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Development of E-Learning Based PBL-STEM Learning Tools on Students' Science Process Skills and Critical Thinking Ability

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Abstract: Education in the 21st century must be in harmony with technological developments where students are expected to be able to master useful skills to be responsive to changes and developments over time and to have in-depth knowledge and understanding to become lifelong learners. Based on these problems, the researcher aims to produce e-learning based PBL-STEM learning tools that are valid, practical and effective. This research procedure follows the Borg and Gall research and development method. Where the research method is pre-experimental, researchers use the One Group Pretest - Posttest Design approach. The results of this research are: the teaching tools were declared valid in terms of validation results of 95%, the practicality of the teaching tools seen from the student response questionnaire obtained a score of 95% and the student activity observation sheet as supporting data obtained a value of 98%, and the effectiveness of interactive e-modules can be seen from the average N-Gain value of the science process skills test obtained an average N-Gain value of 0.73 and in the critical thinking ability test obtained an average N-Gain score of 0.70 so it can be concluded that the teaching tools developed are suitable use in learning.

Keywords: Critical Thinking; Learning Tools; PBL-STEM; Process Skills Science

Introduction

Education in the 21st century must be in harmony with technological developments (González-Pérez & Ramírez-Montoya, 2022; Darling-Hammond et al., 2020). In the 21st century, students are expected to be able to master useful skills to be responsive to changes and developments over time and to have in-depth knowledge and understanding to become lifelong learners (Mlambo et al., 2021; Li, 2022). In reality, the graduates produced are not capable answer the problems of the 21st century because they do not meet the required qualifications (Poláková et al., 2023); (Van Laar et al., 2020). Based on PISA by the 2019 OECD shows that the science abilities of high school students in Indonesia are at a low level with a score of 396, ranking 67th out of 72 countries. In the OECD presentation, it was explained that Indonesia from 2003-2018 was not optimal in providing good quality education for students (Irnidayanti & Fadhilah, 2023; Sari, 2019).

Problem Based Learning (PBL) is a learning model that is able to meet the educational goals of the 21st century (Markula & Aksela, 2022; Guo et al., 2020). PBL involves the 4C principles, namely critical thinking, communication, collaboration, and creativity. Problem-based learning can improve high-level thinking abilities. Apart from that, PBL can improve students' Science Process Skills. In this model, students are required to be active in getting concepts that can be applied by solving the concepts themselves that must be mastered, asking questions and arguing,

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honing investigative skills, and undergoing other scientific work procedures (Lavee & Itzchakov, 2023; Albay, 2019).

Chemistry learning is closely related to technology (Sari* et al., 2023; Putri et al., 2022). Technology can help and support the development of people's lives. These conditions really enable integration in chemistry learning oriented with science, technology, engineering and mathematics (STEM) (Xu & Ouyang, 2022; Nguyen et al., 2020). Through STEM learning, students have high- level thinking skills and science process skills along with technology that is visible from reading, writing (Ješková et al., 2022; Kelley & Knowles, 2016), observing and doing science so that they can be used as provisions for living in society and solving problems faced related to the STEM science field (Tan et al., 2023; Park et al., 2020).

The results of a study conducted by the research team at Kedamean 1 Senior High School showed that 42% of students still lack science process skills and critical thinking skills (Maison et al., 2021). Therefore, tools to support the implementation of student learning activities are needed in the form of learning tools. E-learning based learning tools can of course be developed based on models that are integrated with approaches to support the achievement of students' abilities. Researchers will develop related learning tools, including teaching modules, reference learning materials or learning media, student activity sheets, and supporting assessments.

Method

Research and development type of research, where through this research e-learning based PBL-STEM learning tools will be developed. The development model used in this research was adapted from Borg & Gall (2003), (Meng et al., 2023), namely model development which is carried out through repetitive activities starting from designing the model to implementation as presented in Figure 1.

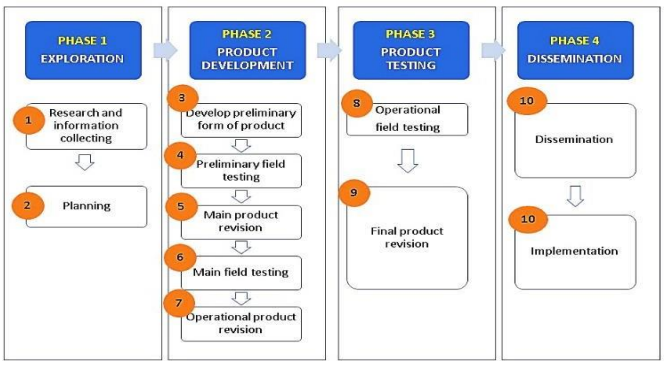

Figure 1. R&D Stage According to Brog and Gall

Procedure study Which used on study This refers on design R&D using the Borg and Gall method and has been modified only to a limited trial stage. To achieve the research objectives, an educational research and development approach will be taken according to Borg and Gall. In general, the stages in this research are as follows; Potential and Problems. This research began by analyzing the problems in chemistry learning experienced by high school students by looking at previous research. Apart from that, at this stage a survey is also carried out to determine the condition and application of the product to be developed; Data Collection. This stage is also called the pre-experimental stage where the aim of this stage is to find out what aspects are considered difficult or problematic for students.

