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Innovation of science student worksheet on biology material to enhance junior high school students' critical thinking skills

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Abstract

Most of the worksheets currently used by students are unable to develop their critical thinking skills due to misconceptions about the content, a lack of meaningful activities, and incompatibility with the demands of the 21st century curriculum. This study aims to test the effectiveness of science worksheets on biology material in improving students' critical thinking skills. The study uses a formative evaluation approach with the Tessmer model, which consists of five stages: self-evaluation, expert review, one-to-one evaluation, small group, and field test. Data collection was conducted using validation instruments, observation sheets, and critical thinking skill tests. The results of the study indicate that the developed student worksheets are very valid, practical, and effective in enhancing students' critical thinking skills in learning science concepts in biology. Thus, these developed student worksheets have the potential to be used in science education for biology topics. These findings highlight the potential of such worksheets as an alternative learning tool aligned with the curriculum and 21st-century competencies, offering conceptual and practical value for enhancing effective science education that improves students' critical thinking skills.

Abstrak. *Sebagian besar lembar kerja peserta didik yang digunakan saat ini belum mampu mengembangkan keterampilan berpikir kritis siswa karena miskonsepsi konten, minimnya aktivitas bermakna, dan ketidaksesuaian dengan tuntutan kurikulum abad ke-21. Penelitian ini bertujuan untuk menguji hingga efektivitas lembar kerja peserta didik IPA pada materi biologi dalam meningkatkan keterampilan berpikir kritis peserta didik. Penelitian menggunakan pendekatan evaluasi formatif dengan model Tessmer yang terdiri atas lima tahapan, yaitu self-evaluation, expert review, one-to-one evaluation, small group, dan field test. Pengumpulan data dilakukan melalui instrumen validasi, lembar observasi keterlaksanaan, dan tes keterampilan berpikir kritis. Hasil penelitian menunjukkan bahwa lembar kerja peserta didik yang dikembangkan memperoleh kategori sangat valid, praktis, dan efektif dalam meningkatkan keterampilan berpikir kritis peserta didik dalam belajar konsep IPA pada materi biologi. Dengan demikian, lembar kerja peserta didik yang dikembangkan ini berpotensi untuk digunakan dalam pembelajaran IPA materi biologi. Temuan ini menyoroti potensi lembar kerja semacam itu sebagai alat pembelajaran alternatif yang selaras dengan kurikulum dan kompetensi abad ke-21, menawarkan nilai konseptual dan praktis untuk meningkatkan pendidikan sains yang efektif meningkatkan keterampilan berpikir kritis peserta didik.*

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A. Introduction

Science education aims to encourage students to actively inquire and explore in order to gain a deep understanding of the natural world (Bílek, 2018; Alp & Onan, 2023). The learning process becomes more meaningful when connected to students' real-life experiences. In this context, active student engagement through direct interaction with tangible objects is essential (Prima et al., 2018; Fahmi et al., 2021).

Science as a discipline encompasses not only a body of facts and concepts, but also scientific principles, laws, and theories (Depdiknas, 2019). Therefore, science learning fundamentally involves three key components: scientific attitudes, scientific processes, and scientific products. Learning science should not be passive, but rather an active process involving reasoning, inquiry, and exploration of natural phenomena.

One of the essential components in science learning is biology. This subject is complex and dynamic, continually evolving alongside advancements in science and technology. To deliver the material effectively, teachers require instructional tools that actively engage students. One such tool is the student worksheet, developed in alignment with the 2013 Indonesian Curriculum.

The 2013 Curriculum promotes the integration of 21st-century skills, namely critical thinking, creativity, communication, and collaboration (4C). student worksheets designed based on these principles can help students develop higher-order thinking skills, particularly critical thinking (Fahmi, 2018). An effective student worksheet facilitates knowledge construction, concept application, and deep comprehension.

Specifically, student worksheets play an important role in supporting comprehensive and concrete science learning (Putri et al., 2021; Miranti et al., 2022; Noor et al., 2023). When designed using a constructivist approach, student worksheets can help students discover concepts, practice scientific processes, and document their learning (Bakri et al., 2020; Sumarmi et al., 2021).

However, several challenges persist in the practical use of student worksheets, many of which hinder the development of students' critical thinking skills. A key issue is the misalignment between student worksheet content and the core competencies outlined in the curriculum, which emphasize higher-order thinking (Fazira & Jayanti, 2023; Irawan et al., 2023). Many student worksheets merely contain routine and mechanical exercises that can be completed without engaging in analytical or evaluative thought processes. This limits students' ability to develop critical thinking, as they are not encouraged to question, investigate, or draw conclusions from phenomena. Some student worksheets even contain misconceptions due to inaccurate content, reinforcing flawed understanding and weakening students' logical reasoning.

