

Development of a STEM-Integrated Problem-Based Learning Student Worksheet for Teaching the Digestive System to Improve Critical Thinking Skills among Senior High School Students

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ABSTRACT

Critical thinking is an essential twenty-first-century competency that enables students to solve real-world problems related to biology. However, the results of a critical thinking assessment conducted among Phase F (Grade 11) students at SMA Negeri 4 Jambi City revealed that most students demonstrated low levels of critical thinking skills. This condition was attributed to the suboptimal implementation of the Problem-Based Learning (PBL) model in fostering these competencies and the lack of instructional materials to support its implementation in teaching the digestive system. Therefore, this study aimed to develop a STEM-integrated Problem-Based Learning Student Worksheet that is valid, practical, and effective in enhancing students' critical thinking skills. This study employed a research and development (R&D) approach using the Plomp development model. The research participants were Phase F (Grade 11) students at SMA Negeri 4 Jambi City, Indonesia. The research instruments included validation sheets, practicality questionnaires, and a critical thinking skills test. Data were analyzed using descriptive statistics and inferential statistical methods, including validity testing, practicality testing, independent-samples *t*-test, and N-gain score analysis. The findings indicated that the developed STEM-integrated Problem-Based Learning Student Worksheet met the criteria of being highly valid, highly practical, and effective in improving students' critical thinking skills.

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INTRODUCTION

Biology learning in Phase F of senior high school should no longer focus solely on students' mastery of concepts but should also foster their ability to analyze phenomena, evaluate information, and generate practical solutions to real-world problems. This expectation is consistent with the goals of twenty-first-century education, which recognizes critical thinking as a fundamental competency that should be cultivated through classroom learning. Nevertheless, Sukma et al., (2022) reported that students have not yet developed adequate critical thinking skills. Similarly, the 2022 Programme for International Student Assessment (PISA) results indicated that Indonesian students ranked 70th out of 78 participating countries in critical thinking-related performance, with an overall decline in achievement compared to previous assessment cycles (OECD, 2023)

The development of critical thinking skills is essential in biology education, as these skills enable students to identify problems, analyze their underlying causes, evaluate scientific evidence, and formulate rational, evidence-based solutions. Without well-developed critical thinking skills, students tend to acquire only a superficial understanding of biological concepts and experience difficulties in applying their knowledge to solve real-world problems.

Previous studies have consistently reported that Indonesian students' critical thinking skills in biology remain unsatisfactory. Students are generally insufficiently trained in problem-solving because they struggle to identify and analyze problems systematically. Furthermore, when responding to problem-solving tasks, students tend to rely on information directly obtained from textbooks or teachers' explanations rather than constructing their own evidence-based reasoning (Fadhlullah & Ahmad, 2017; Hulu & Zega, 2024; Sapphira et al., 2023; Yokhebed, 2019)

A similar issue was identified at SMA Negeri 4 Jambi City. The results of a preliminary assessment of critical thinking skills administered to 30 Phase F (Grade 11) students indicated that the overall level of critical thinking was low. This finding was reflected in the students' scores and their frequency distribution, as presented in Table 1.

Table 1. Results of the Preliminary Assessment of Critical Thinking Skills among Phase F Grade 11 Students at SMA Negeri 4 Jambi City.

Score Range (%)	Frequency		Criteria
	Students (n)	Percentage (%)	
0 - 20	26	86,70	Very Low
21 – 40	4	13,30	Low
41 – 60	0	0	Moderate
61 – 80	0	0	High
81 - 100	0	0	Very High

As shown in Table 1, the majority of students demonstrated very low levels of critical thinking skills, with 26 out of 30 students (86.70%) falling into this category. These findings indicate that the implementation of Problem-Based Learning (PBL) for Phase F (Grade 11) students at SMA Negeri 4 Jambi City has not yet effectively fostered critical thinking skills, particularly in learning the digestive system. Interviews with biology teachers revealed that although the PBL model had been incorporated into lesson plans and implemented during classroom instruction, its application had not been fully optimized. One of the primary challenges was facilitating students' active engagement in identifying problems and developing appropriate solutions.

The instructional materials currently used in biology classes at SMA Negeri 4 Jambi City include teaching modules, textbooks, student worksheets, and PowerPoint presentations. Among these resources, only the PowerPoint presentations were developed independently by the teachers as ICT-based instructional materials. Regarding the teaching of the digestive system, biology teachers reported that they relied on student worksheets obtained from existing teaching modules or online sources. This practice was primarily due to the difficulty of designing worksheet activities that align with each stage of the PBL model. In addition, the considerable amount of time required to develop high-quality worksheets, together with administrative responsibilities at school and other professional obligations, discouraged teachers from developing their own instructional materials.

Considering these challenges, the development of instructional materials is necessary to better support the enhancement of students' critical thinking skills in biology learning. One promising instructional resource is the Student Worksheet. The need for developing a new worksheet is justified by the fact that commercially available worksheets generally contain only concise summaries of learning materials, sample questions, and evaluation exercises, without being systematically designed according to contemporary instructional approaches or learning models recommended by the current curriculum (Islami et al., 2019).

The effective use of student worksheets has been reported to improve the teaching and learning process by promoting active student participation and creating a more engaging classroom environment (Estitika et al., 2022). Similarly, Khatimah et al., (2018) argued that student worksheets encourage active learning while simultaneously fostering students' problem-solving skills throughout the learning process.

The implementation of Problem-Based Learning worksheets should also be supported by an appropriate instructional approach. One such approach is Science, Technology, Engineering,

and Mathematics (STEM), which integrates scientific knowledge, technology, engineering design, and mathematics to provide students with a holistic understanding of interdisciplinary concepts through authentic twenty-first-century learning experiences. STEM-based learning emphasizes contextual learning by engaging students in understanding and solving problems encountered in their everyday lives.