In addition, the selection of aspects that are considered difficult can be based on a pre-experiment questionnaire given to students or by looking at the final test scores for science process skills and critical thinking abilities; Product Design. This stage is carried out by creating learning tools consisting of teaching modules, reference learning materials or learning media, studentactivity sheets, and assessments or test instruments; Design Validation. Device validation is carried out by experts; Design Revision. At this stage, revisions arecarried out based on suggestions or input for improvements from validator experts; Limited Trial. Limited testing was carried out on students. According to (Yeager et al., 2019), limited trials can be carried out in one, two, or three schools, using 6 to 12 test subjects. Then, if after conducting limited trials there are still errors and problems during implementation, revisions will be made to the product that has been developed.

Result and Discussion

To achieve the objectives of this research, an educational research and development approach was taken as written by Borg and Gall (Aka, 2019). Educational research and development (R&D) is a process for developing and validating educational products in the form of learning objectives, methods, curriculum, evaluation, both hardware, software and methods or procedures. The product developed in this research is a PBL-STEM based learning device. In research and development, three methods are mainly used, namely survey, evaluative and experimental (Aspers & Corte, 2019; Priya, 2021). Surveys are used as preliminary research to determine supporting conditions and practices related to the product to be developed (Dwivedi et al., 2023). Meanwhile, the use of experimental methods in this research refers to a

pre-experimental design, which aims to find out and select chemical materials that are considered difficult.

The research procedure in this study refers to R&D design using the Borg and Gall method and has been modified only to a limited testing stage, which is presented below:

Potential and Problems

This research began by analyzing chemistry learning problems by reviewing the results of previous research. Apart from that, at this stage a survey is also carried out to determine the condition and application of the product that has been developed. Relevant research on the development of e-learning based PBL-STEM learning tools including the following (Strat et al., 2023) with the title Integrating local resources into inquiry-based teaching materials to train students' science process skills. As a result, integrating local resources in inquiry-based teaching materials can train science process skills (Aidoo, 2023).

Comparative Study of Students' Critical Thinking Ability Using Problem Based Learning and Discovery Learning Models on Buffer Solution Material. As a result, the Problem Based Learning model can improve students' critical thinking skills; (Stevani & Sucahyo, 2022), with the title Development of Blended Learning Oriented Learning Tools on Periodic System of Elements Material for Class X Senior High School. The results show that the learning tools developed are suitable for use in the learning process; (Suryani et al., 2020). Analysis of the Practicality of Developing Student Activity Sheets (known with LKPD) with a Blended Learning Orientation on Acid-Base Material. The results show that the LKPD that has been developed is able to train critical thinking skills on acid-base material.

Data Collection

This stage is also called the pre-experimental stage where the aim of this stage is to find out what aspects are considered difficult or problematic for students. In addition, the selection of aspects that are considered difficult can be based on a pre-experiment questionnaire given to students or by looking at the final test scores for science process skills and critical thinking abilities (Wale & Bishaw, 2020; Nursalam et al., 2022; Rusmansyah et al., 2021).

Product Design

This stage is carried out by creating PBL-STEM based learning tools which consist of teaching modules equipped with assessments, reference learning materials or learning media, and student activity sheets. At this stage, a draft of the components of PBL-STEM based learning tools is carried out. This aims to design the media format that will be developed and explain the material that will be discussed in a teaching material. Researcher make draft initial (prototype) or design product. Product Which PBL-STEM learning tools will be developed that are adapted to the results of the previous stage analysis. The initial draft of the PBL-STEM learning tools includes media display formats such as teaching module components and their assessments, reading materials (descriptions of colloid system material), and PBL-STEM based student worksheets which contain two learning activities. The initial draft or initial storyboard is as shown in figure 2.

Figure 2. Initial Draft of PBL-STEM Based Learning Tools

Design Validation

The validation stage aims to assess whether the PBL-STEM learning tool is good e-learning based which has been developed so that it can be categorized as valid as a teaching tool in chemistry subjects, especially the topic of colloid systems. Assessment is based on content and construct validity criteria. PBL-STEM learning tools e-learning based validated by five validators. Validity result data is calculated based on a Likert scale and the percentage results are interpreted to determine its validity and can be said to be valid if the percentage is ≥61%.