A review conducted by the researchers on several student worksheets used in schools revealed that most lacked representative visual elements, clear instructions, or systematic subtopic mapping. As a result, students' critical thinking skills did not develop optimally, as existing student worksheets failed to guide them in analyzing, evaluating, and synthesizing information deeply.

These findings are supported by interviews with science teachers at SMP Negeri 30 Banjarmasin, who noted that the current student worksheets in use are overly simplistic printed in black ink on low-quality paper, containing only summaries and questions, with no practical activities or meaningful discussions. Yet, the curriculum requires science learning to emphasize hands-on practice and active engagement to foster higher-order thinking skills (Depdiknas, 2019). Consequently, students' critical thinking development and academic achievement remain suboptimal.

Because these student worksheets lack visual support, clear guidance, and coherent structure, students tend to follow procedural instructions without being trained to analyze, assess, or solve problems in depth. As a result, they are not equipped to formulate questions, evaluate information, or draw logical conclusions—core components of critical thinking. This condition also affects academic performance, as learning becomes less meaningful and fails to promote conceptual understanding. This situation highlights the gap between the ideal vision of student worksheet development and its actual implementation in the classroom, thus calling for continuous improvement grounded in empirical research and the contextual needs of learners.

Research on student worksheet development has been conducted consistently over the past decade (Diniaty & Atun, 2015; Setiawati & Senam, 2015; Irianti & Nurcahyo, 2016; Rumansyah et al., 2016; Mundilarto & Pamulasari, 2017; Tukiran et al., 2017; Firdaus & Wilujeng, 2018; Parwati et al., 2018; Saban et al., 2019; Winarti et al., 2019; Bakri et al., 2020; Zaini et al., 2020; Lessy et al., 2021; Noorhidayati et al., 2021; Miranti et al., 2022; Uzel & Bilici, 2022; Irawan et al., 2023; Susilawati et al., 2023; Paul et al., 2024; Szalay et al., 2024). However, most of these developments focus primarily on conceptual aspects in specific regional contexts and have not demonstrated their effectiveness in improving students' critical thinking skills more broadly. Many student worksheets still present single-answer questions with minimal reasoning steps, providing little opportunity for students to engage in systematic, analytical, and reflective thinking.

Ideally, student worksheets should not only serve as learning aids but also as tools to foster higher-

order thinking skills (HOTS), especially critical thinking. This gap highlights the need to develop student worksheets that are not only contextually relevant but also pedagogically designed to gradually and deeply cultivate students' scientific reasoning.

Therefore, the development of critical thinking-based student worksheets must continue as a strategic effort to promote contextual, meaningful, and 21st-century aligned science education.

B. Material and method

Type of research

This study employed educational design research to develop a science student worksheet focused on biology topics, specifically the sub-concepts of the locomotor system in living organisms, the human digestive system, and related disorders along with their prevention. The developed student worksheet was designed to be suitable for training junior high school students' critical thinking skills.

The formative evaluation model used in this study followed Tessmer (1998) framework. Formative evaluation involves systematic trials of instructional materials for the purpose of refinement. The term instructional materials in this context may include lesson plans, instructional media, worksheets, assessment tools, and other supporting components. The goal of formative evaluation is to gather information for improvement, rather than merely assessing or determining the success of the materials (Plomp & Nieveen, 2010).

Research subjects

The subjects in this study consisted of science teachers and students, with the following details: 1) The one-to-one evaluation subjects were three students with different academic abilities (high, moderate, and low) selected from the same school. 2) The small group evaluation involved six students. 3) The selection of students for both stages was purposive, based on varying academic levels within the same class. 4) The field test was conducted with 24 students from the same school, using the developed student worksheet for Grade VIII biology topics. 5) Both the small group and field test stages utilized the student worksheets designed to train students' critical thinking skills on Grade VIII biology content.

Research procedure

The research procedure adopted the formative evaluation stages of Tessmer (1998) development model, consisting of; 1) self-evaluation, 2) expert review, 3) one-to-one evaluation, 4) small group evaluation, and 4) field testing. This study was conducted following the systematic scheme as outlined in the formative evaluation process (see Figure 1).