Previous studies have demonstrated that integrating STEM with the Problem-Based Learning model significantly improves students' critical thinking skills, with reported learning gains of approximately 72% (Putri et al., 2020; Siswa, 2020). The rationale for integrating STEM into the PBL model in the present study is that conventional PBL activities primarily emphasize information gathering and conceptual argumentation for problem solving, while placing relatively less emphasis on designing practical solutions that can be developed, tested, and evaluated empirically. The integration of STEM complements this limitation by incorporating engineering design processes and interdisciplinary problem-solving activities, thereby enabling students to construct and validate evidence-based solutions to authentic biological problems.

The integration of STEM and the Problem-Based Learning (PBL) model in student worksheets has been shown to provide a positive contribution to students' critical thinking skills. demonstrated that the development and implementation of STEM-integrated PBL-based worksheets could improve students' critical thinking abilities. Previous studies indicate that, within the field of biology education, only two studies have specifically focused on this area, which developed learning materials on biodiversity, and which focused on environmental pollution materials (Adisty & Manalu, 2024; Budiarti & Wiyatmo, 2025; Budiyatno et al., 2024; Hasanah et al., 2021; Milala & Harahap, Fauziyah, 2024).

Based on the research problems described above, this study aims to develop a Problem-Based Learning (PBL)-based Student Worksheet integrated with Science, Technology, Engineering, and Mathematics (STEM) for the digestive system topic among Phase F students (Grade XI) in senior high school. Furthermore, this study analyzes the validity level of the developed STUDENT WORKSHEET based on expert evaluations (validators), its practicality level based on teachers' and students' responses to its implementation, and its effectiveness in improving students' critical thinking skills.

RESEARCH METHODS

Types of Research

This study employed a Research and Development (R&D) design aimed at producing a Problem-Based Learning (PBL)-based Student Worksheet integrated with Science, Technology,

Engineering, and Mathematics (STEM) on the digestive system topic for Phase F students (Grade 11) of senior high school.

Development Procedure

The development model consisted of three stages: the preliminary research phase, the development or prototyping phase, and the assessment phase. Activities conducted during the preliminary research phase included interviews with biology teachers and students, analysis of existing student worksheets, and curriculum analysis.

In the development or prototyping phase, the activities focused on developing a STEM-integrated PBL-based Student Worksheet for the digestive system topic. This phase was accompanied by formative evaluation aimed at improving and refining the quality of the developed product.

The final stage, the assessment phase, was conducted to determine the effectiveness of the developed product after the prototype development process. The detailed stages of the development procedure are presented in Figure 1.

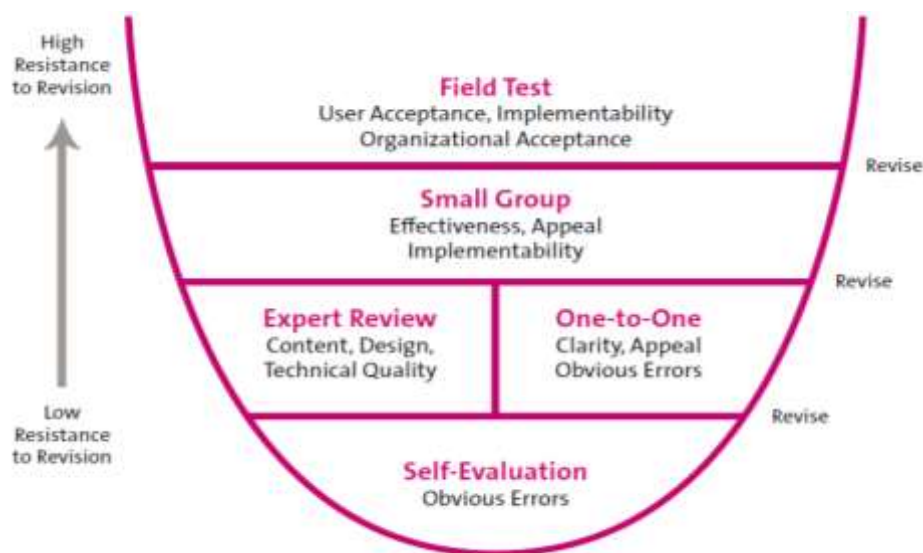


Figure 1. Formative Evaluation Layers in the Plomp Development Model (Plomp & Nieveen, 2013)

The study was conducted at SMA Negeri 4 Jambi City, involving design experts, subject matter experts, language experts, biology teachers, and Grade XI students as participants in the product trial. The development of the STEM-integrated PBL-based Student Worksheet followed a series of stages, including needs analysis, product design, product development, expert validation,

product revision, practicality testing, and effectiveness testing. The detailed development procedure is presented in Figure 2.

