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Improving critical thinking skills through the implementation of E-worksheets based on differentiated PjBL-STEM

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Abstract

Background: Critical thinking is an important skill because it involves reasoning and logic in problem solving efforts. Although it is important, it turns out that students' critical thinking skills are currently still low.
Aims: This study aims to describe the practicality and effectiveness of e-worksheets based on Differentiated PjBL-STEM to improve critical thinking skills.
Methods: This research is a Research and Development that refers to the Borg and Gall model. The population is all grade IX students at one of the junior high schools in Tanjung Bintang District. Research instruments were questionnaires for the needs of educators and students, questionnaires for validating e-worksheets by experts, questionnaires for responding educators and students, pretest-posttest, critical thinking skills data analysis techniques using t-test.
Result: The validation results of e-worksheets for the suitability of content, attractiveness, and readability obtained an average of 88.35%, meaning that e-worksheets is valid, while the educator's response was 98.29%, the average student response for the attractiveness and readability aspects was 96.11%, meaning that e-worksheets is practically. The results of the t-test sig.2 tailed value of 0.000 mean that the average critical thinking skills in the experimental class are higher than those in the control class. This is supported by an effect size of 1.29 which is categorized as "large".
Conclusion: Differentiated PjBL-STEM-based e-worksheets effectively improve students critical thinking skills with a significant impact on tolerance of differences in student learning readiness. Therefore, differentiated PjBL-STEM learning is important to implement in schools, especially project-based learning that is relevant to the real world.

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INTRODUCTION

The 21st century is marked by openness or globalization, meaning that human life in the 21st century is experiencing fundamental changes that are different from the order of life in the previous century (Dirlik, 2006; Scott, 2000). Education in the 21st century demands various skills that must be mastered by students, so that education is expected to prepare students to master these various skills in order to become individuals who are ready to enter the world of work in the future (Angga et al., 2022). In line with this, one of the 17 goals of the Sustainable Development Goals (SDGs) is developing "Quality Education", which postulates that every student must acquire the knowledge and skills needed to promote sustainable development (Kopnina, 2020). Quality education can develop students to become creative and responsible world citizens who critically reflect on the idea of sustainable development by implementing an environmentally friendly lifestyle and using environmentally friendly technology (Spannring, 2019). Based on this, to achieve the goal of improving quality, the existing education system must be created with a pleasant learning environment and process that encourages students to develop their skills to the maximum (Khlaisang & Songkram, 2019). Assessment and teaching of 21st Century Skills (ATC21S) categorizes 21st century skills into 4 categories, namely way of thinking, way of working, tools for working and

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skills for living in the world (Care et al., 2018). One of the important skills of the way of thinking is critical thinking, problem solving, and decision making.

Based on the PISA 2022 study on student science literacy in countries around the world, it states that the average score of student science literacy in Indonesia is 383 and is ranked 63rd out of 76 countries (OECD, 2023). This indicates that student science literacy in Indonesia, including Lampung province, is still relatively low. So that low student science literacy will result in low critical thinking skills of students (Rahayuni et al., 2016). Critical thinking skills can be stimulated through discovery-based learning using a scientific approach (Liu et al., 2018; Sutiani et al., 2021). Classroom activities such as the process of students searching for information will develop problem-solving skills which have been proven to have a positive impact on students' critical thinking skills (Tsai et al., 2013). Another aspect that affects critical thinking skills is the diversity of students in one class. Individual differences in the learning process that include differences in abilities, talents, interests and learning methods of students will affect the way of thinking and improving learning outcomes (Chen & Wang, 2021; Stern, 2017). These elements have been fully integrated into the principles and implementation of the Merdeka curriculum.

The Merdeka Curriculum has main characteristics including the application of project-based learning models and differentiated learning. The PjBL model is intended for the development of soft skills and character which include faith, piety, mutual cooperation, global diversity, independence, critical reasoning, and creativity (Sari et al., 2025). This curriculum is expected to provide more space for the development of character and competence of students so that students can pursue their interests more flexibly. Educators are expected to have the flexibility to carry out learning that is in accordance with the abilities of students (teaching at the right level) or differentiated learning (Mulyasa, 2023). Differentiated learning begins with mapping, one of which is the differences in student readiness (Djatmika & Astutik, 2023; Tomlinson et al, 2003). Several studies have shown that the application of differentiated learning can improve students' learning outcomes in science learning well (Astuti et al, 2023; Setiawan et al, 2023). Differentiated learning with the PjBL model creates meaningful learning, trains knowledge, and provides direct experience to students, as well as developing critical thinking skills (Atmojo et al, 2025; Putri et al, 2023).

Learner-centered STEM teaching not only enables investigative, action-adapted learning but also fosters independent learners who respond to their natural environment (Campbell & Speldewinde, 2022). The application of project-based learning models in science learning can be integrated with a learning approach that can train holistic thinking in solving a problem (Priantari et al., 2020). The application of STEM is suitable for use in science learning. STEM-based learning can train students to apply their knowledge to create designs as a form of solving environmental problems by utilizing technology (Alkair et al., 2023; Chai et al., 2020; Chan & Nagatomo, 2021). PjBL-STEM combined with the engineering design process is described as an educational system that embeds mathematical knowledge in the context of design technology, creating a problem-solving learning environment in which students envision design solutions, gather information, and tackle real-world problems (Wahono et al., 2020). The implementation of PjBL-STEM can train logical, creative, innovative, problem-solving, critical thinking skills, and the ability to work in a team (Baran et al., 2021; Retno et al., 2025; Purwaningsih et al., 2020). The advantages of implementing PjBL-STEM include the transfer of knowledge and skills to real-world problems, increased motivation to learn, and increased knowledge of mathematical and scientific concepts (Laboy-Rush, 2011). In school learning, especially in South Lampung, 79.4% of teachers have known the PjBL model and the STEM approach, but only 38.2% understand the integration of the two in PjBL-STEM. This limited understanding has an impact on the low implementation of worksheets which improves critical thinking skills with only 44.1% of teachers having used the PjBL model. This is reinforced by the recognition of students as many as 14.8% who admitted that they had been given questions

related to problems in everyday life to be solved and invited to identify and explain scientific phenomena in the learning process. In addition, as many as 80% of students have also worked on project-based assignments involving the principles of energy change or environmentally friendly technology. The project worked on was a simple water filtration device that imitated a YouTube link provided by the teacher.

