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ORIGINAL ARTICLE

Instrument for Assessing Project-based Problem-solving Skills in Biotechnology: Analysis of Practicality and Effectiveness

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ABSTRACT

This research investigates the practicality and effectiveness of an instrument for assessing project-based problem-solving skills in the biotechnology topic in the *Merdeka* Curriculum. Although several research have been conducted on the analysis of problem-solving skills in the context of biology topics, specific measurements in biotechnology remain very limited, given that biotechnology learning requires students to solve real-world problems as part of 21st century skills. This research is part of a holistic project to develop an instrument for assessing project-based problem-solving skills in biotechnology, in which the previously identified feasible instrument were tested with 72 students to assess their practicality and effectiveness. Using a practicality questionnaire, an average of 96.07% across ease of use, attractiveness, and efficiency of use was obtained, indicating that students found the developed instrument practical for learning. Meanwhile, the effectiveness, as assessed through statistical analysis, showed an n-gain of 0.4882, which falls within the moderate category, indicating that the use of the developed project-based instrument was moderately effective in improving students' problem-solving skills in biotechnology. The results of the research imply that the practical-proven instrument can provide students with opportunities to explore problems in biotechnology, develop alternative solutions to the problems they explore, and produce products that apply related concepts through project-based learning.

KEY WORDS: Assessment instrument, biology learning, biotechnology, problem-solving skills, project-based learning

INTRODUCTION

Biotechnology is known as a multidisciplinary field of science that is constantly advancing and driving innovation in various sectors, such as agriculture (Ezeorba et al., 2024), health (Liao et al., 2023), food science (Wei et al., 2022), and environmental management (Zhang et al., 2025). As a field of science that is constantly evolving, secondary schools certainly face challenges in preparing students who not only have a strong conceptual understanding of the concepts contained in the topic of biotechnology, but also the ability to apply their knowledge to solve various real-world problems related to the topic. Therefore, problem-solving skills are now recognized as one of the essential skills to master in the 21st century (Dolmaci and Acar, 2025; Mafarja et al., 2025; Sari et al., 2021), enabling students to analyze complex situations or problems, critically evaluate information, and create evidence-based solutions. However, assessing students' problem-solving skills in project-based settings is a persistent challenge, especially for the biotechnology topic that requires students to engage with complex biological concepts while comprehending the ethical and social implications for society.

The complexity of learning biotechnology topics necessitates assessment instruments that are not only suitable for learning outcomes on these topics but also capable of reflecting students' problem-solving skills. Nilimaa (2023) argues that traditional approaches to learning and simple traditional instruments tend to fail to engage students and do not prioritize the development of creative thinking, critical thinking, and problem-solving skills. In fact, biology learning activities as part of science education should support student involvement in scientific phenomena and solving science-related problems (Wicaksono and Korom, 2023). In educational research, the development of assessment instruments must be accompanied by systematic evaluation to ensure their quality and usefulness in the actual learning process. Two critical forms of systematic evaluation to be carried out are practicality and effectiveness. Practicality aims to review the ease of use of the instrument by students (Lutfiyah and Supardi, 2019; Richter and Richter, 2024), while effectiveness involves the ability of the instrument to accurately measure and produce meaningful data on student performance (Nagy and Duma, 2023; Yihan et al., 2025). Therefore, practical and effective instruments support the learning process that encourages decision-making, determines student competence, and provides feedback that can guide learning activities smoothly.

Although several research have explored the measurement of problem-solving skills in biology learning, such as Lestari and Djukri (2019) and Putra et al. (2024), research focusing on instruments on the topic of biotechnology is still very limited. Therefore, this research attempts to address these gaps by developing and testing a project-based assessment instrument to train students' problem-solving skills on the topic of biotechnology. Specifically, this research aims to analyze the practicality and effectiveness of the developed instrument. Through a structured investigation of these two

aspects, this research produces empirical evidence regarding the applicability of the developed instrument and its ability to support science competency-based biology learning. This research is expected to contribute to improving the quality of biology learning in secondary schools, particularly on the topic of biotechnology, enhancing learning assessment practices, and training students to master 21st century skills and modern biological sciences.