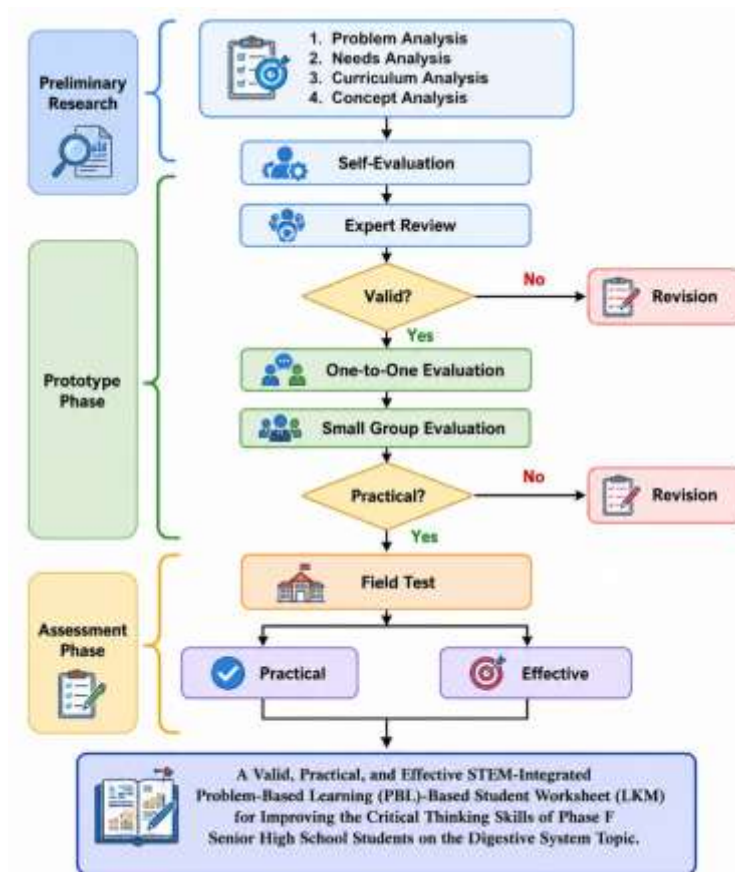


Figure 2. Development Procedure of the STEM-Integrated PBL-Based Student Worksheet

The research instruments consisted of a validation sheet, a practicality questionnaire, and an essay test. The validation sheet was used to evaluate the feasibility of the developed Student Worksheet in terms of its design, content, and language based on expert judgments. The practicality questionnaire was administered to both biology teachers and students to assess the ease of use, attractiveness, and usefulness of the STUDENT WORKSHEET during the learning process. The essay test was employed to measure students' critical thinking skills on the digestive system topic through pretest and posttest administrations. Prior to its implementation, the test instrument underwent validity, reliability, discrimination index, and difficulty level analyses to ensure that only appropriate test items were used in the study.

Data were collected using survey and test techniques. The survey technique involved the use of validation and practicality questionnaires to obtain data regarding the quality of the developed product based on evaluations from experts, teachers, and students. The test technique

employed an essay test to measure students' critical thinking skills before and after the implementation of the STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet .

The research data were analyzed using both qualitative and quantitative approaches. Qualitative data, consisting of comments and suggestions provided by the validators, teachers, and students, were analyzed descriptively using the interactive analysis model, which includes data reduction, data display, and conclusion drawing. The findings from this analysis served as the basis for revising and improving the developed product. Quantitative data were analyzed using descriptive statistics. The validity and practicality levels of the STUDENT WORKSHEET were calculated using the following formula:

$$\text{Score} = \frac{\text{Total score obtained}}{\text{Maximum possible score}} \times 100\%$$

The developed STUDENT WORKSHEET was considered feasible if it achieved a validity and practicality percentage of $\geq 61\%$, according to the predetermined assessment criteria. The effectiveness of the STUDENT WORKSHEET was determined based on students' critical thinking scores obtained from the pretest and posttest and was subsequently analyzed using the statistical procedures employed in this study. The score ranges and assessment criteria used to determine the validity and practicality of the developed STUDENT WORKSHEET are presented in Tables 2 respectively.

Table 2. Validity and Practicality Score Ranges and Assessment Criteria for the Developed Student Worksheet

No	Validity		Practicality	
	Score Range (%)	Kriteria	Score Range (%)	Criteria
1	81 – 100	Very valid	81 – 100	Very Practical
2	61 - 80	Valid	61 – 80	Practical
3	41 - 60	Fairly valid	41 – 60	Fairly Practical
4	21 - 40	Less valid	21 – 40	Less Practical
5	0 - 20	Invalid	0 – 20	Imractical

RESEARCH RESULT

This research and development (R&D) study adopted the Plomp development model, which consists of three phases: the preliminary research phase, the development or prototyping phase, and the assessment phase. The results of each phase are described as follows.

1. Preliminary Research Phase

Problem Analysis

The problem analysis was conducted through interviews with a biology teacher at SMA Negeri 4 Jambi City and a questionnaire administered to 30 Grade XI students. This stage aimed to identify the current condition of biology instruction, the learning materials used, and the challenges encountered by both teachers and students in learning the digestive system topic.

The interview results revealed that the teacher had implemented the PBL model in classroom instruction. However, its implementation had not yet been fully optimized because many students experienced difficulties in identifying problems, conducting investigations, and proposing appropriate solutions to the given problems. During group discussions, most students tended to be passive, while only a few actively expressed their opinions or contributed to completing group tasks. Furthermore, although students generally stated that they understood the learning materials when given the opportunity to ask questions, they rarely demonstrated curiosity by asking questions or engaging in more in-depth discussions.

The interview also indicated that the learning materials used in biology instruction consisted of teaching modules, textbooks, and Student Worksheets obtained from teaching modules and various online sources. The teacher had not yet developed student worksheets independently due to limited time to design learning activities aligned with the syntax of the Problem-Based Learning model, as well as the considerable administrative workload required by the school. Analysis of the existing worksheets further revealed that the learning activities within each PBL stage were not systematically integrated, resulting in the absence of a coherent problem-solving sequence.

These findings were supported by the student questionnaire. Most students reported that the digestive system topic was difficult to understand and that they were unable to relate the concepts to real-life problems. In addition, students experienced difficulties in determining daily caloric requirements, understanding the relationship between nutrients and the digestive process, and applying digestive system concepts to everyday situations. The questionnaire results also showed that the majority of students had never used Student Worksheets during the learning of the digestive system topic and had never participated in learning activities integrating the Science, Technology, Engineering, and Mathematics (STEM) approach. A summary of the findings from the problem analysis is presented in Table 4.

