject matter experts to ensure content accuracy and pedagogical feasibility. Afterward, a testing and revision cycle began to identify and address any weaknesses. This stage included a small-group pilot with 9th-grade junior high school students to solicit feedback on the learning process from students. The main purpose of testing at this stage is not to measure student learning outcomes but to get feedback to improve product drafts (media, worksheets, modules, etc.). Researchers wanted to know if ASBL products were confusing, not whether the content was difficult. This more detailed feedback is invaluable for researchers to make targeted revisions to their products. These trials are often also referred to as one-to-one evaluations or small group evaluations whose purpose is to find "holes" or errors in product drafts.

The Disseminate stage involved the formal implementation of the refined ASBL products. In the Disseminate stage, which is the final stage of product development, the researcher's primary goal is to package and share the validated product so it can be adopted and used by other educators. In this study, the researcher did not perform the dissemination stage.

Instruments

This study utilized five primary instruments for data collection: (1) a needs analysis questionnaire; (2) a test of scientific argumentation skills, based on Toulmin's Argumentation Pattern (Toulmin, 2003); (3) expert validation rubrics; and (5) response questionnaires for teachers and students.

The needs analysis was conducted using a four-point Likert-type questionnaire administered to science teachers in Lampung Province. Response options ranged from 'strongly agree' (4) to 'strongly disagree' (1). The questionnaire for teachers and students includes questions about descriptions of science learning, learning resources, and the availability of e-learning, adopted from research by Restanti et al. (2023).

The scientific argumentation skills test was designed to evaluate the quality of students' claims, evidence, and reasoning. Pre-tests and post-tests were administered using a validated instrument based on Toulmin’s Argumentation Pattern (TAP), as outlined in the assessment rubric adopted from Sampson & Clark (2008) and shown in Table 1. A total of 20 questions, the pretest-posttest had a correlation coefficient value (r) greater than the r value in the table, and the Cronbach's alpha value of 0.803 ($p > 0.05$) fell into a high category. Thus, the argumentation skill test used is valid and reliable, allowing the pretest-posttest questions to be employed in research to measure students' argumentative skills.

Table 1. Rubric for Assessing Scientific Argumentation (Sampson & Clark, 2008)

Component	Level 1: Beginning	Level 2: Developing	Level 3: Proficient
Claim	Makes an inaccurate claim or no claim at all.	Makes an accurate but simple or incomplete claim.	Makes an accurate, complete, and specific claim.
Evidence	Provides no evidence, or the evidence is irrelevant to the claim.	Provides appropriate evidence, but it is insufficient to fully support the claim. May include some irrelevant data.	Provides sufficient and relevant, high-quality evidence to support the claim.
Reasoning	Provides no reasoning or repeats the claim as the reason. The link between evidence and claim is not explained.	Provides reasoning that links the claim and evidence, but the link is weak or does not connect to a larger scientific principle.	Provides clear, logical reasoning that explicitly links the evidence to the claim and is supported by established scientific principles.

Expert validation of the ASBL was performed using a Likert-scale rubric. This rubric assessed key components, including content relevance, instructional clarity, visual design, and fidelity to ADI-STEM principles. The expert validation carried out in this study is a systematic evaluation process conducted by experts in their respective fields, specifically two lecturers who are both material experts and instructional design experts, to assess the validity of product drafts. This validation is conducted to ensure that the material or content in the learning product, specifically the ASBL, is scientifically accurate, free from misconceptions, and relevant to the curriculum objectives. Expert validation is a crucial component of the formative evaluation conducted during the development process, assessing whether the developed product aligns with the learning theory or learning model that is claimed to be its foundation. This study also involved one practitioner (senior teacher) to assess the feasibility and practicality of the ASBL. This senior teacher can provide input on whether the product is realistic to apply in the classroom. A product that is valid in content and construct but impractical will fail to be adopted by users. These expert and practitioner validation tests provide an objective external view to identify weaknesses that developers may not be aware of.

The practicality of the ASBL was evaluated through response questionnaires administered to both educators and students. Student responses are considered very important in this study because students are the end-users of learning products. They can assess whether the ASBL is confusing, unappealing, or challenging to use. In other words, student responses focus on evaluating three crucial aspects: usability, attractiveness, and clarity from the student's perspective. Usability refers to the extent to which students can effectively, efficiently, and satisfactorily use a product to achieve their learning objectives. Additionally, it is used to measure interest and motivation, as well as to identify learning difficulties.