Present Instrument

This research focuses on testing the practicality and effectiveness of a project-based assessment instrument for training students' problem-solving skills in biotechnology. The instruments were developed based on preliminary studies in several high schools in West Kalimantan, Indonesia, which revealed that there were no comprehensive and standardized project-based assessment instruments for biotechnology. Project-based assessments conducted in the schools targeted in the preliminary studies only assessed several aspects, such as the preparation of tools, materials, and the final results of the projects, without assessing the overall project assessment stages, making the application of project assessment suboptimal. In addition, the preliminary studies also revealed that there was no instrument available to measure students' problem-solving skills. Therefore, an instrument was developed as a solution to the problems found.

The project-based assessment instrument developed is in the form of a student worksheet consisting of two main components, namely project implementation guidelines and project assessment guidelines. In accordance with the problems revealed in the preliminary studies, the instrument developed integrates two main aspects as the basis for its development, namely project assessment for senior high schools in the *Merdeka* Curriculum by Sudibawa et al. (2021), which covers project planning, implementation, and reporting; and problem-solving skills by Pólya (1973) which covers four aspects, namely understanding the problem, designing the plan, implementing the plan, and reviewing. The instrument used in this research has been assessed for its feasibility through content validity and interrater reliability. The content validation process, which involved five validators, was then analyzed using the validity index proposed by Aiken (1985), which showed a value of 0.96, thus categorized as valid. Meanwhile, interrater reliability through the Intraclass Correlation Coefficient test using the Statistical Package for the Social Sciences (SPSS) version 22 showed an average measure value of 0.820, which was categorized as good with reference to the categories presented by Koo and Li (2016).

METHODS

Research Design

This research is part of a larger project to develop a project-based assessment instrument to train students' problem-solving skills in biology, particularly in biotechnology. Using the Define, Design, Develop, and Disseminate (4D) development model by Thiagarajan et al. (1974), combined with the stages of non-test instrument development by Mardapi (2008), this research focuses on the Develop stage, specifically on the analysis of the practicality and effectiveness of the developed project-based assessment instrument. The 4D development model was used because it is a structured model that provides a systematic process for developing educational products, ensuring that each stage is purposeful and aligned with the intended learning outcomes (Manzano, 2025). Furthermore, the integration of the non-test instrument development stages by Mardapi (2008) was used because these stages specifically emphasize crucial aspects in the preparation of non-test instruments so as to provide a more in-depth and specific evaluative framework to ensure the quality of the instruments.

Participants

The population in this research was 288 tenth-grade students at a public high school in Pontianak City, West Kalimantan. With this population, a purposive sampling technique was used with three criteria determined to meet the research objectives, namely being registered as an active student, having studied the topic of biotechnology, and being willing to participate in the entire research process. The sampling technique used resulted in a sample of 72 students.

Ethical Considerations and Procedure

This research took ethical considerations into account by obtaining permission from the school and providing a research permit letter. Student participation was voluntary, and there was no coercion. In addition, the identities of the students were kept confidential. The research procedure began with the researcher presenting the materials related to the biotechnology topic, followed by a pretest. The learning activities were then carried out with reference to the PjBL stages described by Novalia et al. (2025), namely the identification of problems of interest and related solutions, the design of project plans, remote monitoring of project implementation, the development of project prototype results by students (project reports, work videos, presentation slides, and completion of student worksheets), review and evaluation of the project by peers and teachers, completion and presentation of the project, which was then concluded with reflection and feedback from the teacher. The research then continued with a posttest and the completion of a practicality questionnaire.