Table 4. Summary of the Problem Analysis Results in Biology Learning on the Digestive System Topic

No	Findings	Frequency (n)	Percentage (%)
1	The digestive system topic was difficult for students to understand.	24	80,00%
2	Students were unable to determine their daily caloric requirements.	21	70,00%
3	Students had not yet understood the relationship between nutrients and the digestive organs.	18	60,00%
4	Students were unable to apply the digestive system concepts to everyday life.	24	80,00%
5	Students had never used Student Worksheets for the digestive system topic.	25	83,33%
6	Students had never participated in STEM-based learning.	30	100%

Needs Analysis

The needs analysis was conducted through questionnaires administered to students and interviews with the biology teacher to identify the expected characteristics of the instructional materials. The results indicated that students required Student Worksheets with an attractive layout, clear and comprehensible language, illustrative images, instructional videos, and learning activities that were closely related to real-life situations. The teacher also emphasized the need for instructional materials that could systematically facilitate the implementation of the Problem-Based Learning (PBL) syntax, thereby making the learning process more structured and effective.

In addition to the visual aspects, students expected learning activities that could foster their critical thinking skills through the solution of contextual problems. These findings suggest that the instructional materials currently used have not fully supported the development of 21st-century skills, which constitute one of the primary objectives of the Merdeka Curriculum.

The results of the needs analysis are consistent with the findings of (Budiyatno et al., 2024) who argued that effective instructional materials should not merely provide information but also facilitate students in constructing knowledge independently through meaningful learning activities. Furthermore, Becker & Park, (2011) reported that STEM-integrated learning provides more contextual learning experiences, thereby enhancing the quality of students' learning processes. Based on these findings, the developed Student Worksheet is expected to increase students' engagement throughout the learning process while promoting critical thinking, problem-solving, communication, and collaboration skills. A summary of the students' needs analysis results is presented in Table 5.

Table 5. Summary of Students' Needs Analysis for the STEM-Integrated Problem-Based Learning (PBL)-Based Student Worksheet

No	Needs Assessment Aspect	Percentage (%)
1	Need for a Problem-Based Learning (PBL)-based Student Worksheet	100%
2	Need for a STEM-integrated Student Worksheet	100%
3	Need for contextual problems in the learning process	96,67%
4	Need for images, illustrations, and instructional videos	100%
5	Need for inquiry- or experiment-based learning activities	100%
6	Need for a Student Worksheet that enhances learning motivation	100%

Based on the needs analysis, it can be concluded that both teachers and students require a Problem-Based Learning (PBL)-based Student Worksheet integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach. The developed STUDENT WORKSHEET is expected to provide a more contextual, interactive, and student-centered learning experience, thereby improving both the quality of the learning process and students' learning outcomes on the digestive system topic.

Curriculum Analysis

The curriculum analysis was conducted based on the Biology Learning Outcomes for Phase F of the Merdeka Curriculum. The analysis revealed that the digestive system topic emphasizes not only students' conceptual understanding of the structure and functions of the digestive organs but also their ability to analyze nutritional requirements, explain the relationship between dietary habits and health, identify disorders of the digestive system, and propose solutions to problems related to digestive health.

Based on these findings, the learning objectives and achievement indicators were designed to promote critical thinking, communication, and collaboration skills through the implementation of the Problem-Based Learning (PBL) model integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach. Consequently, the learning activities were designed not only to facilitate conceptual understanding but also to encourage students to apply biological concepts in solving authentic real-world problems.

These findings are consistent with Kemdikbud, (2025) who argued that STEM learning within the Merdeka Curriculum is intended to develop students' ability to integrate knowledge from multiple disciplines to solve everyday problems. Similarly, Bybee, (2013) emphasized that STEM integration is an instructional approach that prepares students to meet the challenges of the twenty-first century.

Concept Analysis

The concept analysis was conducted to determine the scope of the learning content and the integration of Science, Technology, Engineering, and Mathematics (STEM) components within each learning activity. The major concepts included nutrients, digestive organs, digestive mechanisms, digestive disorders, nutritional requirements, and healthy lifestyles.

STEM integration was embedded throughout all stages of the Problem-Based Learning (PBL) model. The science component was represented through activities requiring students to analyze digestive system concepts based on scientific phenomena. The technology component involved the use of digital learning media, QR codes, and online scientific information sources. The engineering component engaged students in designing solutions to nutritional problems and developing innovative healthy food products. Meanwhile, the mathematics component was incorporated through activities involving energy requirement calculations, nutritional content analysis, and interpretation of investigation data.

The concept analysis served as the foundation for designing the learning activities in the Student Worksheet, ensuring clear alignment among biological concepts, problem-solving processes, and STEM integration. Capraro, R.M., Capraro, M.M., & Morgan, (2013) STEM learning designed through project-based or problem-solving activities effectively promotes higher-order thinking skills by actively engaging students in investigation and solution design.

2. Development or Prototyping Phase

The development phase was conducted after completing the preliminary research phase. Following the Plomp development model, this phase consisted of product design, self-evaluation, and expert review. The primary objective of this phase was to produce a valid Student Worksheet prior to classroom implementation.

Product Design

Based on the findings of the preliminary research phase, the initial prototype of a STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet for the digestive system topic was developed. The development process began with determining the overall structure of the worksheet, followed by the formulation of learning outcomes, learning objectives, learning achievement indicators, learning activities, assessment instruments, and supporting instructional media.

The student worksheet was designed according to the five stages of the Problem-Based Learning model: (1) orienting students to the problem, (2) organizing students for learning, (3) guiding individual and group investigations, (4) developing and presenting solutions, and (5)

analyzing and evaluating the problem-solving process. Each stage was integrated with STEM components, enabling students not only to understand digestive system concepts but also to apply scientific knowledge to analyze phenomena, interpret data, and develop solutions to authentic problems.

The developed student worksheet consisted of a cover page, user guidelines, learning outcomes, learning objectives, supporting information, learning activities, investigation worksheets, discussion worksheets, reflection activities, evaluation exercises, a glossary, and references. In addition, it incorporated illustrations, QR codes linked to digital learning resources, and contextual learning activities related to dietary habits, nutritional requirements, and digestive system health. The layout and appearance of the developed student worksheet are presented in Figures 3 and 4.