Content validity focuses on providing evidence for the elements in the measuring instrument and is processed with rational analysis. Content validity is assessed by experts. When measuring instruments are described in detail, the assessment will be easier to carry out. So, data from content validity includes twelve aspects, with content validity results data shown in Table 1.

Construct validity focuses on the extent of PBL-STEM learning tools e-learning based shows study results that are in accordance with the definition. Variable definitions must be clear so that construct validity assessment is easy. This definition is derived from theory. If the definition is based on appropriate theory, and the question or item statement is appropriate, then the product is declared valid in terms of construct validity so that construct validity can be assessed from several aspects, as in Table 2.

Table 1. Data on Content Validity Results

Rated aspect	Percentage
Conformity of learning outcomes with learning objectives	100
Suitability of colloid system material with learning outcomesand learning objectives	100
Coverage and depth of each sub-material of the reading material	100
Ease of material to understand	100
Conformity of content with teaching module components	100
Clarity of assessment tools to measure students' level of mastery	93
Complete glossary	80
Suitability of PBL-based learning syntax in E-LKPD	100
Conformity of content with components of science process skills	93
Conformity of content with critical thinking ability components	100
Science, Technology, Engineering and M*athematics* (STEM) components	100
Systematic, coherent, clear logical flow	93

Table 2. Data on Construct Validity Results

Rated aspect	Percentage
Effective and efficient in developing and using teachingtools	93
Visual layout design and writing on teaching tools are appropriate and attractive	100
The choice of text size and color design in the teaching tools developed is coherent	100
The fonts, text colors, backgroundsand images on the teaching tools developed are harmonious	93
The text and images on the teaching tools developed are appropriate and read well	87
Teaching tools use sentences thatare in accordance with good and correct PUEBI	93
The writing of material on teachingtools is stated clearly and communicatively	100
Language between paragraphs and sentences in coherent teaching tools	93
The language used in teaching tools is easy to understand	100
Teaching tools developed using appropriate chemical symbols (subscript and superscript)	80
The presentation of teaching tools contains clarity of purpose	100
The order of material in teaching tools is systematic	100
Appropriate image presentation	87
The presentation of material encourages students to be activelyinvolved	100

Based on Table 2, assessment of the construct validity of PBL-STEM learning tools Based on e-learning, there are three main aspects, namely appearance, language and presentation. Assessment of each aspect of teaching tools obtained an average percentage of 95%; 93%; and 97% in the very valid category. From each percentage aspect of construct validation, the average category is very valid, so it can be concluded that this teaching tool has an attractive layout and appearance and makes it easier for students to be actively involved in learning colloid systems (Fitriani et al., 2021).

Design Revision

At this stage, revisions are carried out based on suggestions or input for improvements from validator experts. After carrying out media validation, if there are still things that are not appropriate or the score obtained does not meet the criteria, then a re-correction process will be carried out. After repairs are carried out, the PBL-STEM based learning tools will be validated again to determine the validity of the teaching tools. In this research, the aspects assessed received very valid and valid criteria so that there was no need for further revision of the teaching tools being developed, however there was little input from the validator regarding editorial errors and the use of inappropriate diction inthe teaching module (Walter, 2024; Cavalcanti et al., 2021).

Limited Trial

Limited testing was carried out on students. According to Borg & Gall, limited trials can be carried out in one, two, or three schools, using 6 to 12 test subjects. Then, if after conducting limited trials thereare still errors and obstacles during implementation, revisions will be made to the product that has been developed. Trial of PBL-STEM learning tools e-learning based conducted at Wachid Hasyim 3 Sedati High School with research subjects of 33 class X students who had received colloid system material. The research design used in the limited trial was one group pre-test post-test design. Limited trials were used to determine the practicality and effectiveness of PBL-STEM learning tools based on e-learning that has been developed. The data analyzed is in the form of effectiveness and practicality data pretest and posttest sheet instruments which consist of tests of students' science process skills and critical thinkingabilities (Tyas & Novita, 2023).

Table 3. Normality Test of Science Process Skills Test

	Tests of Normality		
		Shapiro-Wilk	
	Statistics	df	Sig.
pre	.964	33	.338
post	.953	33	.166

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Table 4. Normality Test of Critical Thinking Ability Test

	Tests of Normality		
		Shapiro-Wilk	
	Statistics	df	Sig.
pre	0.936	33	0.052
post	0.970	33	0.477

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Normality test was carried out using the IBM SPSS Statistics 26 application. Based on tables 9 and 10. The normality test shows that sig. for the science process skills pretest, namely 0.338 and for science process skills posttest is 0.166. While the normality test shows that sig. for the critical thinking ability pretest, namely 0.52 andfor posttest critical thinking ability is 0.477. From thesedata it can be said that the pretest and posttest science process skills and critical thinking ability scores arenormally distributed in the Shapiro-Wilk test, with sig.> 0.05.