Instruments

This research involved two main instruments to achieve the predetermined objectives, namely a questionnaire to measure the practicality of the developed instrument and a test to measure the improvement in problem-solving skills. The questionnaire used in this research used a Likert scale with four response points (1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree) and consisted of three aspects, namely ease of use, attractiveness, and efficiency of use, which were divided into 12 indicators (Table 1). The test in this research consisted of five essay questions used as a pretest and posttest to be completed individually to measure the problem-solving skills of each student. By presenting problems in the form of

Table 1: Grid of the practicality questionnaire

Aspect	Indicator	Item Number
Ease of use	Easy-to-understand instructions	1
	Systematic and logical arrangement	2
	Helps identify problems	3
	Helps design plans	4
	Facilitates plan implementation	5
	Helps review processes and results	6
Attractiveness	Attractive visual display	7
	Attractive visual elements	8
	Neat content layout	9
Efficiency of use	Helps solve problems	10
	In line with the learning time allocation	11
	Can be used independently	12

animal waste for the pretest and plant waste for the posttest, the tests used in this research were based on the aspects of problem-solving skills Pólya (1973), with the grid presented in Table 2.

Data Analysis

The practicality of the developed instrument was determined based on the results of student responses through questionnaires, calculated using descriptive statistics in the form of percentages and categorized with reference to Putri et al. (2024) (Table 3). Meanwhile, the normalized gain (n-gain) value obtained from the test was calculated using SPSS version 22 software and then categorized with reference to Hake (1998), namely low ($g < 0.3$), moderate ($0.7 > g \geq 0.3$), and high ($g \geq 0.7$).

Table 2: Grid of the effectiveness test

Aspect	Indicator	Item Number
Understanding the problem	When presented with a case of organic waste, students can identify problems that can be solved through biotechnology	1
Designing the plan	When presented with a case of organic waste, students can propose conventional biotechnology project ideas as appropriate solutions	2
	Based on the project ideas they have developed, students can determine the necessary tools and materials	3
Implementing the plan	Based on the designed project, students can explain the implementation steps	4
Reviewing	Based on the designed project, students can explain the advantages and disadvantages to the environment and society	5

Table 3: Categories of practicality

Value	Category
$0\% < P < 20\%$	Very impractical
$20\% \leq P < 40\%$	Impractical
$40\% \leq P < 60\%$	Fairly practical
$60\% \leq P < 80\%$	Practical
$80\% \leq P \leq 100\%$	Very practical

RESULTS AND DISCUSSION

Practicality of the Instrument

The practicality of the project-based assessment instrument that has been developed was examined by reviewing student responses on ease of use, attractiveness, and efficiency. The results of the analysis of the practicality of the project-based assessment instrument are presented in Table 4.

Ease of use

The ease of use aspect consists of six indicators, namely "Easy-to-understand instructions," "Systematic and logical arrangement," "Helps identify problems," "Helps design plans," "Facilitates plan implementation," and "Helps review processes and results." The first indicator regarding easy-to-understand instructions received a score of 95.83% and was categorized as very practical. This indicates that the instructions in the instrument were presented clearly, structured, and did not cause double interpretations. These findings are in line with Vaughn and Fletcher (2021), who emphasize that learning tools should use clear and structured instructions so that students can complete tasks well and develop the expected skills.

The second indicator regarding systematic and logical instrument arrangement scored 95.83% and was categorized as very practical. This indicates that the placement of steps, statements, and the sequence of activities has made it easier for students to follow the project work process from start to finish. This is in line with Darling-Hammond et al. (2020), who emphasize that the sequence of instruments affects the ease of following the work process gradually and continuously.

The third indicator regarding the ease of identifying problems scored 95.48% in the very practical category. This shows that the instrument is able to guide students in finding the core of the problem accurately. The presentation of questions and initial project steps helped students understand the context and formulate problems. This finding is in line with the first stage of problem solving according to Pólya (1973), namely understanding the problem, which emphasizes that students must be able to identify the core of the problem before determining the solution steps. Thus, the results of this practicality test reinforce that the instrument is in accordance with this theory.