Data Analysis

The data obtained in this study were analyzed using both quantitative and qualitative approaches to provide a comprehensive understanding of content validity, construct validity, and practicality. In this case, quantitative data provides a way to generalize, while qualitative data provides information about context and setting. Qualitative data (preliminary study data, expert validity data, practicality validity data, and student response data) will be analyzed using a descriptive qualitative approach. Through this analysis, an overview will be obtained of the needs in the field, the needs of teachers and students in learning, the problems faced by teachers and students in learning, the availability of worksheets, the components of worksheets that need to be revised, the level of validity and practicality of student worksheets, and student responses to the ASBL produced. Quantitative data, in the form of students' argumentative skills, will be analyzed using a descriptive quantitative approach to obtain an overview of their quality. If the results do not meet the learning objectives until they reach certain criteria, the entire learning tool will still be improved.

The validation of the product data was analyzed descriptively by calculating the percentage of validity scores and categorizing them into four categories: "very valid," "valid," "quite valid," and "less valid" (Putri et al., 2020). Students' argumentation skills were analyzed using a scatter plot of the relationship between students' pretest and posttest scores to determine whether there was an improvement before and after the implementation of the learning product. This analysis is important because it aims to see "does this product work in the field?" before it is tested more rigorously. Furthermore, qualitative data obtained from observations and interviews were analyzed using qualitative descriptive techniques to provide in-depth insights into the feasibility and implementation process of the learning product in the classroom, including teacher and student responses during learning activities. By combining quantitative and qualitative analysis, this study provided a holistic answer to questions regarding product validity, user acceptance, and its impact on students' argumentation skills. Summary of research data analysis techniques as shown in Table 2.

Table 2. Summary of research data analysis techniques

Type of Data	Data Collection Instrument	Analysis Technique	Purpose of analysis
Product Validation Data	Expert validation questionnaires	Descriptive statistics (percentage and category)	To determine the validity level of the product
Student Learning Outcome Data	Pre-test and post-test assessments	Scatter Plot	To examine improvement in students' argumentation skills
Qualitative Data	Observation and interview	Descriptive qualitative analysis	To describe the feasibility and implementation process of the product

▪ RESULT AND DISSCUSSION

This section outlines the systematic process of creating and validating the ASBL centered on students' argumentation skills. The development procedure follows the 4D model stage of Definition, Design, and Develop, excluding the Dissemination stage. It combines the results of each stage, offering a clear narrative of how the ASBL were developed, and their theoretical foundations as demonstrated by a trial with junior high school students in Lampung Province, Indonesia.

Define Stage: Foundational Analysis

The initial stage of this research, the Define stage, focused on laying a strong foundation for developing the ASBL. This involved a multi-dimensional analysis to ensure the tool would be relevant, appropriate, and effective for its purpose. Based on the analysis of the questionnaire results from 20 science teachers throughout the city of Bandar Lampung, information was obtained about the problems teachers face in learning Biotechnology material, as detailed in Table 3.

Table 3. Preliminary analysis results (front-end analysis)

No	Statement	Percentage
1	Teachers experience difficulties in teaching Biotechnology material.	89.5%
2	Difficulties faced by teachers:	
	1. Lack of laboratory technology	63.2%
	2. Lack of adequate learning resources	26.3%
	3. Lack of adequate teaching materials	36.8%
	4. Lack of learning media	21.1%
	5. Student learning motivation	47.4%
3	Learning models often used in teaching Biotechnology material:	
	1. Argument-Driven Inquiry (ADI)	0%
	2. Problem-Based Learning (PBL)	31.6%
	3. Project-Based Learning (PjBL)	42.1%
	4. Inquiry Learning	10.5%
	5. Contextual Learning	10.5%
	6. Cooperative Learning	5.3%
4	Teachers are familiar with the ADI learning model and its stages.	31.6%
5	Teachers have applied the ADI learning model in teaching.	5.3%
6	Teachers know the STEM approach.	89.5%
7	Teachers apply the STEM approach in teaching.	57.9%
8	Teachers know that the ADI model can be integrated with the STEM approach.	26.3%
9	Teachers are familiar with teaching materials in the form of e-Liveworksheets (Electronic Student Worksheets).	21.1%
10	Teachers know the Liveworksheets application.	78.9%
11	The school allows students freedom to use mobile phones in the learning process.	62.3%
12	The school provides Wi-Fi facilities to support the learning process.	31.6%
13	Teachers know about argumentation skills.	78.9%
14	Teachers have trained students in argumentation skills for science learning, especially in biotechnology materials.	42.1%
15	Students appear confident in expressing opinions.	5.3%
16	Students are brave in asking questions and expressing opinions.	21.1%
17	Students can use good and correct language when expressing opinions.	10.5%
18	Teachers are interested in using ADI-integrated STEM-based e-Liveworksheets in the learning process.	94%