The pre-test and post-test scores are converted into N-Gain scores which are used to determine the increase in science process skills and critical thinking abilities that have been achieved by students. Teaching tools can be said to be appropriate in terms of effectiveness if the N-Gain value is at least 0.3 or is in the medium and high criteria. Apart from that, the effectiveness of teaching tools must be supported by classical completeness of test results with a percentageof 75% (Wang & Tahir, 2020). Students are said to be complete if the score achieved by students at least reaches the Minimum Completeness Criteria (known with KKM), namely 75 (Triyanto et al., 2022). The N-Gain results show that 15 students in this study were in the high criteria and 18 students were in the medium criteria. The overall n-gain test shows a score of 0.73 for improving the science process skills test and 0.70 for increasing the critical thinking ability test, so it can be said that the teaching tools developed are effectively used to improve students' science process skills and critical thinking ability.

Apart from analyzing data on validity and effectiveness, researchers also analyzed practicality data. The data from the student questionnaire serves todetermine the level of practicality of the PBL-STEM learning tools e-learning based. Student response questionnaires were given after limited trials and analyzed quantitatively descriptively which are presented in Table 5.

Table 5. Results of Student Response Questionnaire

Rated aspect	Percentage
The teaching tools used in learning make it easier for me to understand the material.	100
The teaching tools used in learning make me passive in learning.	87
The teaching tools used in learning can cause conceptual errors in me.	90
Applied learning helps me relatethe material to phenomena that occur in everyday life.	93
The teaching tools used in learning are very monotonous and boring.	97
The design of the teaching tools used in learning is interesting and interactive.	93
Instructions for using the teachingtoolsused in learning are easy to understand.	100
The teaching tools used in learningcan help me to improve my process skills and critical thinking abilities well.	100

In the student survey there is also a section for suggestions and comments regarding the teaching tools, especially the LKPD being developed. The results of students' answers gave rise to suggestions to install an answer key at the end of each lesson so that students do not have difficulty finding the answers. The overall average for the eight assessments in the questionnaire was 95% with the overall student response rate being 100% so it can be assumed that the teaching tools are suitable for practical learning. Observations of student activities can be used to support survey response data. At the observation stage, 33 students of class X Wachid Hasyim 3 Sedati Senior High School were observed which received colloidal system material. Student activities were observed by three observers. The results of observing student activities are described in Table 6.

The results of observing student activities show that all the activities expected in learning have been completed. When the researcher explained the systematics of learning with the help of teaching tools, there were two students who were not paid attention to and caused the students to become passive during the process. This also affects student test results who have not reached the maximum percentage. The results of observations of student activities as a whole show a success rate of 98% in the very practical category so it can be assumed that the teaching tools have proven tobe practical when used in learning.

Table 6. Observation Results of Student Activities

Rated aspect	Percentage
Students pay attention to the teacher's explanation	87
Students read the teaching tool guide	100
Students read material in reading materials	90
Students understand the concept	93
Students carry out each phase or syntax of problem-based learning	100
Students identify problems	100
Students are able to formulate problems through presenting phenomena	100
Students propose hypotheses after formulating appropriate problems	100
Students determine tools and materials, variables, and experimental procedures through phenomena	100
Students write down the results of their observations	100
Students analyze the results of experiments	100
Students conclude the results of the data analysis that has been obtained	100

Revision after Limited Trial

After a limited trial, revisions will be made again if there are still errors and obstacles during the implementation of the PBL-STEM learning tools to test high school students' science process skills and critical thinking abilities. In this research, no further revisions were carried out because there were no obstacles when implementing the learning tools at the limited trial site.

Conclusion

This research was carried out using the Research and development method with an adaptation development model from Borg & Gall and has been modified only to the revision stage after limited trials. The product development in this research is in the form of PBL-STEM based teaching tools which are declared feasible and influential in improving science process skills and critical thinking abilities in learning: The validity can be seen from the validation results using a validation sheet, namely 95% with very valid criteria; The practicality can be seen from student response questionnaires and student activity observation sheets as supporting data. The student response questionnaire obtained a score of 95% with very practical criteria, while the student activity observation sheet obtained a score of 98% with very practical criteria; The effectiveness can be seen from the N-Gain value. The results of the pre-test and post-test on the science process skills test obtained an average N-Gain value of 0.73 with high criteria and on the critical thinking ability test an average N-Gain value of 0.7 was obtained with high criteria, as well as classical completion on both tests each of them is 100%. Therefore, this teaching tool can be used as the main reference source in carrying out learning on colloid systems, especially influencing the improvement of students' science process skills and critical thinking abilitie.

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Author Contributions

Conceptualization, K. D.; methodology, S.; validation, A. L.; formal analysis, R. H.; investigation, S., and. U. A.; resources, A. A.; data curation, K. D.: writing—original draft preparation, S and U. A.; writing—review and editing, A. L.: visualization, R. H and S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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