Jati Agung District, South Lampung Regency is known as one of the largest rice producing areas in the region. So far, farmers in Jati Agung have relied on regular seasonal patterns, namely the rainy season from October to March for the rice planting season, and the dry season from April to September for the corn planting season. However, in recent times, climate change has caused the seasons to become uncertain. In the period that should be the rainy season, it turns out that there is more hot weather than rain. As a result, the flow of water from the river which is usually used to irrigate rice in the fields because the volume of water has decreased drastically. This condition causes many rice fields to dry out, so that rice growth is disrupted and yields decrease. This problem can be integrated into science learning in schools to invite students to solve problems with the PjBL-STEM.

The STEM-based PjBL model simultaneously improves critical thinking skills and learning outcomes (Retno et al., 2025; Rahardhian, 2022). Based on the results of the teacher needs analysis, most teachers (61.8%) have used Student Worksheets (LKPD) in science learning, especially on the topic of environmentally friendly technology, but only 11.8% have utilized electronic-based worksheets. The main obstacles in the use of e-worksheets include a lack of understanding in compiling and limited mastery of information technology, so that the majority of teachers still rely on worksheets from books or the internet that are adjusted to school conditions. Research related to PjBL-STEM on differentiated learning has been conducted previously, Silfiyani & Suyatna (2024) stated that e-LKPD based on PjBL-STEM is effective in improving students' scientific literacy, with a focus on the differentiation aspect of students' learning styles. Research by Sekarningrum et al (2025) which states that STEM-PjBL digital worksheets with process differentiation at each phase, in the form of group variations based on gender and learning styles, are valid and practical. Priantari et al. (2020) shows that the STEAM approach and PjBL model have a positive effect on students' critical thinking skills. Based on this, there has been no research related to PjBL-STEM that focuses on the differentiation aspect of learning readiness towards critical thinking skills. Therefore, this research will develop an electronic-based student worksheet that guides students in solving real problems in everyday life by considering the level of student learning readiness. By raising real problems in everyday life in learning projects, learning will be more contextual and meaningful. The designed e-worksheet not only trains students' understanding but also in a series of problem-solving processes that integrate every aspect of STEM, by encouraging students to integrate various disciplines, it can contribute to training critical thinking skills.

METHOD

Research Design

Research and Development (R & D) with the Gall et al. (2003) model because it has detailed Development Steps. The research conducted produced a product, namely e-worksheets based on Differentiated PjBL-STEM to train critical thinking skills of junior high school students on environmentally friendly technology material. The research steps carried out by researchers according to the Gall et al. (2003) model were 10 steps, namely research and information collection, planning, initial product development, limited field testing, initial product revision, main field testing, revision of the main field test product results, operational field testing, final product revision, and dissemination and implementation. The research flow can be seen in Figure 1.

Participant

Participants in this study included 115 students and 34 science teachers in South Lampung in the analysis of the needs of e-worksheets to be developed, three science experts who are lecturers at the University of Lampung to validate e-worksheets based on Differentiated PjBL-STEM to improve students' critical thinking skills. Furthermore, participants in the practicality test of e-worksheets included 3 science teachers in South Lampung and 15 students at Senior High School Class X in South Lampung. Three expert lecturers and science teachers assessed e-worksheets on aspects of content suitability, readability, and attractiveness, while students assessed aspects of readability and attractiveness. After e-worksheets is valid and practical, the next step is to test the effectiveness of e-worksheets. The effectiveness test of e-worksheets based on Differentiated PjBL-STEM was conducted using a quasi-experimental design with the matching-only pretest-posttest control group design (Fraenkel et al., 2012). The population in this study were students of class IX at one of the junior high schools in South Lampung, which included three classes with a total of 96 students. The sample in this study was taken using a purposive sampling technique using the two-average equation analysis technique, so that classes IX A and IX B were obtained as research samples. Class IX B was chosen as an experimental class that uses differentiated learning using e-worksheets based on Differentiated PjBL-STEM to improve critical thinking skills, while class IX A was designated as a control class that applied conventional learning.