Based on Table 3, it was found that most teachers (89.5%) experienced difficulties in learning science material, particularly Biotechnology material. Factors that cause difficulty in learning biotechnology materials include a lack of laboratory equipment, inadequate student motivation, insufficient teaching materials, limited learning resources, and insufficient learning media. The teaching model often used by teachers in learning Biotechnology material is the Project-Based Learning (PjBL) model. However, there are limitations in practicing argumentation skills among students, so that their argumentation skills remain relatively weak. Only 5.3% of teachers have implemented the ADI learning model, 57.9% have implemented the STEM approach, and 26.3% know that the ADI model can be integrated with the STEM approach. This is due to the lack of training, knowledge, and socialization with related teachers.

Additionally, a learner analysis was conducted to understand the target students, specifically junior high school students in Lampung, Indonesia. This considered their cognitive development, prior biology knowledge, and typical learning styles. Recognizing that students are transitioning from concrete to abstract thinking, yet still rely heavily on visual aids. The ASBL was designed to be visually engaging and scaffolded to support the construction of the components of students' scientific arguments (claims, evidence, reasoning). Students tend to be more interested and motivated when they are directly involved in an active, exploratory, and experience-based learning process that incorporates real-life experiences. In addition, the investigative process provides an opportunity for learners to cooperate and take responsibility in a team that exchanges ideas, much like scientists, where they not only passively receive information but also build knowledge through the investigative process.

After recognizing this need, a learning analysis was conducted to align the instrument with the Indonesian Independent Curriculum for Phase D (Classes VII-XI). This curriculum emphasizes conceptual understanding and practical application of knowledge. The learning objective is centered on students' ability to understand the application of Biotechnology in daily life. Key topics include: Basic concepts of conventional and modern biotechnology, Biotechnology products used in the surrounding environment, the process of applying food biotechnology in daily life, the positive and negative impacts of applying food biotechnology in the surrounding environment, and the benefits and challenges of using biotechnology in local food processing. This is the basis for learning materials on Biotechnology Innovation, which often involve project activities and arguments that can be difficult for beginners to interpret accurately.

Concept analysis breaks down the broad topic of biotechnology into specific concepts and skills. The main focus is on the implementation of the ADI-STEM learning model through e-Liveworksheets, specifically so that, through task identification activities, data collection, production of tentative arguments, interactive argumentation sessions, preparation of reports, double-blind peer review, and reflective discussions, students can understand the application of food biotechnology in meeting daily needs. Based on the learning outcomes, the concepts to be learned are obtained, specifically related to the depth of Food Biotechnology in daily life, which includes conventional food biotechnology such as tempeh, tapai, and yoghurt, as well as the biotechnology processes that occur in these products.

Design Stage: Structuring the Assessment

In the Design stage, the conceptual foundation from the Define stage was transformed into the ASBL tangible structure. This process involved systematically specifying test items, selecting media, designing formats, and creating an initial prototype. The ASBL compiled is expected to facilitate the complex 8-step syntax of ADI. This means that the e-Liveworksheets must have features to guide investigations, provide collaborative workspaces for data analysis, and provide a platform for argumentation sessions and peer review. In the face of the challenge of integrating STEM, the ASBL is centered on authentic engineering problems. Designing real-world, challenging, yet still solvable problems for students with digital tools (Technology & Math) and relevant Science concepts.

The design was heavily influenced by the ADI model, developed by Sampson & Walker (2012), which, integrated with STEM (Science, Technology, Engineering, and Mathematics), is designed to produce contextual, collaborative, and solution-oriented science learning. This integration emphasizes the importance of 21st-century skills, mastery of cross-disciplinary concepts, and the development of global awareness while remaining grounded in local wisdom. The ASBL was created using the Canva application and Liveworksheets, as shown in Figure 2.