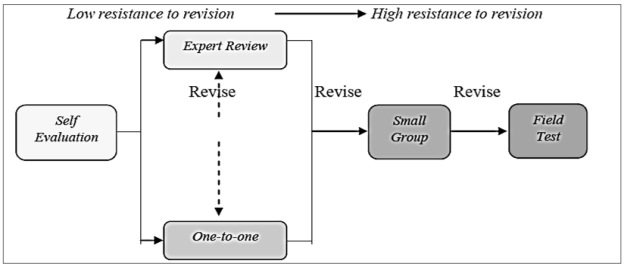

Figure 1
Formative evaluation scheme based on Tessmer's model

Data analysis techniques

The data was divided into three parts, namely for validity, practicality, and effectiveness analysis. Validity is analyzed by calculating the average score from three validators using a Likert scale. Practicality was analyzed based on the average score of student worksheet usage, which also used a Likert scale. Then, the validity and practicality categorized according to Table 1. Upon completion of the prototype and subsequent development stages, trials were carried out to examine the effectiveness of the developed student worksheet.

Scale	Criteria	
	Validity	Practicality
4.21 – 5.00	Very valid	Very practical
3.41 – 4.20	Valid	Practical
2.61 – 3.40	Quite valid	Quite practical
1.81 – 2.60	Less valid	Less practical
1.00 – 1.80	Not valid	Not practical

(Source: adapted by Arikunto, 2013)

The analysis of both expected and actual effectiveness began with scoring students' responses to critical thinking test items embedded in each student worksheet. The procedure involved the collection and recapitulation of individual student scores, the aggregation of critical thinking skill performance across each worksheet, and the calculation of expected and actual effectiveness. These calculations were based on six core indicators of critical thinking skills: interpretation, analysis, evaluation, inference, explanation, and self-regulation, which served as the primary reference points for determining the effectiveness of the student worksheet (see Figure 2). The criteria for the effectiveness of learning outcomes in terms of critical thinking skills are based on the Table 2, and critical thinking skills improvement based on Table 3 normalized gain (N-gain) test criteria.

Table 2 Criteria for critical thinking skills test

Score	Category
76-100	High
60-75	Moderate
0-59	Low

(Source: Widoyoko, 2012)

Table 3 Criteria for critical thinking skills N-gain

N-gain	Category
(g) > 0.7	High
0.3 < (g) < 0.7	Moderate
(g) < 0.3	Low

(Source: Hake, 1998)

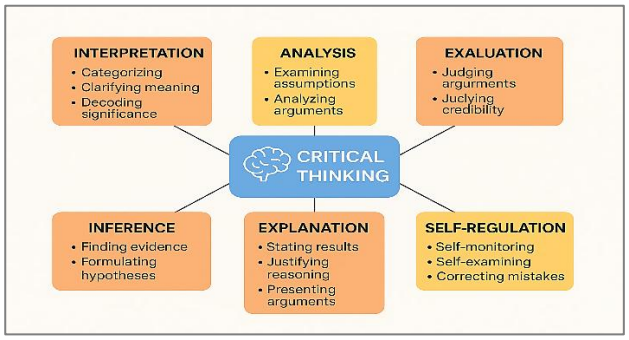

Figure 2 Critical thinking flow based on Facione's indicators

C. Results and discussion

Constructivist theory-based learning emphasizes the importance of an active thinking process in building students' cognitive understanding. According to this theory, information received is not immediately accepted as knowledge but undergoes a process of interpretation, integration, and reconstruction by the students, resulting in a deeper and more meaningful understanding (Afgani et al., 2019; Bada & Jita, 2023). One learning model derived from the constructivist approach is the inquiry model, which encourages students to think reflectively, solve problems, ask questions, seek information, and conduct investigations. This model has been proven to enhance learning effectiveness constructively (Byeon & Kwon, 2023; Cevik & Surmeli, 2024).

In the context of this study, student worksheets were developed as a learning medium designed to train students' critical thinking skills. The student worksheet was developed based on critical thinking indicators and validated through Tessmer's formative evaluation stages, which include: self-evaluation, expert review, one-to-one trial, small group trial, and field test.

The expert review stage showed that the developed student worksheet was declared highly valid based on experts' assessments, both in terms of content suitability, integration with basic competencies, and potential to promote students' critical thinking skills. The validity results are presented in Table 4. Based on the validation results by three validators, the developed student worksheet obtained an average score of 4.63 with a "very valid" category, covering aspects of content suitability (4.7), integration with basic competencies (4.5), and potential to encourage critical thinking (4.7). These results indicate that the student worksheet has met quality standards in terms of substance, alignment with the curriculum, and effectiveness in stimulating students' critical thinking skills. Therefore, the student worksheet is deemed feasible to proceed to the next trial stage in learning to assess its practicality and effectiveness empirically.