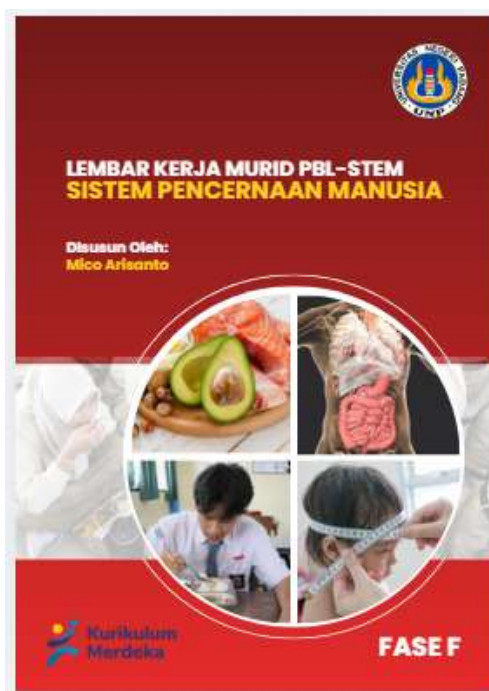


Figure 3. Cover STUDENT WORKSHEET



Figure 4. Content Student worksheet

Prototype I was developed by considering the principles of instructional material development, namely systematic organization, clear communication, attractive presentation, and suitability for students' characteristics. In addition, the learning activities were designed based on the characteristics of the Problem-Based Learning (PBL) model described by Arends, (2012), in which learning begins with authentic problems that stimulate students to conduct investigations and construct solutions through inquiry.

Self Evaluation

The initial prototype (Prototype I) was subsequently evaluated through a self-evaluation process. The preliminary analysis of the Student Worksheets previously used by teachers and students revealed that although all stages of the Problem-Based Learning model were included, each stage functioned independently without a coherent sequence linking one learning activity to the next. Consequently, the worksheets did not adequately support a systematic problem-solving process.

The needs analysis also indicated that none of the students had previously been introduced to the Science, Technology, Engineering, and Mathematics (STEM) approach or participated in STEM-integrated learning activities. Questionnaire responses further showed that all students supported the development of a biology Student Worksheet incorporating the STEM approach to foster critical thinking skills. In addition, all students expressed a preference for learning materials containing attractive illustrations and instructional videos to facilitate their understanding of the learning content.

Based on the curriculum analysis, the researcher determined the sequence and scope of the learning materials in accordance with the Biology Learning Outcomes for Phase F of the Merdeka Curriculum. Furthermore, the learning objectives and learning achievement indicators for the digestive system topic were formulated to ensure alignment with the expected competencies.

Expert Review

The design validation of the developed Student Worksheet was conducted in two rounds involving a design expert. The design was evaluated based on three aspects: didactic quality, construction quality, and technical quality. The validation results indicated that the STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet met the required design standards and was considered suitable for field testing after revisions based on the validator's recommendations. The results of the design expert validation are presented in Table 6.

Table 6. Results of the Expert Validation of the Developed Student Worksheet

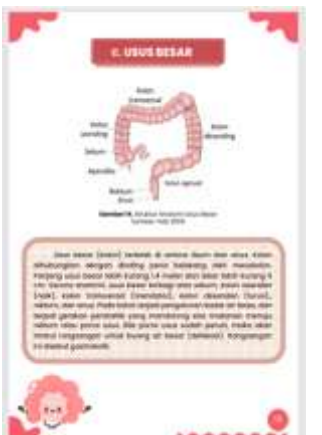
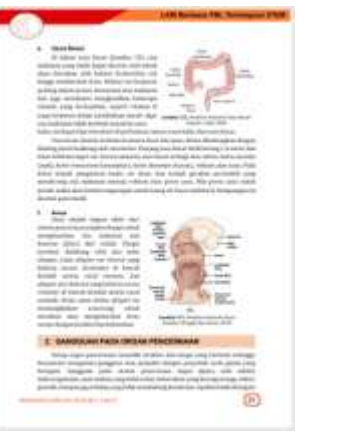
Aspect	Validity Score Range (%)	Percentage (%)	Category
Design	81% -100%	96,87%	Very Valid
Content	81% -100%	88,88%	Very Valid
Language	81% -100%	100%	Very Valid

The content expert provided several recommendations to improve the developed product. Based on the validation results presented in Chapter IV, revisions were made to enhance the quality and relevance of the Student Worksheet . These revisions included the addition of learning

materials on the Balanced Nutrition Pyramid and My Plate guidelines in accordance with the recommendations of the Indonesian Ministry of Health, the inclusion of information on disorders affecting each digestive organ, and the replacement of the problem presented during the problem-orientation stage with a more authentic issue closely related to students' daily lives, namely the habit of consuming unhealthy foods. The details of the product revisions are presented in Table 7.

Table 7. Product Revisions

No	Expert Advice	Revision	
		Before	After
1	The cover should display the characteristics of PBL-STEM		
2	Add material about “Tumpeng Gizi Seimbang” and “Isi Piringku” as an introduction to food and nutrient content.		

No	Expert Advice	Before	Revision
3	Additional material regarding disorders of each organ of the digestive system		
4	Replace the issue or problem at the problem orientation stage with a problem that is relevant to the student's life and the material in the STUDENT WORKSHEET, for example the problem of the habit of consuming Ultra-Processed Food (UPF) in teenagers.		
5	Improve consistency in the use of fonts and font sizes		

3. Assessment Phase

At this stage, two types of evaluation were conducted: practicality testing and effectiveness testing.

Practicality Testing

The practicality of the developed Student Worksheet was evaluated through three stages: a small-group evaluation, a field test, and an evaluation by the biology teacher. The field implementation was conducted in the experimental class, which consisted of 36 Grade XI students. The practicality assessment focused on three aspects: ease of use, attractiveness, and usefulness of the developed STUDENT WORKSHEET. The results of the practicality evaluation are presented in Table 8.