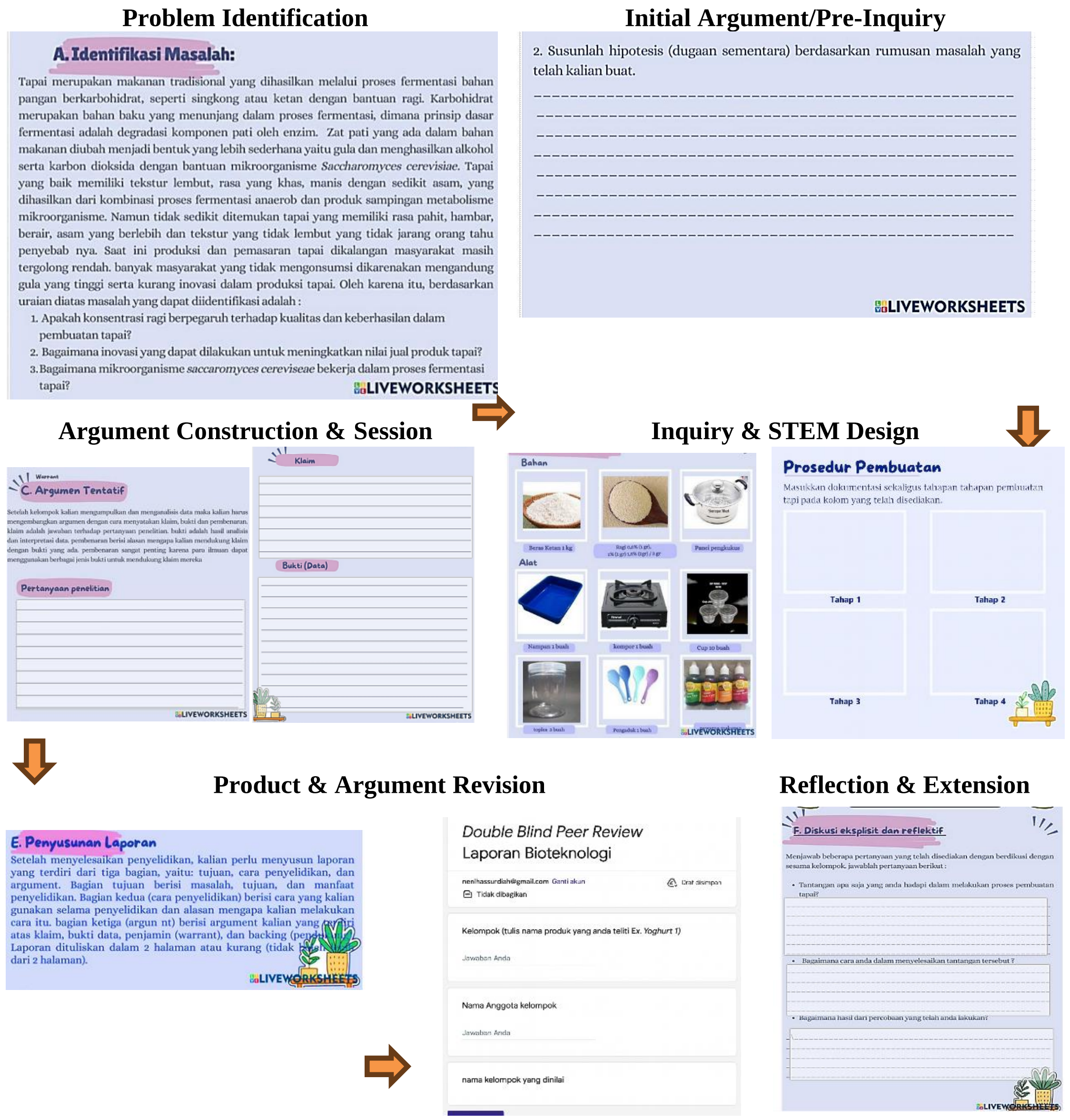

Figure 2. Biotechnology learning activities with the ASBL

The first stage of the STEM-integrated ADI model is task identification. At this stage, students focus on the topic of discussion introduced by the educator. Then the educator connects the topic with the students' past and present learning experiences (what the students already know and do not know). The integration of the STEM approach at this stage primarily involves the science aspect. Next, students formulate two problem questions that will be investigated during the data collection process. At this stage, it is hoped that students will clearly understand the problems to be investigated.