The small group stage was conducted after the product was declared feasible based on previous validation results. At this stage, the student worksheet was tested on six eighth-grade students with varying academic abilities. The purpose of this stage was to identify the initial effectiveness of the student worksheet in training aspects of critical thinking skills. Assessment was based on the results of assignments contained in the student worksheet, which were designed according to six critical thinking indicators by Facione (2011), namely: interpretation, analysis, inference, evaluation, explanation, and self-regulation. The results of this stage to determent the practicality can be seen in Table 5.

Table 4 Results of student worksheet validity test

No	Aspect assessed	Validator			Average	Validity category
		1	2	3		
1	Content suitability	4.6	4.8	4.7	4.7	Very valid
2	Integration with basic competencies	4.5	4.6	4.4	4.5	Very valid
3	Potential to encourage critical thinking	4.7	4.6	4.8	4.7	Very valid
Total average		**4.6**	**4.7**	**4.6**	**4.6**	**Very valid**

Table 5 Results of practicality test

No	Student	Interpretation	Analysis	Evaluation	Inference	Explanation	Self-regulation	Average
1	A	4	3	4	4	3	4	3.7
2	B	3	4	3	3	4	3	3.3
3	C	5	4	5	5	4	4	4.5
4	D	4	3	4	4	3	3	3.5
5	E	3	3	3	3	3	4	3.2
6	F	4	4	4	4	4	4	4.0
Total average								**3.7**
Practicality category								**Practical**

Table 6 Results of student worksheet effectiveness test in small group trial

Skill	Maximum score	Average score	Percentage (%)	Category
Interpretation	13	11.8	90.76	High
Analysis	20	18.0	90.00	High
Evaluation	14	12.4	88.57	High
Inference	20	15.6	78.00	High
Explanation	18	14.6	81.11	High
Self-regulation	15	13.0	86.67	High

Table 7 Results of student worksheet effectiveness test on pretest and posttest scores

No	Critical Thinking Aspect	Skor	
		Before	After
1.	Interpretation	61.58	82.50
2.	Analysis	74.79	77.29
3.	Evaluation	40.29	75.54
4.	Inference	57.95	82.15
5.	Explanation	67.53	76.73
6.	Self-regulation	48.27	72.50
Total		**350.41**	**466.71**
Average		**58,40**	**77,79**
Category		**Moderate**	**High**

The practicality test results at this stage were analyzed by distributing the student worksheet and questionnaires to the students, along with explanations on how to use them. Students then completed the tasks in the student worksheet according to the instructions. Each answer was analyzed to assess the achievement of each critical thinking indicator. These findings align with the research by Lessy et al. (2021), which states that achieving the critical thinking skill indicators is evidence of the student worksheet's practicality in supporting meaningful learning oriented toward the development of higher-order thinking skills.

Table 6 show student worksheet effectiveness assessment from the scores of students' critical thinking skills reflected in the questions within the student worksheet. The effectiveness of the student worksheet was reviewed based on the achievement of critical thinking skill aspects through questions given from the beginning to the end of the learning process during both small-group and large-group trials. These aspects include problem formulation, hypothesis development, evidence-based reasoning, data analysis, and drawing conclusions.

The questions presented included items or aspects of critical thinking skills that students were able to complete successfully. These results are in line with studies by Arifin et al. (2020); Irawan et al. (2023); and Fajeriadi et al. (2024), which explain that critical thinking occurs when students can think deeply to solve a problem. Further elaborated by Magdalena et al. (2021); Irhasyuarna et al. (2022); and Noor et al. (2023), critical thinking is also defined as a reasoning process used for making sound decisions. Therefore, the developed student worksheet can be used to enhance students' critical thinking skills.

Based on the Table 7, the student worksheet is considered effective because students' critical thinking skills after using the student worksheet fall into the "high" category. This is further supported by students' cognitive learning outcomes, which reached classical mastery of the indicators and showed an overall improvement from the pretest to the posttest. These findings are supported by studies by Bakri et al. (2020); Sumarmi et al. (2021); and Irawan et al. (2023), which explain that the implementation of developed learning tools is effective in training students' critical thinking skills. The student worksheet has a positive impact on students' learning outcomes, leading to improved thinking skills.

This is because the student worksheet, which is structured systematically, accommodates students' spiritual, social, knowledge, and skill competencies (Firdaus & Wilujeng, 2018; Zaini et al., 2020; Magdalena et al., 2021).

