JSER

Journal of Science Education Research

Journal homepage: https://journal.uny.ac.id/index.php/jser/index

ISSN: 2597-9701

Electronic Worksheets For Students On Conventional Biotechnology Kombucha to Improve Critical Thinking And Creativity Skills

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Abstract

This study develops an electronic Student Worksheet (LKPD) integrated with Project-Based Learning (PjBL) on conventional biotechnology material, specifically kombucha fermentation, to strengthen Phase E students' critical thinking and creativity. The research is based on the limited mastery of 21st-century skills, particularly critical thinking and creativity, which remain challenges in schools. A Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) was employed. The product underwent validation by media and material experts, followed by practicality testing with teachers and students. A limited trial in two Grade 10 classes involved questionnaires, observations, and tests. Data were analyzed descriptively and inferentially using MANOVA. Validation results indicated that the PjBL-based electronic LKPD is highly feasible in terms of content, technical quality, and presentation. Practicality testing also showed very good responses from teachers and students. Furthermore, MANOVA analysis confirmed a significant effect of the LKPD on improving both critical thinking and creativity simultaneously (Hotelling's Trace, $p < 0.05$). In conclusion, the developed LKPD is feasible, practical, and effective as an innovative learning medium. It enhances critical thinking, fosters creativity, and contributes to the mastery of essential 21st-century competencies.

History

Received:

Revised:

Accepted:

Keywords:

Electronic student worksheets, PjBL, critical thinking skills, creativity

How to cite:

Fadilah, N., Mercuriani, I.S., Paidi (2026). Electronic Worksheets For Students On Conventional Biotechnology Kombucha to Improve Critical Thinking And Creativity Skills. *Journal of Science Education Research,* 10(1), 131-142. https://doi.org/10.21831/jser.v.10il.91837.

1. INTRODUCTION

Learning in the 21st century is designed to prepare the current generation to face various global demands and challenges. The rapid development of technology and information in this era has a significant impact on every aspect of human life, including education. Education has a strategic role as a means of improving the quality of life of society as well as a driver of national development. The transformation of 21st-century education is characterized by modern skills, including digital literacy, information literacy, and media literacy. This century's learning model emphasizes and explains activities that hone students' skills through active management and control of the learning process. In this century's learning system, attention is shifted from the role of the educator to the active involvement of students as the main subjects of learning. The goal is to provide students with thinking and learning skills. The term "The 4C Skills," introduced through the framework (21st Century Student Outcomes, 2015), covers four main competencies, one of which is communication and collaboration. Critical thinking, according to (Erdogan & Vacide, 2019), states that in order to respond to future changes, students must master critical thinking skills, generate ideas, collaborate, and communicate. Creativity, critical thinking skills, collaboration, and communication support student success in the learning process, as all of these skills are used to solve problems, collaborate, communicate, obtain information, and adapt to change. According to (Santrock, 2007), critical thinking means using fundamental thinking techniques, which include

the skills of analyzing arguments, broadening one's horizons, and systematically interpreting information within a logical framework, understanding the underlying assumptions, and justifying a position.

Critical thinking skills enable students to prepare concise, structured, and convincing presentations. Critical thinking skills enable students to analyze problems systematically and overcome challenges that arise during the problem-solving process, ask creative questions, and find appropriate solutions (De Filippis et al., 2018). Critical thinking skills are one of many important skills that students need to have. There are also skills needed to process information into new knowledge. Students must be creative in finding new solutions and generating new ideas that support more dynamic and effective learning. To face the challenges and changes in the digital and globalization era, it is very important to increase creativity in education and shape a generation with superior abilities and character (Nugraha et al., 2023).

Creativity in education is very important in order to improve students' skills in higher-order thinking and innovation, as well as problem-solving skills. The main responsibility of education is to improve students' creativity and boost their self-confidence. Traditional or outdated methods are still used in teaching. These methods focus only on improving learning outcomes, but they do not teach students to be creative and make things. According to (Latifatus et al., 2021), improving students' understanding of certain subjects can be done by understanding their level of learning creativity.