Table 8. Practicality Evaluation Results of the Developed Student Worksheet

Aspect	Score Range (%)	Percentage (%)	Category
Small-Group Evaluation	81–100	89.35	Very Practical
Field Test	81–100	87.70	Very Practical
Teacher Evaluation	81–100	94.31	Very Practical

Effectiveness Testing

The effectiveness test was conducted in two Grade XI classes: Class XI F1 as the experimental group and Class XI F3 as the control group. Students' critical thinking skills were measured using pretest and posttest assessments. The mean scores of students' critical thinking skills are presented in Table 9.

Table 9. Mean Scores of Students' Critical Thinking Skills

Group	Pretest	Posttest
Experimental	42.85	85.56
Control	40.42	65.35

Based on the critical thinking skills assessment administered to the students, five dimensions of critical thinking were evaluated: providing simple explanations, building basic skills, drawing conclusions, providing further explanations, and developing strategies and techniques. A comparison of the mean posttest scores for each dimension of critical thinking between the experimental and control groups is presented in Figure 5

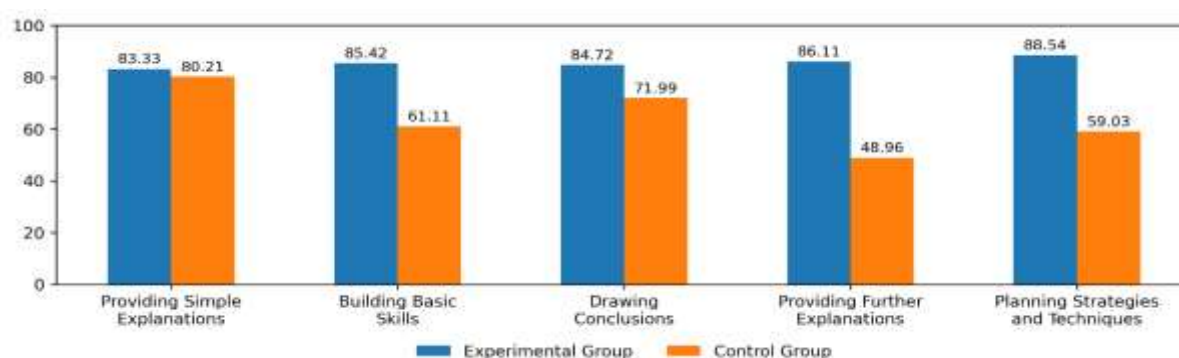


Figure 5. Comparison of the Mean Posttest Scores of Students' Critical Thinking Skills Between the Experimental and Control Groups

N-Gain Analysis

The N-gain score was calculated to determine the magnitude of improvement in students' critical thinking skills in both the experimental and control groups following the implementation of the developed Student Worksheet. In addition, the N-gain score was used to evaluate the effectiveness of the developed STUDENT WORKSHEET in improving students' learning outcomes. The results of the N-gain analysis for students' critical thinking skills in the experimental and control groups are presented in Table 10.

Table 10. N-Gain Scores of Students' Critical Thinking Skills in the Experimental and Control Groups

Variable	N-Gain Score	Experiment	Control
Critical thinking skills	Mean	0,75	0,42
	Minimum	0,32	0,05
	Maximum	1,00	0,74

Comparison Test

To determine whether there was a statistically significant difference in the improvement of students' critical thinking skills between the experimental and control groups, an independent-samples t-test was performed. The statistical analysis was conducted using IBM SPSS Statistics version 23. The results of the analysis are presented in Table 11.

Table 11. Results of the Independent-Samples *t*-Test for Students' Critical Thinking Skills

Variable	t	df	Sig. (2-tailed)	Mean	Std. Error	Decision
Critical thinking	6,540	70	0,000	17,777	2,718	Ha Accepted

The results of the independent-samples *t*-test (Table 11) showed a *t*-value of 6.540, which exceeded the critical *t*-value (2.000). In addition, the significance value was 0.000 ($p < .001$), which was lower than the predetermined significance level ($\alpha = .05$). Therefore, the alternative hypothesis (H_1) was accepted, indicating a statistically significant difference in the improvement of critical thinking skills between the experimental and control groups. These findings demonstrate that the STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet on the digestive system topic was effective in enhancing the critical thinking skills of Phase F (Grade XI) senior high school students.

DISCUSSION

This research and development study successfully produced a Science, Technology, Engineering, and Mathematics (STEM)-integrated Problem-Based Learning (PBL)-based Student Worksheet for the digestive system topic. The development process followed the Plomp development model, which comprises three main phases: the preliminary research phase, the development or prototyping phase, and the assessment phase. The Plomp model was selected

because it provides a systematic framework for developing educational products through iterative stages of needs analysis, product design, evaluation, revision, and quality assessment, thereby ensuring that the final product meets the expected standards of validity, practicality, and effectiveness.

The development process began with the preliminary research phase, which included problem analysis, needs analysis, curriculum analysis, and concept analysis. The problem analysis revealed that although the biology teacher had implemented the Problem-Based Learning (PBL) model in teaching the digestive system topic, its implementation had not been fully optimized. This limitation was primarily attributed to difficulties in designing learning activities that were aligned with the instructional stages of the PBL model. The needs analysis further demonstrated the necessity of developing new instructional materials. Questionnaire results indicated that most students perceived the digestive system topic as difficult, experienced challenges in relating biological concepts to real-life situations, had never participated in STEM-integrated learning, and expected a Student Worksheet that was more attractive, contextual, and enriched with illustrations, instructional videos, and inquiry-based learning activities. These findings suggest that learning the digestive system topic requires instructional materials capable of supporting students in understanding abstract concepts through meaningful and well-structured learning experiences.