Another supporting factor is the organization of activities within the student worksheet like logical role, which also plays an important role. When the student worksheet is designed with a logical and gradual sequence, students can follow the learning process more easily, construct concepts independently, and build confidence in understanding the material (Zaini et al., 2020; Noor et al., 2023).

To validate the measurement results of the effectiveness level of the science student worksheet on biology material in improving the understanding of sub-concepts related to the locomotor system in living beings, the human digestive system, and related disorders and prevention efforts, an N-gain score was conducted by calculating the difference between the pretest and posttest scores. The N-gain test results from the pretest and posttest can be seen in Table 8.

Table 8 Results of N-gain for student worksheet effectiveness based on pretest and posttest scores

Student	N-gain score	Category
1	0.82	High
2	0.85	High
3	0.91	High
4	0.82	High
5	0.91	High
6	0.66	Moderate
7	0.68	Moderate
8	0.60	Moderate
9	0.74	High
10	0.69	Moderate
11	0.80	High
12	0.65	Moderate
13	0.66	Moderate
14	0.78	High
15	0.80	High
16	0.79	High
17	0.80	High
18	0.82	High
19	0.66	Moderate
20	0.93	High
21	0.65	Moderate
22	0.82	High
23	0.80	High
24	0.82	High
Average	**0.74**	**High**

Looking at all aspects of critical thinking skills which include interpretation, analysis, evaluation, inference, explanation, and self-regulation they fall into moderate to high categories. Thus, all aspects of critical thinking skills embedded in the tasks within the student worksheet are effective for students.

The study shows that the developed student worksheet is highly effective in enhancing critical thinking skills. These improvements are supported by quantitative data from pretest and posttest results, showing an increase in the average score from 61.74 to 66.12, although still within the "moderate" category. However, for several aspects such as interpretation and analysis, the achieved category was "high."

In science education, particularly biology, the material designed through this student worksheet successfully integrates scientific aspects with hands-on practice aligned with the 2013 Curriculum. This demonstrates a positive impact on deeper conceptual understanding, including in real-world contexts. The critical thinking skills trained through this student worksheet are part of the 21st-century skills framework, namely the 4Cs: critical thinking, creativity, communication, and collaboration. This impact is significant in the context of modern education, which demands that students be capable of solving complex problems independently and systematically.

Critical thinking skills are essential competencies that students must possess to face 21st-century challenges. These skills are not only important for academic success but also for making rational decisions in everyday life. Therefore, critical thinking must be continuously trained through intentionally designed learning processes. One effective solution for developing these skills is the use of student worksheets. Research findings show that structured, critical thinking-based student worksheets significantly enhance students' thinking abilities (Firdaus & Wilujeng, 2018; Lessy et al., 2021; Irawan et al., 2023).

In this context, critical thinking is also a key indicator in evaluating the effectiveness of developed learning tools. The success of a learning tool, including student worksheets, greatly depends on how well it accommodates the stages of critical thinking—such as formulating problems, developing hypotheses, collecting and analyzing data, drawing conclusions, and making logical and systematic decisions.

This study provides a concrete contribution to the educational literature, particularly in the use of effective instructional tools to enhance students' critical thinking skills. This is evidenced by the positive results obtained when implemented with junior high school students in South Kalimantan. These findings can serve as a reference for the application of similar learning tools at various levels and in different regions, both nationally and internationally. This research has a strong scientific impact, as it not only addresses the problem of critical thinking skills in education but also presents a replicable methodological approach. Through an evidence-based approach, this study contributes significantly to improving the quality of education in Indonesia.

D. Conclusion

The science student worksheet on biology material has been proven effective in improving junior high school students' critical thinking skills. This effectiveness is reflected in the high scores achieved across the six critical thinking indicators according to Facione, as well as an increase in the average learning outcomes from 61.74 to 66.12, and an average N-gain of 0.74 categorized as high. The success of the student worksheet in enhancing students' critical thinking skills is influenced by several important factors, including the validity of the evaluation instruments, the structured and gradual arrangement of learning activities, the integration of scientific approaches with local context, and the presentation of problems that encourage students to explore and reason independently. The student worksheet design, based on constructivist theory and oriented toward active learning, enables students to optimally engage in higher-order thinking processes. The implications of these findings indicate that systematically designed student worksheets based on critical thinking skills can serve as an alternative learning tool relevant to the demands of the 2013 Curriculum and the needs for 21st-century competency development. This study offers both conceptual and practical contributions toward improving the quality of science learning at the junior high school level and can be used as a reference for the application and development of contextual learning tools across various education levels more broadly.

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