According to Aderibigbe in (Ngabdiningsih et al., 2023), there are four characteristics of creative thinking: (1) Fluency, which means the ability to generate a variety of ideas; (2) Flexibility, which means the ability to generate diverse and unique ideas; (3) Originality, which means the skill of creating new or unprecedented ideas; and (4) Elaboration, which means the ability to expand or extend ideas so that they become complex or detailed concepts. Because both require critical thinking skills, creativity and higher-order thinking skills are closely related to each other.

To respond to the various challenges of entering the 21st century, students are required to master critical thinking and creative thinking skills. However, the 2018 PISA international assessment data shows that Indonesian students still face many problems; the country ranks 70th out of 79 countries in literacy, mathematics, and science. Only about 1% of Indonesian students have high abilities, demonstrating critical, reflective, and argumentative thinking skills in solving complex science problems (*OECD*, 2019).

At the national level, the review presented by (Melisa et al., 2025) has not been able to identify scientific problems logically and critically. Similar research was also conducted by (N. P. S. R. Dewi et al., 2017) which stated that critical thinking skills components included in biology learning in grade X high school are still at a low level, particularly 4 in the aspect of interpreting and evaluating information. In addition, the creativity skills of high school students appear to be experiencing a downward trend. Research conducted by (Sari et al., 2021) on 347 students in various schools shows that only about 18% of students are able to produce original solutions in biology learning. The main factors causing low student creativity are teaching methods that are too dependent on teachers, the use of outdated media, and a lack of project-based and experimental activities. Research conducted by (Pamungkas et al., 2023) indicates that as many as 64% of high school students experience difficulties in analyzing information and developing ideas creatively in biology lessons. The learning model in which the teacher is the main focus of learning activities, the use of ordinary media, and the lack of project and experiment activities are the main causes of low student creativity.

Based on interviews with biology teachers at SMAN Yogyakarta, another significant problem was identified, namely the low level of creativity among students, especially in grade X. This problem has a direct impact on learning outcomes, as shown by biology scores based on academic data, which remain below the Minimum Passing Grade. The lack of student creativity is thought to be influenced by several factors gathered from observations and interviews conducted with fifty tenth-grade students. These factors include students' lack of confidence in expressing their creative ideas, fear of failure that hinders exploration and improvisation of ideas, and the tendency of most students to have a structured and rigid mindset. In addition to internal factors, limited learning resources also hinder the development of creativity in the classroom. The learning process is still dominated by the use of textbooks, printed modules, and conventional worksheets that are not designed to encourage exploration, collaboration, or the development of creative ideas. These limitations result in less dynamic learning activities and minimal stimulation of students' creative abilities. Therefore, these findings highlight the importance of innovative pedagogical interventions, such as the development and application of technology-based learning tools and constructivist approaches such as Project-Based Learning in the form of electronic worksheets. Such interventions are expected to provide strategic solutions to foster student creativity more effectively and have a positive impact on student learning outcomes.

Thus, a flexible learning approach, such as electronic worksheets, allows access anytime and anywhere via laptops or smartphones. According to (Miqro et al., 2021), Electronic worksheets are learning tools that educators can use to manage learning activities effectively. Electronic worksheets According to (Wulan et al., 2021), the use of electronic worksheets can increase students' creativity and critical thinking skills through

guidelines designed to increase student participation during learning activities in various activities related to skill and creativity development. The application of the project-based learning (PjBL) model allows for the development of electronic worksheets and PjBL to work together to improve students' understanding while honing their critical thinking and creativity skills. Furthermore, the PjBL model can provide structured guidance to students in completing projects. Electronic LKPD helps students identify the actions that need to be taken, the problems that must be solved, and the resources that are needed (Wulan et al., 2021). Project-based learning is an approach that encourages students to actively engage in the learning process through projects designed to solve real-world problems. The process of implementing this model consists of several stages, namely (1) project planning, (2) project launch, and (3) guided inquiries and product creation (Markula & Aksela, 2022).

