Jurnal Edukasi Biologi
Volume 12 No 2, September 2026, 195-203
ISSN: 2986-5484 E-ISSN: 2986-4828
DOI: 10.21831/edubio.v12i2.30231

Development of a project-based learning (PjBL)-STEM biology student worksheet on the human respiratory system to improve students' critical thinking skills

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Abstract. This study aimed to develop a Biology student worksheet based on Project-Based Learning (PjBL) integrated with Science, Technology, Engineering, and Mathematics (STEM) on the human respiratory system and to determine its validity, practicality, and effectiveness in improving students' critical thinking skills. The study employed a research and development approach using the 4D model consisting of Define, Design, Develop, and Disseminate stages; development was conducted up to the Develop stage. The needs analysis involved a Biology teacher and Grade XI students, followed by expert validation, practicality testing, and effectiveness testing. The effectiveness test involved 25 Grade XI students, while 10 students participated as representatives in the student practicality response. Data were collected using content, media, and instrument validation sheets, teacher and student response questionnaires, and pretest-posttest questions aligned with critical thinking indicators. Content validation reached 95.83%, media validation 89.58%, and instrument validation 95.00%. Practicality testing showed a teacher response of 91.66% and a student response of 96.63%. The mean pretest score of 50.20 increased to 91.56 on the posttest, with an N-gain score of 0.83 (82.65%), categorized as high. These findings indicate that the PjBL-STEM Biology student worksheet is valid, practical, and effective in supporting students' critical thinking skills on the human respiratory system. The product has practical implications for Biology teachers seeking a structured resource for contextual, collaborative, and project-oriented learning, while further studies are needed to test its implementation in broader settings.
Keywords: Critical thinking, Human respiratory system, PjBL, STEM, Student worksheet

Received: 22 August 2022 Revised: 31 August 2026 Accepted: 31 August 2026 Published: 08 September 2026

INTRODUCTION

Biology learning in the twenty-first century is expected to help students understand concepts while developing the higher-order thinking skills needed to analyze problems and formulate reasoned solutions. Critical thinking is an important learning outcome because it involves interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2011). Studies in Biology education have also emphasized the importance of strengthening students' critical thinking skills (Fitriani et al., 2022; Hulu et al., 2024). Research on STEM project-based learning indicates that contextual project activities can give students opportunities to analyze information, design solutions, and reflect on their decisions (Mutakinati et al., 2018; Rizki & Suprapto, 2024).

A student worksheet can organize such learning activities by guiding students through structured learning experiences, investigation, discussion, data analysis, and reflection (Lestari & Rakhmawati, 2024; Manurung & Anazifa, 2024). A well-designed worksheet therefore functions not merely as a collection of questions but as a learning guide that connects objectives, concepts, activities, and assessment (Febriani et al., 2026). Interactive and systematically designed worksheets can support students' engagement with learning activities (Suwastini et al., 2022). In Biology education, this type of resource is particularly useful when students need to relate biological concepts to observable phenomena and real-life problems.

A needs analysis at MA Asmah Zaijuli Hamid indicated that the available worksheets were still relatively simple and did not optimally facilitate students' active involvement and critical analysis, particularly in understanding respiratory mechanisms. Students had difficulty connecting inspiration and expiration with changes in thoracic cavity volume, air pressure, and air movement. The teacher also required a more attractive and systematic worksheet with clear language and learning steps that could accommodate discussion, experimentation, and product-oriented activities. The needs analysis also showed that students preferred activities involving direct practice, group discussion, illustrations, and active participation. These preferences informed the product design by providing clear activity steps and contextual respiratory problems that students could discuss and investigate collaboratively.

Project-Based Learning (PjBL) provides an opportunity to address these needs because students learn through identifying problems, planning activities, developing products, presenting results, and reflecting on their work (Apriani & Sudrajat, 2025). Integration with STEM further connects scientific concepts with technology, engineering design, and mathematical reasoning (Rahmania, 2021; Teo et al., 2021). Previous research has reported that STEM-integrated project-based learning can support higher-order and critical thinking through contextual problem-solving and product development (Fitriyani et al., 2020; Mutakinati et al., 2018; Putri & Dwikoranto, 2022; Rizki & Suprapto, 2024; Rohman et al., 2024).

The selection of PjBL was based on its emphasis on meaningful tasks and products. Students were expected to identify problems, formulate hypotheses, plan activities, develop a product, present the results, and reflect on the learning process (Zhong et al., 2022). STEM integration complemented this sequence by connecting scientific concepts with technology, engineering design, and quantitative reasoning (Teo et al., 2021). In the developed worksheet, Science addressed respiratory organs, mechanisms, gas exchange, and disorders; Technology included relevant information sources; Engineering involved project design and product development; and Mathematics involved calculating and interpreting respiratory-frequency data.

The project activities focused on the human respiratory system and included options such as a respiratory-health poster, a simple model of the breathing mechanism, healthy-lung educational media, and a healthy-lifestyle campaign (Hmyria & Kuznetsova, 2023). Students also collected and compared respiratory-frequency data before and after physical activity (Ling et al., 2021). These activities were intended to move students from identifying a biological problem to developing and evaluating a concrete response while using evidence to justify their decisions.