The fourth indicator regarding the ease of designing plans for problem-solving scored 96.18% in the very practical category. This indicates that the instrument successfully guided students to develop alternative solutions and implementation plans in a structured manner. The presentation of work steps and thinking space in the instrument proved to make it easier for students to create problem-solving strategies. This finding is in line with the second stage of problem solving according to Pólya (1973), namely making plans that emphasize the

Table 4: Results on the instrument's practicality

Aspect	Criteria	Percentage	Average (%)	Category
Ease of use	The instructions in the developed instrument made it easier for me to understand the project implementation steps	95.83	96.12	Very practical
	The items in the developed instrument were arranged systematically and coherently, making them easy-to-understand	95.83		
	The presentation of the developed instrument made it easier for me to accurately identify and understand the problem	95.48		
	The presentation of the developed instrument made it easier for me to design solutions and create a precise problem-solving plan	96.18		
	The presentation of the developed instrument made it easier for me to implement the problem-solving plan accurately	96.87		
	The presentation of the developed instrument made it easier for me to review the problem-solving process and results accurately	96.52		
Attractiveness	The developed instrument has a visually appealing appearance	96.87	96.75	Very practical
	The use of visual elements is harmoniously arranged, clarifying the content	97.22		
	The layout of the developed instrument is neat and easy to follow	96.18		
Efficiency of use	The use of the developed instrument helped me complete project assignments efficiently	97.22	95.36	Very practical
	The use of the developed instrument fits within the allocated learning time	94.09		
	I can use the developed instrument independently without direct supervision from the teacher	94.79		
Average			96.07	Very practical

importance of students' ability to formulate logical solution steps before taking action. Thus, the instrument has supported students in designing solutions systematically in accordance with this theory.

The fifth indicator regarding the ease of implementing the designed plans scored 96.87% in the very practical category. This shows that the instrument really makes it easy for students to carry out the plan step by step without confusion. This finding is in line with the third stage of problem solving, according to Pólya (1973), namely implementing a plan that emphasizes the importance of students' ability to apply the steps that have been designed consistently and purposefully. Thus, this instrument has supported students in implementing problem-solving plans purposefully in accordance with this theory.

The sixth indicator regarding the ease of reviewing the process and results (reflection) scored 96.52% in the very practical category. This indicates that the instrument facilitates students to review the process and results of project implementation. The reflection guide in the instrument helps students identify strengths, weaknesses, new experiences, and suggestions based on their work experience. This finding is in line with the fourth stage of problem solving, according to Pólya (1973), namely reviewing, which emphasizes the importance of evaluating and reflecting on the process and results to improve strategies or steps for solving problems in the future. Thus, this instrument supports students in conducting practical reflection in accordance with this theory. Overall, the average score of 96.12% on all indicators in the ease of use aspect shows that this instrument greatly helps students in understanding instructions, following work steps, planning solutions, implementing projects, and reflecting. Thus, the ease of use aspect is in the very practical category.

Attractiveness

The attractiveness aspect includes three indicators, namely "Attractive visual display," "Attractive visual elements," and "Neat content layout." The first indicator regarding attractive visual appearance scored 96.87% and was classified as very practical. This shows that all students rated the instrument as having an attractive visual appearance. An attractive visual appearance can support learning motivation and foster students' interest and attention in learning. This finding is in line with Tomita (2018), who stated that an attractive visual appearance alongside the context of the topic can increase learning motivation and understanding of the topic in learning.

The second indicator regarding the harmonious composition of visual elements scored 97.22% in the very practical category. This indicates that the combination of visual elements helps clarify information and makes it easier for students to understand the content of the instrument. This finding is consistent with Andrée et al. (2024) and Saborío-Taylor (2025), who state that a harmonious and appropriate esthetics of visual elements can improve readability, facilitate understanding, and foster learning motivation. Meanwhile, the third indicator regarding a neat and easy-to-follow layout scored 96.18% in the very practical category. This indicates that each part of the instrument is presented in a structured and logical manner. This is in line with the opinion of Belawati et al. (2023), who argue that the presentation of structured instruments can help students build understanding gradually and increase learning independence. Overall, the average score of 96.75% on all attractiveness indicators shows that this instrument has an attractive visual appearance, harmonious visual element composition, and a neat and easy-to-follow layout. Thus, the attractiveness aspect can be considered very practical.