In the context of 21st-century skills, each stage of project implementation is integrated with critical thinking, creativity, communication, and collaboration skills.(Mubarokah & Wahyudi, 2019) shows that the application of the project-based learning paradigm can increase students' thinking skills from 62% to 82.31%.

Biotechnology is one of the essential subjects in high school biology education, especially in phase E of the Merdeka Curriculum. This subject examines the use of living organisms to produce products that are beneficial to human life. The topic of biotechnology covers two main aspects, namely conventional biotechnology and modern biotechnology, which have direct applications in various fields, such as food, health, the environment, and industry. From an educational perspective, biotechnology is highly relevant as teaching material that can hone critical thinking skills while encouraging creativity in students. Students are asked to observe, analyze, and create simple products through a real scientific process. The main focus remains on the concepts and practices of conventional biotechnology, which provides an optimal opportunity for students to improve their critical thinking in designing and reflecting on processes, as well as developing creativity in the form of products and scientific presentations.

The habit of drinking tea has long been known to Indonesians. According to (De Filippis et al., 2018), tea fermented with microorganisms can vary in how it is consumed. Fermented teas, such as kombucha, offer higher nutritional value and support better health than regular tea. Kombucha tea is an interesting traditional drink because it is the result of fermentation by a symbiotic culture. This beverage is made by fermenting sweet tea using a consortium of yeast and bacteria as an inoculum, also known as tea fungus or scoby (Selvaraj & Gurumurthy, 2023). The Indonesian Ulema Council (MUI) Fatwa Number 10 of 2018 concerning food and beverages containing alcohol or ethanol stipulates that the addition of alcohol or ethanol in beverage formulations that are not classified as khamr is permissible (mubah) as long as it does not pose a medical risk and the alcohol or ethanol (C_2H_5OH) content in the final product does not exceed 0.5%. In addition, the MUI emphasizes that fermented beverages with an alcohol or ethanol content of 0.5% or more are categorized as haram (Riswanto & Rezaldi, 2021). Kombucha contains low levels of ethanol, making it halal for consumption. Given these characteristics, kombucha has the potential to be an innovation in learning. The kombucha production process can be integrated into learning through biological innovation technology material by applying the Project-Based Learning stages.

Consuming fermented products such as kombucha is a practice that is culturally considered beneficial to the health of Indian society (Mallappa et al., 2021). Although quite popular in the East, kombucha has also begun to be sold in Western regions. Americans consume kombucha as a healthy substitute for soda (Kim & Adhikari, 2020). Kombucha is a well-known beverage obtained by fermenting various types of tea (e.g., green and black tea) and sugar (Abaci et al., 2022). One of the most popular beverages in recent years, kombucha is a fermented product that first became popular in China and traditionally uses black or green *Camellia sinensis (L.)* Kuntze tea as its substrate. As it became increasingly popular in Japan, the name “kombucha” was created by combining “konbu,” seaweed, and “cha,” which means tea. Kombucha is sold as a tea beverage in the market, but it can also be made at home. The traditional method involves fermenting black or green tea with 5-10% sucrose (Emiljanowicz & Malinowska-Pańczyk, 2020). According to standard practice, black or green tea is steeped with *sucrose* for five minutes and then cooled to room temperature. After the cooled product is filtered, kombucha liquid obtained from previous production is added. This liquid is a biofilm called a “mother” or “SCOBY” *(Symbiotic Community of Bacteria and Yeast),* which consists of a collection of bacteria, mainly from the *Acetobacter* family (Kaashyap et al., 2021). Conventional biotechnology uses living organisms or their products to produce useful products through traditional processes such as fermentation. One common use is to make kombucha, a fermented tea drink rich in probiotics. Kombucha is an application of conventional biotechnology (Fadhilah et al., 2021). Kombucha is made through the fermentation of sweet tea using a colony of bacteria and yeast called SCOBY, which is a symbiotic culture of bacteria and yeast. Essentially, the sugar in the tea is consumed by the SCOBY microbes, which then convert it into organic acids.