Previous development studies have examined PjBL-based or STEM-oriented worksheets, including digital student worksheets and Biology worksheets (Ahmad et al., 2025; Khalifah & Sakti, 2021; Sekarningrum et al., 2025; Tarisna & Suma, 2023). Studies comparing PjBL and PjBL-STEM also show the potential of STEM integration in project-oriented learning (Karina et al., 2024). However, this development specifically combines PjBL-STEM activities, the human respiratory system, project products, quantitative respiratory observations, and assessment aligned with critical-thinking indicators. This study's distinctive contribution is the development of a student worksheet that links respiratory concepts to a structured project sequence and provides explicit opportunities to practice interpretation, analysis, evaluation, inference, explanation, and self-regulation. Accordingly, this study aimed to develop a Biology student worksheet based on PjBL-STEM on the human respiratory system and to determine its validity, practicality, and effectiveness in improving the critical thinking skills of Grade XI students.

METHOD

Research design and participants

This study used a research and development (R&D) approach with the 4D development model consisting of Define, Design, Develop, and Disseminate (Thiagarajan et al., 1974). Development was conducted through the Develop stage. The effectiveness test involved all 25 Grade XI students at MA Asmah Zaijuli Hamid using total sampling because the entire class was included in the field test. For the student practicality response, 10 students were involved as class representatives. One Biology teacher participated in the teacher practicality assessment. The student response participants were selected as class representatives; the research report did not apply a separate named sampling technique to these 10 students.

Instruments and data collection

Data were collected using content, media, and instrument validation sheets; teacher and student response questionnaires; and pretest-posttest questions. The critical thinking test was developed with reference to interpretation, analysis, evaluation, inference, explanation, and self-regulation. The pretest was administered before the student worksheet was implemented, and the posttest was administered after the learning activities were completed. Teacher and student response questionnaires were administered after implementation to assess the usability and practicality of the developed product.

Development procedure

The Define stage included front-end analysis of the learning process, existing worksheets, students' conceptual difficulties, and teacher and student needs. The Design stage translated these findings into the student worksheet structure, including learning objectives, contextual problems, PjBL-STEM activities, project planning, critical thinking tasks, and assessment components. The Develop stage included expert validation, revision, practicality testing, and effectiveness testing. This study did not include the Disseminate stage.

Data analysis

Validity and practicality were calculated by comparing the obtained score with the maximum possible score and expressing the result as a percentage. The effectiveness of the product was analyzed using normalized gain (N-gain) based on students' pretest and posttest scores. An N-gain above 0.70 was categorized as high, 0.30–0.70 as moderate, and below 0.30 as low (Hake, 1999). The analysis described changes in students' critical thinking performance after learning with the developed student worksheet.

RESULTS AND DISCUSSION

Results

Needs analysis and product design

The needs analysis showed that learning about the respiratory system required a learning resource that could guide students through more active, structured activities. The identified learning difficulties included explaining the relationship among thoracic cavity volume, air pressure, and air movement during inspiration and expiration. Students preferred discussion, illustrations, group work, direct practice, and project activities connected with everyday situations.

The developed student worksheet was designed using PjBL-STEM learning activities. Science was represented through respiratory organs, mechanisms, gas exchange, and respiratory disorders. Technology was incorporated through relevant information sources and learning technology. Engineering was represented through project design and product development, while Mathematics was integrated through calculating and interpreting respiratory-frequency data. The activities were organized around essential questions, project planning, scheduling, project monitoring, testing, presentation, evaluation, and reflection.

Learning implementation

The learning implementation was conducted for 6 lesson hours using the developed student worksheet. Students first completed the pretest and were introduced to the respiratory-system problem. In groups, they identified the problem, formulated hypotheses, and planned a project by selecting the product form, tools and materials, work steps, and task distribution. During project implementation, students observed and recorded respiratory frequency before and after physical activity, constructed their selected project product, documented the process, and received monitoring and guidance from the teacher. The final activities involved testing the project, comparing observation results, presenting the product, responding to questions, evaluating the project, and reflecting on the learning experience. The implementation documentation showed group discussion and project construction followed by presentation of project results (Figure 1).

Figure* 1. *Students presenting a respiratory-health project product

Figure 1 shows an example of a student project product developed during the PjBL-STEM learning activities. The presentation activity provided students with an opportunity to communicate their understanding of the human respiratory system, explain the product they developed, and respond to questions related to their project.

Product validity

The validation results show that all assessed components achieved a high level of feasibility after revision based on validator feedback. Table 1 shows the validation results.

Table 1. Validation results of the PjBL-STEM Biology student worksheet

Aspect	Percentage	Category
Content validation	95.83%	Very valid
Media validation	89.58%	Very high
Instrument validation	95.00%	Very high

Based on Table 1, content validation obtained 95.83%, including 94.44% for content feasibility, 96.42% for language, and 96.87% for presentation. Media validation reached 89.58%, while instrument validation reached 95.00%. These findings indicate that the product and its supporting assessment instrument were suitable for use after revision.