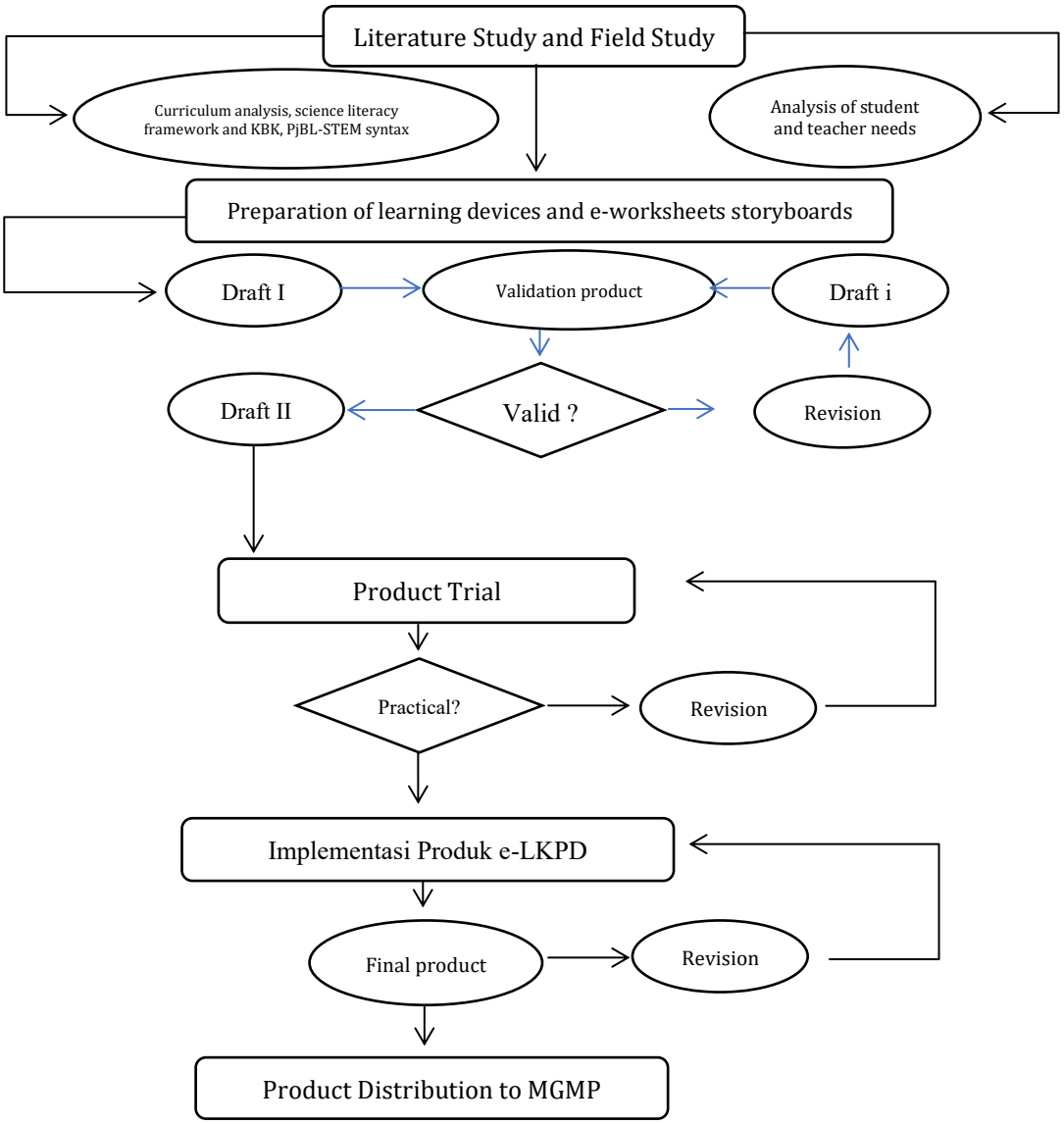


Figure 1. Research flow

Instrument and Analysis Data

The instruments in this study include test and non-test instruments. The test instrument in this study was used to determine the effectiveness of e-worksheets, namely pretest-posttest questions on students' critical thinking skills totaling 5 questions according to the critical thinking skills indicators according to Ennis (1996). Non-test instruments include teacher and student needs questionnaires, e-worksheets validation questionnaires by experts on aspects of content suitability, readability, and attractiveness, and e-worksheets practicality questionnaires covering aspects of content suitability, readability, and attractiveness for teachers, and aspects of readability and attractiveness for students. The validation questionnaire of e-worksheets by experts, and practicality by teachers and students was conducted using a Likert scale with a value of 1 meaning strongly disagree, 2 disagree, 3 less agree, 4 agree, 5 strongly agree, after that calculating the average value of the answers of experts, teachers, and students. Before being used to measure students' critical thinking skills, the pretest-posttest questions were tested for validity and reliability using SPSS. The validity and practicality criteria for e-worksheets using (Arikunto, 2013) interpretation are shown in Tables 2. Data analysis was carried out using descriptive statistical analysis. The pretest-posttest data obtained were then used to calculate the students' n-Gain values and interpreted according to Hake (2002) in Table 1. Next, the n-Gain value was analyzed using SPSS software version 25.0 using the independent sample t-test to determine its effectiveness. Then continued to measure the effect size based on Cohen (1998) .

$$N - gain = \frac{skor\ postes - skor\ pretes}{100 - skor\ pretes}$$ (Hake, 2002)

Tabel 1. n-Gain Criteria (Hake, 2002)

n-Gain	Criteria
> 0,7	High
0,3 < n-Gain ≤ 0,7	Medium
n-Gain ≤ 0,3	Low

Table 2. e-worksheets Validation/ Practical Criteria (Arikunto, 2013)

Percentage	Validity Level	Deskription
76% – 100%	Valid/ Practical	Worthy/no need for revision
51% – 75%	Fairly Valid/ Practical	Decent enough/partial revision
26% – 50%	quite valid/ Practical	Inadequate/partial revision
< 26%	Invalid/Inpractical	Not feasible/total revision

Procedures and time frame

This research was conducted for 7 months, namely from December to June. For one month, the researcher collected data, namely the analysis of the needs of students and teachers throughout South Lampung, in addition, the researcher requested data from the Central Statistics Agency (BPS) regarding the progress of the rice harvest over the past year and direct observation of the rice fields regarding the actual conditions of the rice fields. Then the researcher conducted a literature study related to the critical thinking skills framework that will be used, learning outcomes, the PjBL-STEM framework that will be used. After completion, the researcher created an e-worksheets storyboard using the Canva application. After getting the final storyboard, the researcher then started making e-worksheets for approximately two months. Then validate the e-worksheets to science experts for approximately two weeks, then the researcher made improvements to the suggestions and input given by the validator. After the product was declared valid, the researcher conducted a practicality test on teachers and students for one week. Then conduct a product trial on a large scale for one month, after that analyze the research data.