The second stage is data collection (investigation). At this stage, the teacher divides the students into several groups to work collaboratively on conducting experiments, investigations, and observations related to the phenomena being studied. Students can collect data systematically to answer research questions that have been formulated beforehand. In this process, the STEM approach applied is the engineering aspect in designing and carrying out experimental tools or procedures, as well as the mathematical aspect in analyzing and presenting research data. At this stage, it is hoped that students can develop scientific skills, critical thinking, and the ability to work collaboratively, as well as connect science concepts with their real-life applications in an integrated manner.

The third stage is the production of tentative arguments. At this stage, students work in groups to draft scientific arguments in writing. The arguments prepared consist of three main components: claim (a statement or answer to research questions), ground (data or observation results from investigations conducted), and warrant (a logical explanation connecting the evidence to the claim). Students are expected to be able to develop coherent and evidence-based argumentation schemes. The aspects of the STEM approach applied are Science (students' knowledge to formulate arguments) and mathematic (to analyze and calculate numerical data, interpret graphs, or calculate the results of experiments to strengthen their claims). Through this process, students are trained to articulate ideas, evaluate evidence, and apply logical reasoning. Group discussions enable learners to assess one another and refine their arguments, thereby identifying and correcting inaccurate assumptions or conclusions. Thus, this stage aims to improve students' critical thinking skills and scientific argumentation skills.

The next stage is the interactive session of arguments. At this stage, students from each group presented scientific arguments that they had prepared beforehand. The argument includes claims, evidence, supporting reasons, and supporting sources. Furthermore, other groups respond to the form of questions, criticisms, inputs, or suggestions to the arguments presented. The STEM approach applied is the science aspect. This stage aims to evaluate and improve the quality of students' arguments, as well as determine the most valid claims based on evidence and logical reasoning. In addition, learners are trained to think critically, respect others, and develop scientific argumentation skills. This activity also encourages students to critically review the product of the investigation (claim or argument), the investigation process (method), and the context (theoretical foundation) of the investigation, thereby improving their understanding of the scientific concepts being studied.

The fifth stage involves preparing reports. At this stage, the Learner compiles an individual investigation report that explains the research objectives, methods used, and investigative steps and provides well-reasoned arguments. The sixth stage is Report Review and double-blind peer review. Students are allowed to assess each other, evaluate quality, and provide feedback to their peers. The assessment is conducted using a review sheet provided by educators. The STEM approach applied is engineering and science.

The seventh stage involves students revising the report based on the peer review results. At this stage, if the revised report has reached a satisfactory and acceptable level of quality, then it can be finalized. However, if the revision of the report is not acceptable, it will be returned to the author for revision. The final stage in the ADI model is reflective discussion. At this stage, students reflect on the entire investigation process they have undergone, from identifying problems to preparing the final report. This discussion aims to evaluate the understanding of the concept, the effectiveness of the methods used, and the quality of the arguments that have been built. Through this reflection, students are expected to identify strengths and weaknesses in their learning process and plan improvements for future investigation activities.

Develop Stage: Validation and Refinement

The Develop stage focuses on the empirical evaluation and refinement of the learner worksheet through pilot testing, confirming its validity, practicality, and characteristics as an ASBL. Validity is a crucial aspect in the development of instructional tools, as it ensures that the developed materials align with the intended competencies and the characteristics of the learners. In this study, the validity of the ASBL was assessed by experts and practitioners, with a focus on content suitability, design, construction, and readability. The result revealed that the overall average score reached 87.4%, which is categorized as "very good" (see Table 4), indicating that the developed ASBL is valid and can proceed to the next stage with minor revisions.

Table 4. Expert validation results of the ADI-STEM-Based e-Liveworksheets

Aspect	Score (%)	Category
Content Suitability	85.2%	Very Good
Design Construction	88.7%	Very Good
Average	87.4%	Very Good

In the content validation sub-aspect, the alignment of the ASBL components and learning objectives was found to be 87.5%, while the alignment with the curriculum learning outcomes scored equally at 87.5%. The appropriateness of activities and questions to foster scientific argumentation scored 75%, indicating that minor improvements were needed to provide more explicit argumentation prompts (see Table 5).