2. RESEARCH METHOD

This study used the Research and Development (R&D) method with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model developed by (Dick & Carey, 1996). The ADDIE model was chosen because it emphasizes product feasibility through evaluation by media experts, subject matter experts, biology teachers, and students. The implementation stage was carried out by distributing electronic PjBL worksheets on conventional biotechnology material for making kombucha at SMAN Yogyakarta.

The research data consisted of quantitative and qualitative data. Quantitative data was in the form of scores obtained from student tests and validator questionnaires. Qualitative data consisted of narrative descriptions covering criticism, product development suggestions, and explanations of the trial process. Data collection instruments included expert validation sheets, teacher response sheets, student response sheets, and Likert scale analysis. The data analysis approach was carried out in two stages:

The analysis of the expert assessment results on the instruments in this research and development was carried out using the following steps:

1. The validation sheet was given to subject matter experts, media experts, and biology teachers, who then calculated the total scores from the experts using a Likert scale in the form of a checklist and calculations following the provisions in the questionnaire sheet. The questionnaire sheet was adapted from research (Melinda Lasaret, 2022 ;Mursid & Gultom, 2019). These components were assessed by media and teaching material experts using a Likert scale with four options: very good, good, not so good, and very poor. These values are illustrated in the following table (Sugiyono, 2018) :

Table 1. Likert Scale

score	category
4	Very Good
3	Good
2	Not So Good
1	Not So Good

The aspects assessed by media and teaching material experts include several aspects, namely: graphic suitability, presentation, technical aspects, content suitability, and language. As explained in the following table (Tohiri, 2024):

Table 2. Grid for expert validation of media and teaching materials

No	Assessment aspects	Indicators
1	Graphic Design Feasibility Aspects	Pleasing color combinations
		Compatibility of pleasing color combinations between the images displayed and the content
		Compatibility between the background color and the overall appearance of the background
		The placement of titles, subtitles, illustrations, and image descriptions does not hinder understanding
		Sharpness and clarity of the images used
2	Presentation Aspects	Language presentation
		Sentence structure
		Syntactic clarity Project-based learning
		Question clarity
		Clarity of usage instructions
3	Technical Aspects	Use of font types is not overly diverse.
		The spacing between paragraphs is proportionate.
		The cover design is in line with the content of the LKPD.

			The table of contents is presented clearly and is easy to understand.
			Use of fonts that are easy to read.
			Appearance is in line with the content.
			Images are in line with the content.
4	Content Aspects	Feasibility	The suitability of the content with the Learning Objectives (ATP) and Basic Competencies (KD)
			The accuracy of the information presented in the material
			The availability of additional material that supports the learning process
5	Linguistic Aspects		Use of language appropriate to the developmental stage of the students
			Illustrations used to clarify the content of the material
			Communicative and easy-to-understand style of language
			Titles of worksheets and sections of material that attract interest in reading without containing provocative elements

The questionnaire was adapted from Tohiri's (2024) research. The assessment was conducted by high school teachers using a Likert scale with four alternatives: very good, good, not so good, and very poor, as described in the following table:

Table 3. Skala *Likert*

score	category
4	Very Good
3	Good
2	Not So Good
1	Not So Good

The assessment conducted by high school teachers covers four main aspects, namely material, didactics, technical, and language. The following table present the assessment result from high school biology teachers:

Table 4. Aspects of high school biology teacher validation assessment

No	Assessment aspects	Indicators
1	Presentation	Clarity of objectives
		Clarity of learning instructions
		Questions given are in line with theory
2	Visual	Clarity of images
		Relevance of images to the material
		Clarity of videos
		Display design
3	Language	Readability
		Effective and efficient use of language
4	Usefulness	Expands knowledge
		Reflection, feedback, and follow-up