RESULTS AND DISCUSSION

Results

This development research was conducted using Gall et al. (2003)10 systematic stages. The results for each stage are presented below.

Research and Data Collection Stage

At this stage, a literature study and field study were conducted related to the analysis of teacher and student needs for the product to be developed, namely e-worksheets based on Differentiated PjBL-STEM to improve students' critical thinking skills. The results of the literature study are in the form of e-worksheets writing rules, the PjBL-STEM framework referring to Laboy-Rush (2011), namely reflection, research, discovery, application, and communication. The critical thinking skills framework referring to Ennis (1996) includes aspects of providing simple explanations, building basic skills, concluding, providing further explanations, and arranging strategies and tactics. Learning outcomes are that students can elaborate on sources of solar, water, and wind energy, as well as efforts to preserve their environment. The type of differentiation in this study is product differentiation.

The results of the field study conducted using a student needs questionnaire distributed through Google Forms with 115 students as respondents, stated that students had used worksheets in learning (88.7%) but only 65.2% in electronic form, and 86.1% had implemented PjBL in class but 90.4% were not STEM-based. In addition, 85.2% of students stated that science learning had not been linked to problems in everyday life that had to be solved and had not been invited to identify and explain scientific phenomena during the learning process. This was reinforced by the results of teacher responses derived from the teacher needs questionnaire with the number of teacher respondents, namely 34 teacher statements that learning in schools was project-based but the projects worked on by students were still plagiarizing projects from YouTube and were not STEM-based because 61.8% of teachers did not know about PjBL-STEM. In addition, 41.2% of teachers stated that they had implemented differentiated learning, namely product differentiation (32.4%), content differentiation (15.2%), and process differentiation (52.4%). So that 100% of teachers stated the need to develop e-worksheets based on Differentiated PjBL-STEM which can improve critical thinking skills in science learning.

Planning Stage

At this stage, planning is carried out in the form of a description of e-worksheets based on Differentiated PjBL-STEM in the form of a storyboard. Furthermore, the preparation of the e-worksheets validation instrument includes aspects of content, readability, and attractiveness, as well as the e-worksheets practicality questionnaire includes aspects of readability and attractiveness, in addition to planning the preparation of teaching modules, teaching materials, pretest-posttest grids, pretest-posttest questions, pretest-posttest assessment rubrics, learning implementation sheets, and student response questionnaires for Differentiated PjBL-STEM learning

Initial Product Development Stage

In the next stage, the e-worksheets is prepared based on PjBL-STEM. The e-worksheets draft is prepared using the Canva application, after completion, the e-worksheets draft is consulted with supervisors 1 and 2. Then after going through the revision stage, the e-worksheets draft that is ready to be validated is made in electronic form using liveworksheets software. The results of making e-worksheets Based on PjBL-STEM Differentiated in the introduction, content, and closing sections. The introduction section in this e-worksheets consists of the identity of the e-worksheets in the form of the title of the e-LKPD, the logos of Unila, FKIP, and Kampus Merdeka, material and sub-material, time allocation, class and semester, learning outcomes, group name column, instructions for working on the e-worksheets, and the name of the compiler of the e-worksheets. The content section in the e-

worksheets consists of learning stages that are in accordance with the PjBL-STEM model, and the closing section in this e-worksheets consists of a bibliography and developer profile.

Limited Field Test

In the next stage after compiling the e-worksheets, validation of the e-worksheets product based on Differentiated PjBL-STEM was carried out with science experts, namely two lecturers in the Master of Science Education at the University of Lampung. The validation aspects of the e-worksheets product are in the form of aspects of content suitability, readability, and attractiveness. The percentage of validation results for e-worksheets Based on Differentiated PjBL-STEM by experts is shown in Table 3.

Table 3. e-worksheets Validation Results

Aspect of Validation	Percentage (%)	Criteria
Content suitability	90%	Valid
Legibility	86,15%	Valid
Attractiveness	88,89%	Valid
Average	88,35%	Valid

Based on Table 3, information was obtained that the e-LKPD product based on Differentiated PjBL-STEM is valid with the criteria of "very high". This high percentage is due to the first stage of the PjBL-STEM model, namely reflection. At this stage, students are given a problem phenomenon that exists in the school environment, which is located in the middle of rice fields in Dusun Priangan, Karang Anyar Village. At this stage, the teacher gives a problem that occurs in Karang Anyar Village. Students live in an environment that is directly affected by the problem of the availability of irrigation water for agriculture, especially during the dry season. During the dry season, the rivers in Karang Anyar Village experience a decrease in volume so that the rice fields near the water source cannot be irrigated unless using an electric pump, but not all residents can use an electric pump because the rental and fuel costs are expensive, and it is not environmentally friendly. Based on the phenomenon given, students are asked to determine the problems that exist in Karang Anyar Village during the dry season. Furthermore, students are asked to write down the solutions that are usually done by the community, and reflect on whether the solution is appropriate or not along with the reasons. At this stage, the critical thinking skill aspect is to provide a simple explanation (focusing questions in the form of problems and analyzing arguments).