Table 5. Detailed content validation results

Component	Score (%)
Alignment with ADI-STEM-Based Biotechnology e-Liveworksheets	87.5%
Alignment with curriculum learning outcomes	87.5%
Activity relevance to learning goals	75.0%
Question alignment with goals and learning targets	75.0%
Appropriateness of text content and scientific context	87.5%
Text stimuli to identify problems	87.5%

The validation model used in this study refers to Nieveen's framework, which states that a learning tool is considered valid if experts assess all its components as relevant and aligned with the needs and context of the learning environment. Furthermore, according to Akbar & Zahfa (2025), content validity is crucial in ensuring the alignment of teaching materials with the demands of the applicable curriculum. Furthermore, content validity considers the substance of the material, the presentation structure, the appropriateness of the language, and the suitability of supporting media. Expert evaluations indicate that the developed tool encompasses these aspects holistically, making it suitable for classroom implementation. As stated by Utaberta & Hassanpour (2012), valid learning tools must be directly aligned with learning outcomes and able to accommodate student characteristics.

Furthermore, the content validity supports previous work by Prastika & Masniladevi (2021), who emphasize that learning materials designed with technological platforms such as Liveworksheets can promote conceptual understanding if properly aligned with inquiry models. The validation also shows strong curriculum alignment, particularly with the Indonesian Merdeka Curriculum Phase D, which emphasizes the development of scientific communication and reasoning skills. The explicit inclusion of biotechnology content ensures contextual relevance, aligning with Bybee's (2013) claim that STEM-based materials should address real-life and meaningful scientific contexts. Moreover, the ASBL design encourages learners to construct arguments grounded in scientific evidence actively, fulfilling the demands of both curriculum goals and 21st-century learning standards (Osborne, 2010; Trilling & Fadel, 2009).

A subsequent empirical validation involved 30 Grade IX A students from SMPN 1 Tanjung Bintang, with data analyzed using SPSS 27.0 software. The next empirical validation involved 30 grade IX students from SMPN 1 Tanjung Bintang. The results from the small group trial and field testing, conducted using a quasi-experimental design with a one-group pretest-posttest design, showed a significant increase in scores from the pre-test to the post-test (see Figure 3).

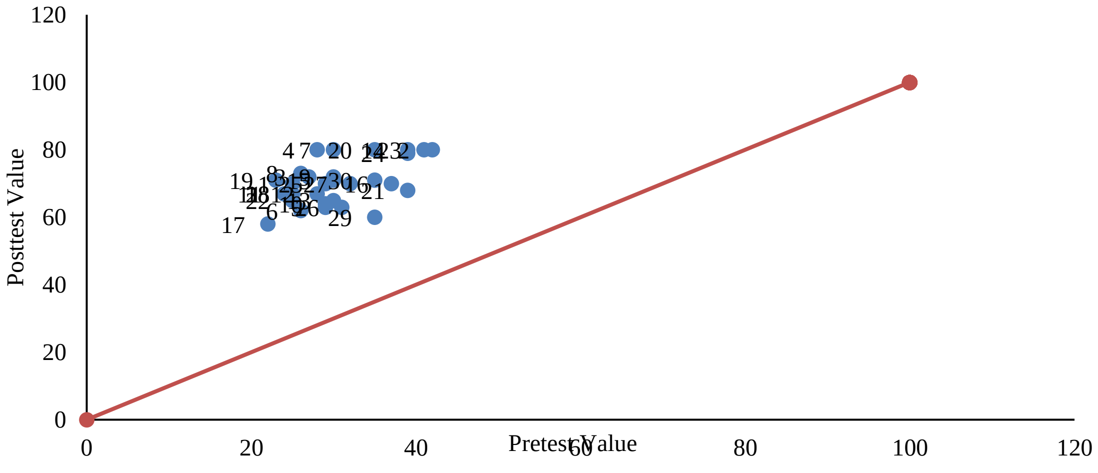

Figure 3. Increase in posttest score from pretest score of the scientific argumentation skills

Based on Figure 3, it is known that each student experienced an increase in score (gain) after treatment (post-test) compared to the score before treatment (pre-test). This conclusion is drawn because all data points (representing students 1-30) are above the diagonal line (red line) or are in the "Improvement" quadrant. This shows that the interventions or learning that occur between pre-tests and post-tests have a consistent positive impact on each individual. There was a substantial increase in students' argumentation skills after participating in the learning process using the ASBL.