Efficiency of use

The aspect of efficiency of use consists of three indicators, namely "Helps solve problems," "In line with the learning time allocation," and "Can be used independently." The first indicator regarding helping to complete tasks efficiently scored 97.22% in the very practical category. This indicates that the instrument supports the problem-solving process so that students can complete projects in a structured manner. This finding is in line with Berezi (2025), who stated that efficient learning instruments must facilitate the optimal task completion process and increase student productivity.

The second indicator regarding the appropriateness of learning time allocation scored 94.09% in the very practical category. These results show that almost all students considered the instrument to be completed within the specified time, in accordance with the allocated learning hours. This indicates that the instrument did not burden the students and allowed the project activities to run on time. This result is in line with the views of Afandi et al. (2024), who emphasize that an efficient instrument must be able to adjust learning activities to the available time without reducing the quality of learning. The third indicator regarding the instrument's ability to be used independently scored 94.79% in the very practical category. This result shows that students are able to use the instrument without requiring continuous guidance from the teacher.

This indicates that the instrument supports independent learning, allowing students to control their own learning process. Overall, the average score of 95.36% across all indicators of efficiency of use shows that this instrument helps students complete tasks efficiently, in accordance with the allocated learning time, and can be used independently. Thus, the aspect of efficiency of use can be very practical. Based on the results of the analysis of all aspects and indicators, the project assessment instrument showed an average score of 96.07% and was categorized as very practical. This confirms that the instrument can be used easily, attractively, and efficiently in supporting the measurement of students' problem-solving skills during the implementation of biotechnology projects.

Effectiveness of the Instrument

The use of the instrument developed in biotechnology learning has proven to be helpful and has had a positive impact on students' problem-solving skills. This can be seen from the results of the pretest and posttest data processing, which show an increase in students' problem-solving skills. Complete statistical data from the pretest and posttest results are presented in Table 5.

Based on the SPSS output in Table 5, there was a significant change between the pretest and posttest results of the students' problem-solving skills. The pretest mean score of 62.50 indicated that the students' problem-solving skills before the treatment were still in the adequate category, and most of them did not meet the predetermined minimum mastery standard of 75. After the students participated in learning using the project-based assessment instrument, there was an increase in the posttest average to 82.15, indicating an overall improvement in problem-solving skills. This increase in scores was due to the alignment between the steps in the instrument and the thought processes required for problem solving. The instrument developed included the stages of problem identification, strategy planning, investigation implementation, result analysis, and conclusion drawing, so that the entire learning process provided opportunities for students to think critically, make decisions, evaluate work steps, and solve problems independently or in groups. This is in line with Pólya's (1973) theory on the stages of problem solving and the characteristics of project-based learning, which emphasizes authentic investigation and systematic solution development. After obtaining these results, the next step is to conduct a normality test to determine whether the pretest and posttest data are typically distributed. The normality test was conducted using IBM SPSS version 22 as the basis for determining the appropriate type of statistical tests for the subsequent analyses. The results of the normality test are presented in Table 6.

Based on the SPSS output in Table 6, the Shapiro–Wilk normality test results show that the significance values for both the pretest and posttest data are 0.000. Both values are below the significance threshold of 0.05, so it can be concluded that the pretest and posttest data are not normally distributed. Given these conditions, the statistical analysis used cannot employ a paired sample t-test, but must instead use an appropriate nonparametric test, namely the Wilcoxon signed-rank test. The next step is to conduct a hypothesis test using the Wilcoxon signed-rank test to determine whether the instrument developed is efficacious in improving students' problem-solving skills. The results of the hypothesis test are presented in Table 7.