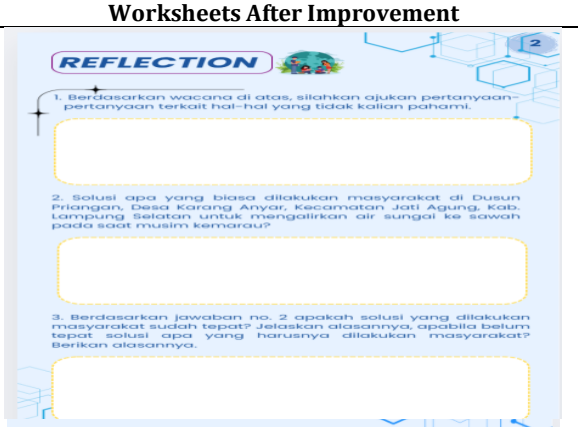
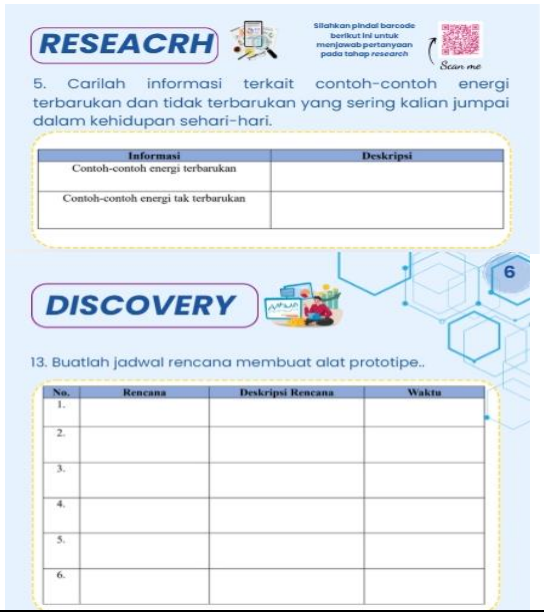
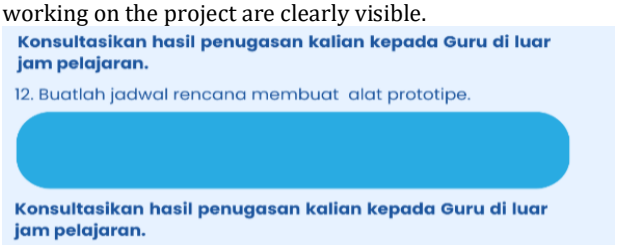
The second stage in the PjBL-STEM model is research, in this syntax students are asked to read, collect information, and relevant sources needed to solve the problems that have been found in the first stage. Students begin to collect information in the form of knowledge concepts that they must understand further to solve problems, determine problem-solving project plans. Educators in this syntax act as consultants for the information that students have searched for and consult on problem-solving project plans. At this stage, critical thinking skill aspects are trained to build basic skills to consider whether a source is reliable or not) and provide further explanations (defining terms). The third stage is discovery. In this syntax, the teacher provides a tool to raise the water of the River to the rice fields that already exist, students are asked to identify the weaknesses and advantages of the tool and then determine the modified product to solve the problems found. Then students are asked to determine the tools and materials and procedures for making the product. During this process, students may consult with educators regarding the e-worksheets that has been completed. At this stage, the critical thinking skill aspect is concluding determining the results of consideration). The fourth stage is application, at this stage students are asked to carry out the project, during the implementation of the project students document each product making process through photos and videos. If the product that has been made is finished, students are asked to try the product, if there are obstacles that are not appropriate, educators can direct students to repeat the previous steps. At this stage, the critical thinking skill aspect is to set strategies and tactics (determine an action). The

fifth stage is communication, in this syntax students are asked to present the products that have been made in the form of prototypes, PPT, videos, and collect reports. Other groups that do not present products are expected to provide feedback in the form of questions and suggestions/input, the same thing is done by educators. At this stage, the critical thinking skill aspect is to provide further explanation (identify assumptions).

Initial Product Revision

After validating the product, the validator provides suggestions and input for improving the e-worksheets product. The validator's suggestions and input can be seen in Table 4.

Table 4. Validator Suggestions and Input

Suggestions and Input	Worksheets After Improvement
The size of the answer column is enlarged and the color is changed from blue to white.	 
In the table of contents, the English words and PjBL-STEM syntax in English are changed to italics.	 
At the research stage, a table is added in the answer column, and teaching materials are added in the form of teaching material barcodes that have been prepared by the teacher to make it easier for students to find literature sources.	 
At the discovery stage, answer columns are created in a table so that the plan, plan description, and time allocation for working on the project are clearly visible.	

Main Field Test and Product Revision Main Field Test Results

After the e-worksheets was declared valid, the e-worksheets draft was ready to be tested on 15 students at a high school in Jati Agung and 3 science teachers at a junior high school in South Lampung. The results of the main field test percentage are shown in Tables 5 and 6.

Table 5. Percentage Results of Teacher Responses to e-worksheets

Aspect	Percentage (%)	Criteria
Content suitability	98,82%	Practical
Legibility	96,85%	Practical
Attractiveness	99,22%	Practical
Average	98,29%	Practical

Table 6. Percentage Results of Student Responses to e-worksheets

Aspect	Percentage (%)	Criteria
Legibility	98,46%	Practical
Attractiveness	93,75%	Practical
Average	96,11%	Practical

Based on Tables 5 and 6, it is obtained that according to three science teachers in South Lampung, in terms of content suitability, readability, and attractiveness, the e-worksheets product based on Differentiated PjBL-STEM that has been developed is good and practical with a category of "very high". Meanwhile, according to 15 students at SMA Al Huda Jati Agung, in terms of readability and attractiveness, the e-worksheets based on Differentiated PjBL-STEM that has been developed is appropriate, interesting, and practical to use in science learning with a category of "very high". Based on the results of teacher and student responses, the product is practical with a category of "very high" so that the e-worksheets based on Differentiated PjBL-STEM can be tested on a larger sample.

Operational Field Testing

The trial of e-worksheets based on Differentiated PjBL-STEM was widely conducted at one of the junior high schools in Jati Agung. Data on the effectiveness of e-worksheets to improve students' critical thinking skills in this study included the The average n-Gain value of critical thinking skills for each student's readiness is shown in Figure 1, then normality test, homogeneity test, independent sample t-test, and effect size test were carried out. The results of the normality, homogeneity, and independent sample t-test of the n-Gain value of students' critical thinking skills in the control class and the experimental class are shown in Table 7, 8, and 9.