These findings suggest that the use of ASBL can enhance students' argumentative skills in constructing complete and data-based claims. Learning using the ASBL in this study has been proven to not only help students in writing claims, but also encourage the linkage between theory and scientific practice. A claim is a central component in scientific argumentation because it shows students' conceptual understanding of the phenomenon being studied. In the learning process using the ADI model, making a statement or claim is a crucial first step because it is the basis of the entire structure of the scientific argument (Walker & Sampson, 2013). Students who can make claims appropriately usually have good conceptual understanding and are able to relate phenomena to relevant scientific knowledge (McNeill & Krajcik, 2008). On the other hand, the integration of digital media, such as Electronic Learner Worksheets using Liveworksheets, supports data visualization and logic mapping, which ultimately helps students formulate Claims based on evidence more systematically and explicitly (Osborne, 2010). In the context of learning with ASBL teaching materials, it can be observed that electronic teaching materials not only facilitate the formulation of claims but also encourage a more systematic relationship between claims, evidence, and reasoning.

Furthermore, students' ability to make evidence based on the results of the research also experienced an increase in the high category, showing that the increase in students' ability to form evidence as part of the argumentation structure showed that students began to get used to collecting, selecting, and presenting relevant data as the basis for the claims they made. In the context of the ADI model, this ability is a crucial stage because evidence functions as a direct link between the observations made and the conclusions drawn. The ADI model systematically directs students not only to passively receive data, but also to analyze and evaluate its quality and relevance to the scientific problem under study (Sampson et al., 2011).

The integration of STEM in the ASBL in this study also strengthened the increase in evidence, as students were involved in project-based activities and experiments that required them to collect quantitative and qualitative evidence from various sources. The skill in gathering the correct data to support a claim is an important indicator in mature scientific arguments (McNeill & Krajcik, 2008; Andriani et al., 2022). Therefore, learning facilitated with teaching materials such as the ASBL not only improves content knowledge, but also equips learners with the scientific skills to develop strong and convincing data-based arguments, not just copying observational data, but involves a high-level thinking process in selecting the most relevant data, interpret the results, and relating them to theory. This process is made more effective with the support of data visualization through the feature in the e-Liveworksheets, which encourages learners to map the relationships between variables and construct well-structured arguments.

The ability of students to reason has also increased. This indicates a development in students' ability to build a complete argument, especially in explaining why the data presented supports the claims made in this case, related to investigations into food biotechnology materials. Reasoning serves as an "inference rule" that provides logical permission to transition from data to a claim, thereby bridging the logical relationship between data and claims. In the absence of reasoning, the claim appears to be merely a personal opinion with an unclear basis, despite the fact that data from a study by Weyand et al. (2018) already exists. In forming reasoning, it is necessary to understand the context of the discipline and interpret the data appropriately; therefore, a theoretical basis or scientific principle is needed that strengthens claims and evidence (Toulmin, 2003). In learning using the ASBL, students are invited to refer to theories, scientific laws, or previous findings in formulating their arguments. The integration of STEM in the ADI model encourages the integration of knowledge across disciplines so that strong arguments require theory-based justification (Johnson et al., 2020). In addition, students are directed to cite scientific laws, previous research findings, or relevant theoretical concepts when formulating reasoning to build arguments that are disciplinary and scientific (Jiménez-Aleixandre & Erduran, 2007).

Through empirical validation, practical data on the ASBL were also obtained. Practicality in developing learning tools refers to the extent to which the tool can be used effectively, efficiently, and easily understood by users, both teachers and students, in a real classroom environment. This aspect is crucial because a theoretically valid tool may not be applicable in practice. Therefore, practicality serves as a bridge between conceptual design and implementation in a real classroom. In this study, practicality was assessed using the teacher self-assessment questionnaires and student responses to the digital learning tools used. Student responses were also considered an important indicator of practicality. The questionnaire results indicated that the majority of students (over 85%) found the ASBL easy to use, engaging, and helpful in guiding their learning process. Teachers reported that the platform enabled efficient progress tracking and assessment of students' argument construction at each learning phase. Additionally, the digital format allowed for flexibility in access and use, with teachers praising features such as automated response checking and multimedia integration (See Table 6). This finding aligns with Plomp (2013), who emphasized that high-quality learning tools should be usable optimally by both teachers and students without significant difficulties.