Based on the results of the Wilcoxon signed-rank test, 69 students obtained positive ranks, indicating an increase in scores, while there were no negative ranks, and three students had identical scores. The analysis results showed a Z value of −7.252 with a significance of 0.000 (<0.05), so it can be

Table 5: Statistical results on the pretest and posttest

Test	*n*	Mean	Min.	Max.	Range
Pretest	72	62,50	25	80	55
Posttest	72	82,15	55	90	35

Table 6: Normality test results (Shapiro–Wilk)

Test	Statistic	df	Significant
Pretest	0.880	72	0.000
Posttest	0.816	72	0.000

Table 7: Hypothesis test results (Wilcoxon signed-rank test)

Statistic	Z	Asymp. Sig. (2-tailed)
Posttest-pretest grades	−7.252	0.000

Table 8: Calculations on the n-gain

Statistic	*n*	Minimum	Maximum	Mean
N-gain score	72	0.00	0.86	0.4882
N-gain percent	72	0.00	85.71	48.8174

concluded that there was a significant difference between the pretest and posttest scores. Thus, the treatment provided resulted in a significant improvement in learning outcomes. The Wilcoxon signed-rank test results show that the Asymp. Sig. (2-tailed) value is 0.000. This value is smaller than the significance level of 0.05, so it can be concluded that H_0 is rejected and H_1 is accepted. Thus, there is a significant difference between the pretest and posttest scores of students after participating in learning using the instrument. These results indicate that the developed instrument is efficacious in improving students' problem-solving skills in biotechnology material. To determine the extent of the improvement, the next step is to calculate the level of effectiveness using the n-gain value. The interpretation of the n-gain score is presented in Table 8.

The n-gain scores of the students showed quite a wide variation, with a minimum score of 0.00, a maximum score of 0.86, and an average score of 0.4882. The average n-gain score was in the moderate category, indicating that the use of the developed project-based instrument was quite effective in improving students' problem-solving skills in biotechnology. The average n-gain score shows that the use of this instrument is able to provide a significant improvement in ability after students have completed the entire series of learning activities and projects. Based on the overall data obtained, these findings prove that there is an increase in problem-solving skills after students are given treatment through the use of the project-based assessment instrument that has been developed. The application of project-based assessment instrument provides opportunities for students to explore problems directly, develop alternative solutions, and produce products as a form of applying concepts in line with the characteristics of project-based learning. These findings are also in line with the objectives of biotechnology learning in the *Merdeka* Curriculum, which is to encourage students to develop critical, creative, and scientific thinking skills through the process of identifying problems, formulating solutions, and solving problems independently and collaboratively. Thus, project-based assessment instruments not only play a role in measuring student abilities but also serve as an effective means of enhancing scientific thinking and problem-solving skills in the context of biology learning.

CONCLUSION

Overall, the developed project-based assessment instrument was categorized as very practical, with an average practicality score of 96.07%. This level of practicality suggests that the instrument is easy and efficient to use, appealing, and well-suited for implementation within project-based learning activities. The students were able to apply the instrument effectively throughout the learning process without encountering significant technical or instructional difficulties. Furthermore, the n-gain of 0.4882 indicates a moderate level of effectiveness in improving students' problem-solving skills. The n-gain obtained demonstrates that the project-based assessment instrument enhances students' skills by facilitating meaningful engagement with problem-solving tasks embedded in projects. Although the improvement observed falls within the moderate category, it still signifies a meaningful learning gain, particularly given the complexity of problem-solving skills, which tend to require sustained practice and repeated exposure to challenging tasks. Therefore, the results of this research imply that the developed project-based assessment instrument has the potential to support the development of 21st century skills when consistently integrated into learning activities.

However, this research used a relatively small sample size, which may limit the generalizability of the findings. Therefore, it is recommended that future research apply the instrument to a larger, more diverse sample to obtain more robust evidence of its effectiveness. In addition, further research can explore factors that influence students' problem-solving skills when using this instrument. Investigating the factors would provide deeper insights into how the project-based assessment instrument can be optimized to maximize its impact on students' problem-solving skills.

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