Product practicality

Table 2 shows the results of the practicality test.

Table 2. Practicality results based on teacher and student responses

Respondent	Percentage	Category
Biology teacher	91.66%	Very high
Student representatives (n = 10)	96.63%	High

The Biology teacher's response reached 91.66%, with language at 100%, attractiveness at 90.00%, and content at 87.50%. The response from 10 student representatives reached 96.63%. These findings indicate that the student worksheet was considered understandable, attractive, and usable as a guide for learning activities.

Product effectiveness

Table 3 shows the product effectiveness test results using N-Gain.

Table 3. Effectiveness results based on pretest and posttest scores (n = 25)

Measurement	Mean score	N-gain	Category
Pretest	50.2	0.83 (82.65%)	High
Posttest	91.56		

Based on Table 3, the mean score increased from 50.20 on the pretest to 91.56 on the posttest. The N-gain score was 0.83 (82.65%), categorized as high. This result indicates a substantial improvement in the assessed critical thinking performance after students participated in learning using the PjBL-STEM student worksheet.

Discussion

The validation results indicate that the developed student worksheet was feasible in terms of content, language, presentation, media, and assessment. Rather than being interpreted only from the percentage scores, this feasibility reflects the alignment among respiratory-system concepts, learning objectives, learning activities, and the critical-thinking assessment. This finding is consistent with the importance of validity as a prerequisite for using worksheets in learning (Wahyuni & Zulyusri, 2023). The revision process based on validator feedback also helped ensure that the worksheet was suitable for classroom implementation.

The practicality results indicate that the worksheet was understandable and usable for both teachers and students. This practicality can be associated with the clear sequence of activities that guides learners from problem identification and project planning to data collection, product development, presentation, and reflection. Similar development studies have reported that clearly organized PjBL-based worksheets can support their use in learning activities (Tarisna & Suma, 2023). Thus, the positive responses in this study support the worksheet's role as a structured guide rather than merely a collection of tasks.

The improvement in students' critical thinking performance after the PjBL-STEM learning activities can be interpreted in relation to the learning process rather than the worksheet alone (Winarni et al., 2022). Students analyzed contextual respiratory problems, formulated hypotheses, collected and interpreted respiratory-frequency data, developed project products, communicated their results, and reflected on the learning process. These activities provided repeated opportunities to practice critical thinking processes (Facione, 2011). This interpretation is consistent with studies showing that STEM project-based learning can foster critical thinking through contextual problem solving, project development, and evaluation of solutions (Rizki & Suprapto, 2024; Rohman et al., 2024).

The human respiratory system was appropriate for the developed PjBL-STEM activities because the concepts could be connected with observable physiological phenomena and everyday health problems. In this study, students examined respiratory frequency before and after physical activity and developed project products such as respiratory-health posters, simple breathing-mechanism models, healthy-lung educational media, and healthy-lifestyle campaigns (Prihatini & Pertiwi, 2026). These activities connected scientific concepts with quantitative observations, product design, collaboration, and communication, thereby making the STEM components visible within the project sequence.

Overall, the findings indicate that the developed worksheet met the assessed criteria of validity, practicality, and effectiveness and can be considered an alternative resource for contextual, project-oriented Biology learning. Nevertheless, these findings should be interpreted within the scope of the development study because the Dissemination stage was not conducted and the effectiveness test involved only one class.

The learning sequence was also aligned with the critical thinking indicators used in the assessment. Students practiced interpretation when they identified information from respiratory cases; analysis when they examined relationships among concepts and observations; evaluation when they assessed alternative solutions and project results; inference when they drew conclusions from observations; explanation during project presentations; and self-regulation through reflection. This alignment between learning activities and assessment strengthens the interpretation that the product supported the intended critical thinking skills (Facione, 2011).

Research implications and suggestions

The developed student worksheet has practical implications for Biology teachers because it provides a structured guide for implementing PjBL-STEM through contextual projects, observations, quantitative data, presentations, and reflection. Future researchers should test the product with larger and more diverse samples, compare it with other learning approaches, disseminate it more widely, and examine changes in individual critical thinking indicators. The main limitations of this study are that the Disseminate stage was not implemented and the effectiveness test was conducted in a single class. Therefore, the findings should not be generalized beyond the research context without further testing in different schools and learning conditions.

CONCLUSION

The Biology student worksheet based on Project-Based Learning (PjBL)-STEM for the human respiratory system was developed through the Define, Design, and Develop stages of the 4D model. The product demonstrated high feasibility, with content validation of 95.83%, media validation of 89.58%, and instrument validation of 95.00%. Teacher responses supported its practicality (91.66%), and student responses were also high (96.63%). The mean score increased from 50.20 on the pretest to 91.56 on the posttest, with an N-gain of 0.83 (82.65%), categorized as high. The findings indicate that the developed student worksheet is valid, practical, and effective in supporting Grade XI students’ critical thinking skills on the human respiratory system. The product has practical implications for teachers implementing contextual PjBL-STEM learning, while further studies should conduct wider dissemination and testing in different schools and learning conditions.

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