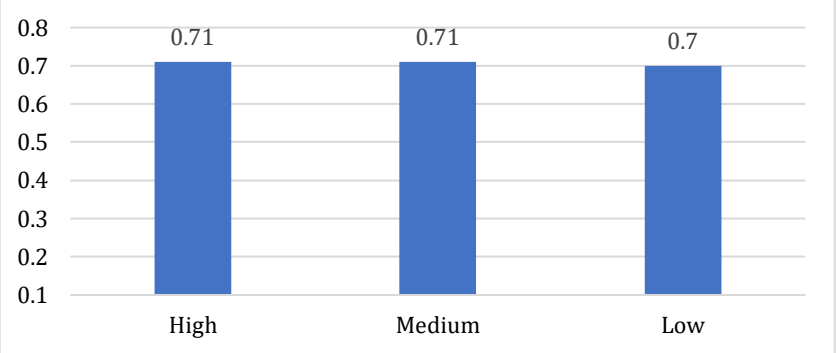


Figure 2. Average n-Gain of critical thinking skills at each level of student learning readiness

Based on Figure 2, it shows that the average value of n-Gain critical thinking skills for each learning readiness, whether low, medium, or high, has a relatively similar value. This means that e-worksheets based on Differentiated PjBL-STEM is able to improve students' critical thinking skills by accommodating each learning readiness.

Table 7. Normality Test Results of Critical Thinking Skills

Class	N	*Sig. Kolmogorov-Smirnov*
Control	30	0,122
Experiment	32	0,144

Table 8. Homogeneity Test Results of Critical Thinking Skills

Class	N	*Sig.*
Control	30	0,146
Experiment	32	

Table 9. Independent sample t-test Result of Critical Thinking Skills

Class	N	*Sig. (2-tailed)*
Control	30	0,000
Experiment	32	

Table 10. Effect Size

Variabel	Cohen'd	Criteria
Critical Thinking Skills	1,29	Large

Based on Table 7. critical thinking skills of students in both the control class and the experimental class have sig. Kolmogorov-Smirnov values > 0.05, meaning that H0 is accepted. The sample comes from research data that is normally distributed. Furthermore, a homogeneity test is carried out as shown in Table 8. The results of the homogeneity test of critical thinking skills in the control and experimental classes have sig. values > 0.05, with the H0 acceptance test criteria, which means that both samples come from a homogeneous population. Therefore, the research data on critical thinking skills obtained are normally distributed and homogeneous, so an independent sample t-test is carried out. Based on the results of the independent sample t-test in Table 9. the sig. value is obtained. (2-tailed) < 0.05, this is in accordance with the H_0 rejection test criteria, which means that there is a significant difference between the average n-Gain value of critical thinking skills of students in the experimental class and the control class, where the average n-Gain value of students in the experimental class is higher than the control class. Based on Table 10, the effect size value (Cohen'd) of critical thinking skills is ≥ 0.08 so that it has the criteria of a "Large" effect. This means that the implementation of e-worksheets based on Differentiated PjBL-STEM has a large influence on improving critical thinking skills

Final Product Revision

Based on the operational field tests presented, it was shown that the developed e-worksheets based on Differentiated PjBL-STEM effectively improved students critical thinking skills and scientific literacy significantly. Therefore, overall, there was no improvement at this stage.

Dissemination and Implementation

The dissemination stage of the product results of the Development, namely e-worksheets based on Differentiated PjBL-STEM to improve critical thinking skills, was carried out in the Science subject teacher deliberation group (MGPM-IPA) throughout South Lampung, so that the products that have been made can be applied to schools in South Lampung.

Discussion

The e-worksheets development stage begins with a needs analysis for students and teachers regarding the needs of e-worksheets based on Differentiated PjBL-STEM. After obtaining the results that it is necessary to develop the e-worksheets, the researcher then makes an e-worksheets design in the form of a storyboard. Then the researcher makes an e-worksheets based on Differentiated PjBL-STEM using the Canva application and the Liveworksheets website, according to the PjBL-STEM Laboy-Rush (2011) syntax and Ennis (1996) critical thinking skills indicators. which is then consulted with the supervisor. The e-worksheets product based on Differentiated PjBL-STEM that has been developed is validated by two experts on the aspects of content suitability (90%), readability (86.15%), and attractiveness (88.89%). Validation is carried out to determine the level of validity or feasibility of the product being developed both in terms of content and appearance (Sugiyono, 2013). Based on the results of expert validation, it was found that the e-worksheets that

was developed was valid and had an average percentage in the aspects of content suitability, readability, and attractiveness in the very high category.

The high validity of the developed e-worksheets is because the e-worksheets is in accordance with the learning outcomes (CP), the content of the e-worksheets is in accordance with the PjBL-STEM syntax Laboy-Rush (2011) which includes reflection, research, discovery, application, and communication. Then the developed e-worksheets contains contextual problems that exist in everyday life to be solved in the form of projects. Project completion is not done by imitation or copying existing projects, but by modifying existing products based on the weaknesses of the product by considering aspects of science, technology, engineering, and mathematics (STEM). In addition, the developed e-worksheets has easy access because it is packaged in electronic form so that it is effective and efficient, because students can work on the e-worksheets not only at school but anywhere and anytime. There are no suggestions and input related to the font size and layout so that the developed module has used the type and size of fonts according to the assessment standards for teaching materials, the correct layout, illustrations, pictures and photos and designs that look clear and attractive (Prastowo, 2011). Other studies such as Nyoman et al (2025) state that the development of e-worksheets with the PjBL-STEM model which has good validity results for the media developed can be the basis that the media has met high quality standards so that it is suitable for use in learning.