2. The next stage of analyzing the expert assessment results on the instruments in this research and development was carried out with the following steps:
   a. The validation sheet was given to subject matter experts, media experts, and biology teachers, who then calculated the total scores of the experts using a Likert scale in the form of a checklist and calculations following the provisions in the questionnaire sheet.
   b. The next stage was to calculate the validation scores of the subject matter experts, media experts, and biology education experts using a formula adapted from Himah (2023):

$$M = \frac{\sum Fx}{\sum N}$$

Explanation:
M : average per aspect
$\sum fx$: total score per aspect
N: number of components

   c. The next step is to change the value from the average of the expert assessment, which was initially quantitative, to qualitative, based on the validity criteria adapted from (Astuti et al., 2020) :

Table 5. Validity level criteria

Percentage (%)	Validity Level
81-100%	Very Valid
61-80	Valid
41-60	Sufficiently Valid
21-40	Less Valid
0-20	Not Valid

3. RESULT AND DISCUSSION

This study used the Research and Development (R&D) method with the ADDIE development model design consisting of five stages, namely Analysis, Design, Development, Implementation, and Evaluation. The results for each stage of LKPD development using the ADDIE model are as follows:

1. Analysis

   The analysis stage successfully identified problems in the learning process, curriculum, and characteristics of student needs.
   a. Curriculum Analysis Results
      Analysis of the curriculum used at SMAN Yogyakarta shows that the curriculum used is the National Merdeka Curriculum.
   b. Results of Student Needs Analysis
      The results of the needs analysis at SMAN Yogyakarta show the importance of developing more relevant and contextual teaching materials, especially in biotechnology learning.
2. Design

   The design stage in this study was carried out systematically to ensure integration between the learning principles adopted in the Merdeka Curriculum and the actual needs in educational units, particularly in building a contextual, adaptive, and inclusive learning environment with the main objective of improving students' critical thinking and creativity skills at SMAN 9 Yogyakarta. The design process began with the selection of a framework design that not only considered the content structure and logical flow of the material but also emphasized flexibility and differentiation in biology learning to suit the diverse characteristics and needs of students.
3. Development

   The development of Project-Based Learning worksheets for students on biotechnology has been successfully completed. The development stage of this research focused on the preparation and refinement of Project-Based Learning (PjBL) worksheets for students, which are intended to strengthen the learning of biotechnology in a contextual, applicable manner based on 21st-century skills.

Picture 1. Student Worksheets (LKPD)

Based on the results of this input, a revision of the first stage of the product was carried out by integrating the suggestions and recommendations of experts to improve the quality of the product both substantially and technically.

4. Implementation

The implementation stage A large-scale trial was conducted to determine the effectiveness of using Project-based learning (PjBL) worksheets in biotechnology education (Laili et al., 2019). This trial involved two classes using a quasi-experimental approach: class X.6 served as the experimental class, and class X.2 served as the control class. The experimental class (X.6) used electronic LKPD to teach PjBL, which was developed and modified based on the results of previous validation and limited trials. Meanwhile, in the control class (X.2), the learning process was carried out using conventional LKPD with conventional methods in accordance with the teaching tools previously used by teachers.

5. Evaluate

The evaluation stage in this study focused on collecting and analyzing feedback from various parties directly involved in the implementation of project-based Student Worksheets (LKPD), (Dewi et al., 2017) particularly teachers and students. Feedback was collected through questionnaires, interviews, and observations during the learning process to obtain a complete picture of the effectiveness, comprehensibility, attractiveness, and usefulness of the LKPD in supporting the teaching and learning process.

a) Product Feasibility Test

1. Product Practicality Test by Biology Teachers

In detail, the aspects evaluated include several indicators, namely material aspects, didactic aspects, technical aspects, and language aspects. The overall assessment results indicate that the learning materials have met the established standards and are very suitable for use in effective and meaningful learning processes in educational units.

Table 6. Results of LKPD Validation by Biology Teachers

No	Aspect	Maximum Score	Score Obtained	Result	Description
1.	Materials	20	20	100%	Very Valid
2.	Didactic	12	12	100%	Very Valid
3.	Technical	12	12	100%	Very Valid
4.	Language	12	12	100%	Very Valid
Average				**100% (Very Valid)**	

The data in the table above shows that the average score for the Biotechnology Biology learning material is very good, with an average score of 100. The assessment results from biology teachers show that this learning material is very suitable for use in the learning process.