The second phase of the Plomp model, namely the development or prototyping phase, focused on designing and refining the prototype through a series of formative evaluations. Based on the findings of the preliminary research, the prototype was developed by considering didactic, construction, and technical aspects. The consistent practicality results obtained from both the small-group evaluation and the field test indicate that the developed Student Worksheet was easy to use, attractive, and beneficial for students in both limited and actual classroom settings. These findings demonstrate that the prototype development process adhered to the principle of iterative formative evaluation, which is a fundamental characteristic of the Plomp development model.

The final phase, the assessment phase, aimed to evaluate the overall quality of the developed product. At this stage, the quality of the Student Worksheet was assessed through practicality evaluation by the biology teacher and effectiveness testing involving students' learning outcomes. Teacher evaluation is particularly important because teachers are the primary users of instructional materials and are therefore able to determine whether the developed worksheet is practical to implement, appropriate for the allocated instructional time, and capable of supporting the planned learning activities. The teacher evaluation yielded a practicality score of 94.31%, which falls within the very practical category. This result indicates that the developed student worksheet

was considered easy to implement, well aligned with instructional needs, and effective in facilitating the systematic implementation of the Problem-Based Learning model.

According to Daryanto et al., (2014) the quality of a Student Worksheet should be evaluated from three essential dimensions, namely didactic quality, construction quality, and technical quality. The didactic aspect refers to the pedagogical characteristics required to ensure that instructional materials effectively facilitate the learning process. Accordingly, before the STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet was implemented in classroom instruction, it underwent comprehensive validation by design, content, and language experts to ensure that the developed product met the established quality standards.

The design expert validation indicated that the developed Student Worksheet met the criteria of a high-quality instructional material, although several revisions were recommended to further improve the product. The high validity score suggests that the student worksheet was developed in accordance with established instructional material design principles, including alignment with the intended learning objectives, systematic organization of content, and an instructional layout that effectively supports students' learning.

The validator also emphasized that the integration of Science, Technology, Engineering, and Mathematics (STEM) within the student worksheet facilitated students' understanding of the digestive system while simultaneously promoting critical thinking skills. These findings indicate that the developed student worksheet extends beyond conceptual knowledge acquisition by fostering higher-order thinking skills. This is consistent with the fundamental characteristics of STEM education, which integrates scientific knowledge, technology, engineering, and mathematics to solve authentic real-world problems, thereby creating more meaningful learning experiences. Similar findings were reported by Budiarti and Wiyatmo (2025) and Budiyatno et al. (2024), who concluded that Student Worksheets meeting the didactic validity criteria effectively align with curriculum requirements and facilitate students' comprehensive understanding of learning materials.

The design expert further assigned very high ratings to the clarity of the learning objectives, the learning achievement indicators, the completeness of STEM elements, the systematic organization of the learning content, the alignment between problem-solving tasks and learning objectives, and the appropriateness of the allocated instructional time. These findings indicate that each component of the developed student worksheet was logically organized and coherently interconnected, resulting in an integrated learning experience. The high level of construction validity observed in this study is consistent with the findings of Lina et al., (2024), who reported

that Student Worksheets satisfying construction validity criteria are easier for students to understand, thereby facilitating more effective learning.

From the technical perspective, the validator reported that the font type and size provided excellent readability, enabling students to read the learning materials comfortably. The use of illustrations, instructional videos, and QR codes was also considered appropriate for the digestive system topic and was judged to enhance students' conceptual understanding by providing more concrete learning experiences. Furthermore, all visual materials were accompanied by appropriate source citations, ensuring compliance with academic and ethical standards in instructional material development. These findings are consistent with those of Adisty & Manalu, (2024), who found that technically valid Student Worksheets are characterized by well-organized layouts, readable typography, and attractive visual elements, all of which contribute to improving students' motivation and engagement in learning. Likewise, Estitika et al., (2022) reported that the inclusion of relevant illustrations in Student Worksheets has a substantial positive influence on students' interest in learning.

Regarding the content aspect, the validator concluded that all learning materials were highly consistent with the targeted competencies. The evaluation of content relevance indicated that every learning topic was systematically organized and successfully connected biological concepts with real-life phenomena. This finding supports the view of Prastowo, (2011), who argued that instructional materials should be organized sequentially, progressing from simple concepts to more complex ones, thereby enabling students to construct knowledge gradually and systematically.

The presentation of the learning materials also received very high ratings, particularly regarding the alignment between the STEM approach and the Problem-Based Learning (PBL) model, as well as the suitability of the learning content for each stage of the problem-solving process. These findings indicate that the developed materials were systematically organized according to the instructional sequence of the PBL model, allowing students not only to acquire conceptual knowledge but also to apply that knowledge in solving authentic problems. According to Arends, (2012), problem-based learning should guide students through a structured process consisting of problem identification, investigation, solution development, and reflection on the problem-solving process. Integrating STEM components throughout these instructional stages further enriches students' learning experiences by encouraging them to apply scientific knowledge within authentic real-world contexts rather than merely understanding theoretical concepts.

The expert evaluation of the novelty aspect indicated that the indicator related to the novelty of the contextual problems was rated highly appropriate, whereas the remaining indicators

were categorized as appropriate. These findings suggest that the developed instructional materials incorporate innovative problem scenarios, although several content components should be updated to better reflect recent advances in scientific knowledge and current health issues.

Regarding the ability of the learning materials to foster students' critical thinking skills, the validator assigned a highly appropriate rating to all indicators. This finding demonstrates that the learning activities provided sufficient opportunities for students to generate ideas, develop alternative solutions, and design strategies for solving authentic problems. Such characteristics are consistent with the objectives of STEM education, which promotes innovation, creativity, and solution-oriented thinking through the integration of multiple disciplines (Bybee, 2013).