Learning media to be practical if the user considers the media can be and is easy to use in a way that is mostly in accordance with the developer's wishes (Nieveen, 2010). The practicality of e-worksheets based on Differentiated PjBL-STEM to improve critical thinking skills is determined based on the responses of three science teachers and fifteen students. The practicality of e-worksheets is determined based on the aspects of readability and attractiveness. The subjects of practicality in this study were three teachers and fifteen students. Based on the results of the practicality questionnaire, the average percentage of the aspects of readability and attractiveness of teachers (98.29%) and students (96.11%) stated that e-worksheets based on Differentiated PjBL-STEM is practical with a very high category.

The high practicality of e-worksheets is due to the ease of use of e-worksheets, instructions for use, and clarity of sentences in e-worksheets. This means that the product is practical to use at any time, the material and language used in e-worksheets are easy to understand, the learning time is short, fast and precise, and the learning steps given in e-worksheets are clear, e-worksheets has an appeal, makes it easy for students to understand the material, and is easy to interpret by teachers and students (Nieveen, 2010; Sukardi, 2008). The ease of students understanding environmentally friendly technology material in e-worksheets is because in the development of e-worksheets at the research and data collection stage, researchers conducted curriculum analysis (Learning Achievements), analysis of student needs, concept analysis, task analysis and then formulated learning objectives that were adjusted to the material, so that the material presented in e-worksheets can be easily understood by students (Pratiwi et al., 2024). The high practicality of e-worksheets is in accordance with research Nyoman et al. (2025) so that the e-worksheets developed is easy to use and helps students to understand learning materials.

The effectiveness test of students was conducted in two classes at one of the junior high schools in Jati Agung, namely class IX A as the control class and IX B as the experimental class. The results of the independent sample t-test stated that there was a significant difference between the n-Gain of critical thinking skills and scientific literacy of students between the control class and the experimental class. The average value of n-Gain of critical thinking skills and scientific literacy of students in the experimental class was higher than the control class. This is in accordance with research which states that projects that are relevant to everyday life and based on scientific principles, cause students to be able to develop an understanding of the material, more active and

enjoyable learning. In addition, project-based learning through the STEM approach can also help students acquire skills in using tools and materials, as well as problem-solving and critical thinking skills (AlAli, 2024). STEM-PjBL learning provides meaningful learning for students, because they not only learn conceptual knowledge but they are also allowed to apply their understanding to real-life problems through STEM projects (Rahmawati et al., 2021).

The influence of e-worksheets based on Differentiated PjBL-STEM in improving critical thinking skills is seen from the effect size value. Based on the calculation results, the effect size value of critical thinking skills is 1.29 with a large category, meaning that learning using e-worksheets based on Differentiated PjBL-STEM has a large influence in improving students' critical thinking skills in groups with high, medium, and low learning readiness. This is appropriate because the application of the STEM approach in learning enables students to increase their interest in science learning and demands active learning activities through the process of designing and building where students can produce a product (Fadhilah, 2022). STEM-PjBL learning has a positive impact on the development of critical thinking because students are involved in identifying a problem, demonstrating conceptual understanding, connecting ideas, and making assumptions and conclusions (Rahmawati et al., 2021).

The great influence of e-worksheets based on Differentiated PjBL-STEM on critical thinking skills is because at each meeting students are trained in indicators for each PjBL-STEM syntax according to Laboy-Rush (2011). Learning applied in class is contextual by integrating aspects of science, technology, engineering, and mathematics with various group project activities so that students are more active in the learning process and meaningful (Kurniahtunnisa et al., 2023). The PjBL-STEM-based learning environment improves students' 4C skills (Triana et al., 2020).

The first meeting in this study began with preliminary activities. The teacher conveyed orientation, motivation, and conducted learning apperception. Furthermore, the teacher conveyed the learning objectives to be achieved today, and divided students based on their learning readiness, namely high, medium, and low. After finishing dividing the groups, the activity continued by distributing pre-test questions and then students worked on the pre-test questions. The next activity was to give students trigger questions, the answers would lead students to the next activity, namely the core learning activity. In this first meeting, students read the discourse at the reflection stage, based on this discourse, participants would be directed about the problems that were currently occurring in their environment. The discourse given would focus students and examine the points of the problems that were currently occurring, how big the condition of the problem was, and what students could do to help solve the problem. Then give students assignments to interview farmers and make direct observations of rice fields that had experienced a decrease in yields. Observations and interviews were carried out to provide precise and complete reasons for the opinions expressed (Kılınç & Fırat, 2017; Ranney et al., 2015).

After observation and interview, each group of students conveys the problems that have been answered in the e-worksheets. At this stage, students are asked to discuss and write down the results of interviews with farmers and the results of observations related to the causes of declining rice production in South Lampung. Then asked to find information related to the relationship between the decline in the number of rice harvests due to lack of water supply. Students are asked to find information on how to raise river water to rice fields. In this syntax, the aspect of critical thinking skills is to provide simple explanations (focusing questions in the form of problems and analyzing arguments).

Next, students continue to the second syntax, namely research, students look for information related to examples of renewable and non-renewable energy in everyday life from various literature that has been provided. Next, ask students to consult the results of the answers to the teacher. Each group discusses looking for information related to the working principles of water wheels and windmills from various literature sources. Next, students are asked to find sources of information

from various literature related to tools that can connect windmills and water wheels so that they can rotate the turbine without any current flowing in the river. When implementing this syntax, students develop from concrete understanding to abstract understanding of the problem (Laboy-Rush, 2011). Then continue with activities in the discovery syntax. Students are asked to observe the tools that already exist to raise river water to the rice fields that have been prepared by the teacher. Furthermore, students discuss with their groups to identify the shortcomings of the tools to raise river water that already exist. After finding the shortcomings of the previously existing tools, students were asked to determine a tool to raise the existing river water based on the shortcomings that had been analyzed and adjusted to the environmental conditions of the rice fields in Priangan Village. After determining the prototype tool to be made, students consulted with the teacher regarding the tool to be made. In the activity of determining the tool to be developed, critical thinking skills are trained, namely concluding (determining the results of considerations). STEM-PjBL-based science learning makes students not only learn about scientific concepts, but also learn to work together effectively, share ideas, solve real problems, and design creative solutions together (Uden et al., 2023).