2. Product Practicality Test

This assessment is intended to obtain an overview of the extent to which the material presented in the electronic LKPD is able to increase students' interest in the subject and encourage them to participate actively in the learning process. (Qiang et al., 2020)The following table and description present the results of the student assessment based on the questionnaire that was given:

Table 7. Validation of LKPD by Students

No	Aspect	Maximum Score	Score Obtained	Result	Description
1.	Presentation	432	394	91%	Very Practical
2.	Visual	576	517	90%	Very Practical
3.	Language	432	387	90%	Very Practical
4.	Usefulness	288	269	93%	Very Practical
Average				**91% (Very Practical)**	

Based on the data presented in the table above, a perfect average score of 91% was obtained, which after conversion became 91, thus falling into the “very practical” category. Based on the practicality test results covering all assessment indicators, a score was obtained that indicated the “very practical” category, indicating that the LKPD had a high level of acceptance in learning practices. According to (Ramadhana & Hadi, 2021), LKPD is a learning medium that serves to facilitate the learning process and build effective interactions between teachers and students, while also increasing learning activity and achievement. In line with the research (Farida et al., 2024), which shows that students' reactions to E-LKPD Liveworksheets are in the good category, students are interested in using the E-LKPD and find it easier to understand the material.

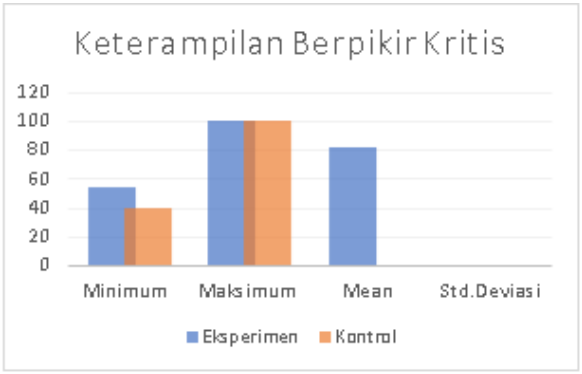
3. Descriptive Analysis of Critical Thinking Skills & Creativity
   a. Critical Thinking Skills
      The evaluation of students' critical thinking skills was conducted using essay questions administered before (pre-test) and after (post-test) the learning process to the experimental and control groups.

The overall results of the responses from teachers and students lead to the conclusion that the electronic LKPD Project-Based Learning for making kombucha is very suitable for use as teaching material in schools.

4. Descriptive Analysis of Critical Thinking Skills & Creativity
   a. Critical Thinking Skills
      The evaluation of students' critical thinking skills was conducted using essay questions administered before (pre-test) and after (post-test) the learning process to the experimental and control groups. Respectively (Halpern, 1999). The results of the analysis are presented systematically in the following table:

Table 8. Resault Critical Thinking Skills

No	Keterangan	Keterampilan Berpikir Kritis			
		Eksperimen		Kontrol	
		Pre-test	*Post-test*	*Pre-test*	*Post-test*
1.	Minimum	0	55	25	40
2.	Maksimum	50	100	77.5	100
3.	Mean	26,3	82	53	73,1
4.	*Std Deviasi*	9,1	11,3	14,6	15,7



Picture 2. Critical Thinking Skills Chart for Students

The increase in N-gain critical thinking skills can be seen in the following table:

Table 9. N-gain Critical Thinking Skills

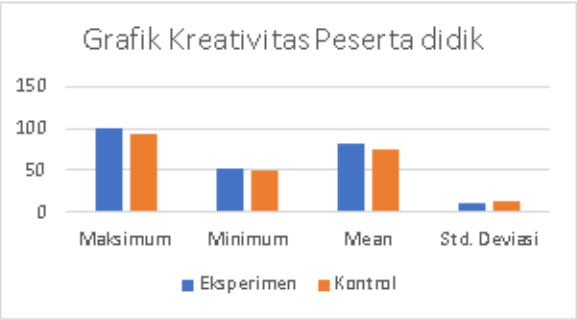
Class	Average	Category
Eksperimen	0,756	High
Control	0,427	Middle