The language validation also produced highly satisfactory results. All indicators related to language appropriateness received the highly appropriate category, indicating that the language used in the Student Worksheet was appropriate for the cognitive and socio-emotional development of Phase F senior high school students. According to the National Education Standards Board (BSNP, 2014), one of the essential criteria for language quality in instructional materials is its appropriateness to students' intellectual development, enabling learners to understand the content without imposing excessive cognitive demands. Likewise, all indicators evaluating language clarity received the highest category. The validator concluded that the sentences accurately conveyed the intended meaning, followed proper Indonesian grammatical conventions, and were expressed in a concise and effective manner. Similarly, all indicators assessing compliance with language conventions were rated highly appropriate, confirming that the instructional materials adhered to the Indonesian Enhanced Spelling System (EYD).

The practicality evaluation also revealed differences in perceptions among respondents. During the small-group evaluation, students assigned the highest score to the clarity of the connections among learning activities within the worksheet. In contrast, students participating in the field test rated the alignment between the worksheet content, classroom instruction, and textbooks as the most favorable aspect. Meanwhile, the biology teacher identified the clarity of the STEM application examples for solving digestive system problems as the strongest feature of the developed worksheet. These differences indicate that each respondent group emphasized different aspects of practicality: students in the small-group evaluation focused primarily on the coherence of learning activities, students in the field test emphasized the relevance of the instructional content to classroom learning, whereas the teacher paid greater attention to the practicality of implementing STEM within the learning process.

The effectiveness evaluation demonstrated that the STEM-integrated Problem-Based Learning (PBL)-based Student Worksheet was more effective in improving students' critical thinking skills than the conventional PBL-based worksheet used in the control group. Integrating STEM components throughout the stages of the PBL model encouraged students to engage in deeper cognitive processes by connecting scientific concepts, utilizing technology, designing engineering-based solutions, and analyzing data using mathematical reasoning. Consequently, students developed stronger analytical reasoning, logical thinking, and evidence-based decision-making skills.

The integration of the science and technology components during the stage of organizing students for learning expanded students' opportunities to explore scientific information required for solving the presented problems, as also reported by Budiarti and Wiyatmo (2025). Likewise, Azizah et al. (2025) found that STEM-integrated PBL encourages students to conduct broader, more systematic, and reflective investigations, thereby strengthening fundamental inquiry skills. This finding may explain why students in the experimental group demonstrated higher performance than those in the control group.

Within the context of learning the digestive system through the developed Student Worksheet, STEM integration became particularly meaningful because the learning activities were centered on authentic issues closely related to students' daily lives, such as the excessive consumption of sugar, fat, and ultra-processed foods (UPFs). When students were required to design innovative local food products as alternatives to reduce UPF consumption, they considered not only product characteristics but also nutritional value, health benefits, and consumer acceptance. Theoretically, these findings support the concept of critical thinking, which encompasses interpretation, analysis, evaluation, inference, explanation, and self-regulation. Problem-Based Learning provides authentic contexts that stimulate students' curiosity and reasoning, while STEM enriches the problem-solving process by providing an interdisciplinary framework for developing evidence-based solutions (Yu & Zin, 2023).

The findings further confirmed that the STEM-integrated PBL-based Student Worksheet was more effective than the conventional PBL-based worksheet in enhancing students' critical thinking skills. The integration of technology, particularly through the use of smartphones and laptops, provided students with broader access to scientific information, theories, and empirical data that supported idea generation and solution development. Consequently, students were able to construct more comprehensive and evidence-based solutions by synthesizing information from multiple sources rather than relying on a single reference.

Conceptually, Problem-Based Learning provides authentic problems that stimulate cognitive engagement, whereas STEM expands this process into a more exploratory, interdisciplinary, and solution-oriented learning experience (Madyani et al., 2019). Within the developed PBL–STEM Student Worksheet, each instructional stage contributed directly to the development of higher-order thinking skills. The science component strengthened conceptual understanding, technology expanded access to information and facilitated idea generation, engineering promoted the design and evaluation of practical solutions, and mathematics enhanced quantitative reasoning and data interpretation. The integration of these four disciplines created a richer and more cognitively demanding learning experience.

Another strength of the PBL–STEM approach lies in the opportunities it provides for collaborative and reflective learning. During the stage of analyzing and evaluating the problem-solving process, students were encouraged not only to assess the final solution but also to critically reflect on the strengths and limitations of the proposed solutions. Such reflective practices are essential for developing critical thinking and continuous improvement, as highlighted by (Budiyatno et al., 2024).

CONCLUSION

This study successfully developed a Science, Technology, Engineering, and Mathematics (STEM)-integrated Problem-Based Learning (PBL)-based Student Worksheet for the digestive system topic using the Plomp development model, which comprises the preliminary research, development or prototyping, and assessment phases. The findings demonstrated that the developed Student Worksheet achieved very high validity in terms of design, content, and language quality, as well as very high practicality based on evaluations from both teachers and students. Furthermore, the STEM-integrated PBL-based Student Worksheet proved effective in enhancing the critical thinking skills of Phase F (Grade XI) senior high school students. These findings indicate that integrating Problem-Based Learning with the STEM approach results in instructional materials that are valid, practical, and effective, providing an innovative alternative for biology instruction aimed at promoting students' higher-order thinking skills.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

M. Arisanto:: conceptualization, methodology, project administration, resources, investigation, formal analysis, writing – original draft, visualization, and writing – review & editing, **Zulyusri**: supervision, project administration, resources, data curation, validation, writing – original draft, and writing – review & editing, **E. Yuniarti**: formal analysis, validation, data curation, and writing – original draft & editing. **D. Rahmawati**: formal analysis, validation, data curation, and writing – original draft & editing.

DECLARATION OF THE USE OF AI

During the preparation of this manuscript, the authors used DeepL to assist with the translation of the manuscript, Paperpal to improve the structure and grammar of the sentences, and ChatGPT (OpenAI) to assist in improving the clarity or readability of the text. After using those tools, the authors thoroughly reviewed, edited, and verified the entire content to ensure it accurately represents their own ideas and interpretations. The authors take full responsibility for the integrity and originality of the published work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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