Table 6. Student and teacher response to ASBL

No.	Statement: ADI-STEM Based Biotechnology e-Liveworksheets…	Percentage (%)
1.	Helps practice expressing opinions.	81.60
2.	Encourages being active in expressing opinions.	71.67
3.	Makes one confident in expressing opinions.	81.70
4.	More innovative in creating food biotechnology products.	80.00
5.	Helps with meticulous in constructing arguments.	76.60
6.	Makes it easier to answer questions based on facts.	80.00
7.	Makes it easier to understand the daily life application of biotechnology	90.00
8.	Prevents getting bored during learning.	78.30
9.	Makes it easier to understand the material.	81.70
10.	Encourages being more active in collecting data.	72.00
11.	Helps practice critical thinking.	83.30
12.	Encourages being more active and creative in developing ideas.	83.30
13.	Provides a memorable learning experience.	80.00
14.	Helps practice creative thinking.	83.30
15.	Helps practice systematic thinking.	80.00

16.	Makes it easier to create food biotechnology products.	88.30
17.	Makes it easier to find facts and data.	73.30
	Average	80.29

Overall, these results indicate that the learning tool meets the criteria of practicality in all aspects, including technical implementation, ease of use, and effective support for the teaching and learning process. Thus, the developed tool is not only content-valid but also highly practical and ready for use in a real-life classroom environment.

▪ CONCLUSION

This research successfully developed and validated the ASBL, a teaching material designed to measure the argumentation skills of Indonesian junior high school students related to biotechnology. The results of the development process confirm the potential of the ASBL as a high-quality teaching material. Expert validation results showed that the material was categorized as very good (87.4%), reflecting its suitability in terms of content relevance, material presentation, language clarity, and support for curriculum demands and student characteristics.

The practical implications for education are significant. In Indonesia, the ASBL can serve as teaching materials that can improve students' argumentation skills. This teaching material was proven by a significant increase in students' abilities to formulate claims, provide evidence, and justify reasoning, according to the TAP indicators. Students can formulate initial claims or hypotheses based on the identification of real, contextual problems. Students are able to formulate claims that directly address the identified "Inquiry Questions." For example, if the question is "Does yeast concentration affect tape quality?", then the student's claim is "We think yeast concentration affects tape quality". Claims submitted by students are specific and can be tested through investigation or experimentation. Students no longer make statements that are too general or opinion-driven. Furthermore, Students are able to select and present the most relevant data to support their claims. For example, students present a "Table of Tape Observation Results" that shows differences in quality (texture, taste, aroma) at different concentrations of yeast. Students are able to organize their evidence systematically, for example, in the form of tables, graphs, or mathematical analysis, rather than simply narrating it. Students can articulate logical explanations that connect specific data (evidence) to their claims. Rather than just restating the data, students interpret it. For example, a student wrote: "From the experiments that have been carried out... Yeast concentration affects... In our observations, the concentration of 1% yeast... soft texture... 0,5%... the sweetness is slightly sour...". This shows the student is explaining the patterns in the data. Ultimately, students are able to strengthen their reasoning by connecting it to scientific principles, theories, or even other relevant research results. "Basically, good tape quality is... Slightly sour sweetness..." and this demonstrates the ability to validate their interpretations using broader scientific knowledge.

Moreover, the ASBL was assessed as very practical based on teacher self-assessments and student responses, indicating that the material was easy to understand and implement in a real classroom environment. Implikasi praktis untuk pendidikan sangat signifikan.These findings confirm that integrating scientific argumentation in an interdisciplinary STEM context can encourage students' ability to construct a whole argument in which claims, evidence, and reasoning are logically interrelated and form a coherent set of explanations. The ASBL also has practical applications for curriculum designers and educators who want to develop 21st-century skills. However, this study has limitations, namely that the validation was conducted on a limited sample from one school in Lampung Province, which restricts the applicability of the results to the broader Indonesian student population. In addition, the current teaching materials, focusing solely on biotechnology, provide focused but narrow results. Future research could explore scaling this model across different science topics, educational levels, or through longitudinal studies to assess retention and transfer of argumentation skills.

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