Based on the data presented in the table, in the experimental class, students had an average N-gain score of 0.756, which is in the high category; in the control class, the average N-gain score was 0.427, which is in the moderate category.

   b. Creativity The evaluation of students' creativity was conducted using essay questions administered before (pre-test) and after (post-test) the learning process in the experimental and control groups. The results of the analysis are presented systematically in the following table:

Table 10. Resault Creativity

No	Keterangan	Keterampilan Berpikir Kritis			
		Eksperimen		Kontrol	
		Pre-test	*Post-test*	*Pre-test*	*Post-test*
1.	Minimum	12.5	52.5	12.5	50
2.	Maksimum	95	100	82.5	92.5
3.	Mean	47.5	81	49.1	74.3
4.	*Std Deviasi*	18.6	11.1	14.5	12.9



Picture 3. Creativity Chart

Table 11. N-gain Creativity

Class	Average	Category
Eksperimen	0.639	Middle
Control	0.580	Middle

Based on the data presented in the table, in the experimental class, the average creativity N-gain score was 0.639, which falls into the moderate category, while in the control class, the average N-gain score was 0.580, which also falls into the moderate category. increase in N-gain critical thinking skills can be seen in the following table.

5. CONCLUSION

Based on the results of the research and discussions that have been conducted, it can be concluded that the development of Project-Based Learning (PjBL)-based Electronic Student Worksheets (LKPD) on Conventional Biotechnology material through a case study of kombucha fermentation has proven to have a high level of feasibility and practicality as a biology learning tool for high school students in phase E.

The feasibility of the product is demonstrated through the validation results from subject matter experts, media experts, and education practitioners who assessed this Electronic LKPD as highly feasible. The assessment covers aspects of content, language, presentation, and media display that are appropriate for the characteristics of high school students . The material presented is considered relevant to the curriculum and capable of supporting the achievement of competencies, particularly in the development of critical thinking and creativity skills. In addition, the use of kombucha fermentation case studies is considered contextual, thereby enhancing students' understanding of the application of biotechnology in everyday life. Thus, this Electronic LKPD can be confirmed as suitable for use as an innovative learning medium in line with the demands of 21st-century learning.

The practicality of the Electronic LKPD can be seen from the results of limited trials on phase E students at SMAN Yogyakarta. Student responses showed a very feasible category, which means that the LKPD is easy to use, interesting, and able to increase student engagement during the learning process. Teacher assessments also supported these results, emphasizing that this LKPD is practical for use in biology learning because it is integrated with the PjBL approach, which encourages collaborative activities and real-world problem solving. The suitability of the instruments, clarity of instructions, and digital-based presentation of material make this LKPD effective for use in classrooms with limited time and resources. Overall, the results of this study prove that PjBL-based Electronic LKPD on conventional biotechnology material is not only substantively and technically feasible, but also practical for use in learning. This product has the potential to make a positive contribution to improving the quality of biology learning in high schools, particularly in developing students' critical thinking and creativity skills.

ACKNOWLEDGMENTS

On this occasion, the author would like to express his deepest gratitude and appreciation to all those who have provided moral and material support. The author would like to thank his supervisor, who has always been willing to devote his time, energy, and thoughts in providing valuable guidance, input, and advice. The author would also like to thank the validators, consisting of subject matter experts, media experts, and biology teachers, for their constructive suggestions, criticism, and recommendations for the improvement of this development product. Furthermore, the author would like to thank the school, especially the principal, teachers, and students of SMAN Yogyakarta, who have given permission, opportunity, and active participation in the product testing process. This support was very helpful in obtaining valid and relevant data. Last but not least, the author would also like to thank colleagues and family who have always provided motivation, prayers, and encouragement

during the research process. Finally, the author hopes that all the help, support, and prayers that have been given will be rewarded by Allah SWT. May this research provide tangible benefits for the development of science, particularly in the field of biology education, and contribute positively to improving the quality of 21st-century learning.

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