After determining the prototype tool to be made, students are asked to find information related to the procedure for making a prototype tool to raise river water from various literature. Then, in groups, identify the tools and materials for making a prototype tool to raise river water based on the procedures that have been obtained and adjusted to the materials available in the surrounding environment. Students are asked to make a schedule for making a prototype tool design, prepare tools and materials to make a prototype tool, make a schedule for making a prototype tool, and report. Then consult the results of the assignment with the teacher outside of class hours. The design of the prototype tool and the schedule for making the tool made by students are as follows:

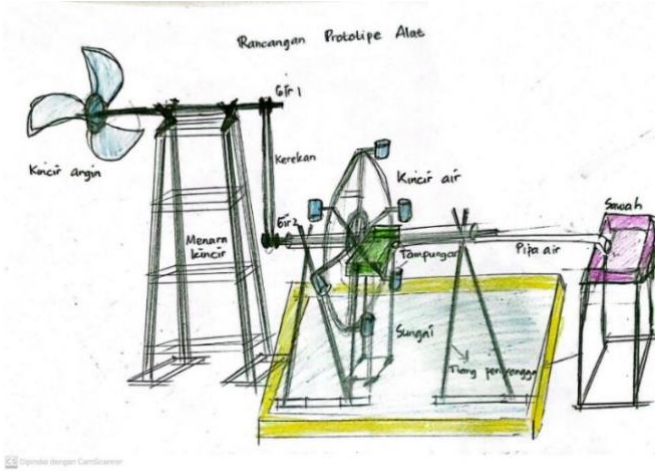


Figure 3. Design results for tools to raise river water

After consulting the results of the prototype tool experiment, the teacher suggested a second test, namely testing the prototype tool using water. Based on the results of the second trial, it was found that each prototype tool made could raise water, but at different speeds. This is because the selection of materials is not the same for each group, the high group uses plastic food lids to make windmill propellers with a total of 4 each, and the number of water containers on the water wheel is 8. The first medium group uses used milk cartons to make windmills with a total of 4 propellers and the number of water containers on the water wheel is 8. The second medium group uses used mineral water cartons to make windmill propellers with a total of 4 each, and the number of water containers on the water wheel is 8. The low group uses used mineral water cartons to make windmill propellers with a total of 4 each for the first low group and 3 for the second low group, and the number of water containers on the water wheel is 8. The difference in the thickness of the windmill propeller material

results in a difference in the rotation speed of the windmill and water wheel. At this stage, the aspect of critical thinking skills is to organize strategies and tactics (determine an action). The tools for raising river water in each group are shown in Figure 4. After being able to evaluate the results of the tool's work before and after being tested using water, students have been trained in aspects of critical thinking skills, namely arranging strategies and tactics (determining an action).

Next on the communication syntax. Students are directed to collect PPT, Reports, and present the results of the prototype tools that have been made. At this stage the teacher provides suggestions and input on the products made, other groups that do not present products are expected to provide feedback in the form of questions and suggestions/input. At this stage the critical thinking skill aspect is to provide further explanation (identifying assumptions).

(a) (b) (c)

Figure 4. a) High Group Prototype Tools; b) Medium group; c) Low group

Implications

The implications of this study include the development of e-worksheets based on PjBL-STEM Differentiated valid and practical instructional product can significantly improve students critical thinking skills by accommodating students' learning readiness. This study produces a product in the form of a tool to raise river water that does not have a current by collaborating water wheels and windmills. So it is expected to help farmers increase their harvest when rainfall is low. Although the developed e-worksheet is very good in terms of content, construction, and ease of access, in its implementation in schools there are still obstacles such as poor student internet access and inadequate school internet facilities that hinder students from accessing and working on the e-worksheet optimally.

Limitations

Although the Differentiated PjBL-STEM-based electronic worksheet has been validated by experts and declared valid and practical in improving critical thinking skills, this study has not explored other influential factors, such as student motivation. In its implementation in schools, there are still obstacles such as inadequate school internet access. Furthermore, future research should involve a larger sample size and consider various other variables, as well as examine the impact of learning media more broadly across various disciplines.

Suggestions

Based on the findings in this study, the researcher suggests that further researchers are expected to be able to create e-worksheets based on PjBL-STEM by considering other differentiation aspects such as students' learning styles, interests, or hobbies and different dependent variables.

CONCLUSION

The results of this study concluded that e-worksheets based on Differentiated PjBL-STEM developed through the Development model was valid and practical. This was indicated by the results of teacher responses to the aspects of content suitability of 98.82%, readability of 96.85%, and interestingness of 99.22% and the percentage of student responses to the readability of 98.46% and interestingness of 93.75%. The high practicality of e-worksheets was due to containing contextual problems, ease of use, instructions for use, and clarity of learning steps. In addition, the e-worksheets that was developed was effective in increasing critical thinking skills of students in Science subjects in junior high schools. This was shown by the results of the independent sample t-test and effect size test. These results revealed a significant difference between the average critical thinking skills scores of the experimental and control groups. Based on these findings, the e-worksheets developed in this study can be considered as a better alternative compared to conventional learning. The e-worksheets developed provides active learning, increases student involvement, and fosters thinking skills.

AUTHOR CONTRIBUTIONS STATEMENT

All authors contributed to the conception and design of the study. Kesi Meirawati (KM) contributed in terms of original draft writing, visualization, and editing. Abdurrhaman (AB) and Tri Jalmo (TJ) contributed in conceptualization, methodology, review, and editing.

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