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Development of Buffer Solution E-Modules Based on Problem Based Learning with Ethnochemistry to Improve Students' Critical Thinking Skills

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Abstract: This study aims to produce an electronic module (E-module) of buffer solutions based on ethnochemistry-integrated problem-based learning to improve students' critical thinking skills and analyze the level of validity, practicality, and effectiveness of the E-module on students' critical thinking skills. This type of research is Research and Development (R&D) with a 4-D development model. The 4-D development model consists of 4 stages of development, namely define, design, develop and disseminate. The results of the construct and content validity tests were 0.88, respectively, in the valid category. The results of the teacher and student practicality tests were 88.33% and 84.93%, respectively, in the very practical category. The N-Gain value analysis in the experimental and control classes was 0.71 and 0.46, respectively, in the high and medium criteria. The t-test results showed that students' critical thinking skills at SMAN 1 Bungo who used the E-module of buffer solutions based on ethnochemistry-integrated Problem-Based Learning were significantly higher than the control class that did not use the E-module. Thus, it can be said that the E-module on buffer solution material is valid, practical, and effective in significantly improving students' critical thinking skills.

Keywords: Critical thinking skills; Ethnochemistry; Problem based learning

Introduction

Education has now entered the 21st-century learning era. One of the basic needs of the 21st century is critical thinking skills. Critical thinking skills are intellectual processes that involve activities and skills in various aspects, including conceptualizing, applying, analyzing, synthesizing, and evaluating information gathered from or generated by observation, experience, reflection, reasoning, or communication, as part of problem-solving and decision-making (Amarila et al., 2021; Aridiadila et al., 2023). Therefore, education must be directed at increasing the nation's competitiveness so that it can compete globally in terms of thought, expertise, and skills (Aulia et al., 2025).

The novelty of this research is the integration of the PBL model with the ethnochemistry typical of Jambi Province and its application specifically to the abstract material of buffer solutions. The concept of buffer solutions is connected to the phenomena of Jambi's community life. This makes the chemistry concept more contextual and meaningful for students. Furthermore, some previous studies still use printed modules, or e-modules that do not utilize the local cultural context in depth (Gutiawati & Wulansari, 2022; Rahmawati et al., 2025). In this study, the e-module was developed digitally and interactively, containing problem scenarios based on local Jambi culture related to the concept of buffer solutions. Through this context, students are invited to analyze real-life problems related to chemistry concepts. The importance of problem-based learning can improve students' understanding of material concepts. This is because students are instructed to discover concepts independently, become more active in solving problems, and hone their critical thinking skills. Furthermore, students can also

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experience the benefits of chemistry learning because the problems they solve are relevant to everyday life. This can increase students' enthusiasm and motivation in learning chemistry (Choerunnisa & Indri, 2024).

This research is important because buffer solutions are a complex chemical concept, involving chemical equilibrium, acid-base concepts, and pH calculations. Many students struggle to grasp these concepts when taught only theoretically. Therefore, innovative learning media, such as problem-based e-modules, are needed to help students understand concepts more concretely and contextually (Efriyani et al., 2026). Furthermore, chemistry instruction in schools still relies heavily on lectures and memorization, leaving students poorly trained in analyzing problems, evaluating information, and drawing logical conclusions. Critical thinking is a crucial 21st-century skill that students must possess. Most chemistry instruction in schools is presented in general terms without linking it to local wisdom or regional culture. As a result, students often perceive chemistry as a science far removed from everyday life. An ethnochemical approach allows chemical concepts to be explained through cultural phenomena. Integrating Jambi's local culture into learning can make chemistry more contextual, meaningful, and understandable to students.

Teachers are required to utilize learning models relevant to the Merdeka Curriculum. One such model is Problem-Based Learning (PBL). PBL is a student-centered learning approach. In this approach, students are confronted with various real-life problems and encouraged to seek and find solutions to these problems, both independently and collaboratively (Susanti et al., 2026). One way to support the implementation of PBL in learning is through teaching materials. One such teaching material used in school learning activities is the e-module. The advantage of the developed e-module is its interactive nature, as it is equipped with learning videos, animations of chemical concepts, and illustrations that support understanding of the material. Furthermore, this e-module is equipped with a barcode that functions to facilitate differentiated learning, allowing students to access additional learning resources according to their learning needs. This e-module also provides practice questions, allowing students to study independently and more actively in understanding the learning material.

Technological developments should be utilized optimally, not only as a means of communication and information, but also as an effective medium for preserving and introducing culture to the younger generation. Ethnochemistry is a branch of science that combines chemistry with cultural anthropology, studying the application of cultural technology to specific community groups (Jofrishal & Seprianto, 2018).

Based on the results of interviews with chemistry teachers at SMA Negeri 1 Bungo, it is clear that, first, the teaching materials used by teachers in chemistry learning, especially on the buffer solution material, have not implemented a learning model. Teachers only use lecture and discussion methods. Second, in explaining chemistry material, there is no approach that connects the material with local culture (ethnochemistry) in the learning process and ethnochemistry-based e-modules on buffer solution material. Third, students' critical thinking skills are still low in chemistry learning. According to chemistry teachers, it is important to develop ethnochemistry-integrated problem-based e-modules because they can train students' ability to solve problems and improve their critical thinking skills. Critical thinking skills are also crucial in learning. Students who can utilize these skills tend to be better able to understand and solve problems, and perform better on tests and exams. Therefore, critical thinking skills need to be instilled from an early age. Improving critical thinking skills can also help us solve problems and face life's challenges. We will be better able to see problems from different perspectives and find better solutions. Furthermore, critical thinking skills also help us avoid biases and errors that may occur in decision-making.

The development of a PBL-based buffer solution e-module integrated with ethnochemistry is one of the teaching materials that has great potential to be developed in improving students' critical thinking skills. The ethnochemistry explored in this study is Jambi's local wisdom, namely the Batanghari river has a natural ability to stabilize the pH of river water through a carbonate buffer system. In addition, in the preservation of smoked fish typical of Jambi province that uses citric acid. Citric acid is very good to be used as an acid buffer solution to maintain a stable pH in the range of around 3.2-4.5 along with its sodium salt in the preservation of smoked fish. Previous research conducted by Arfianawati et al. (2016) examined "Ethnoscience-Based Chemistry Learning Model to Improve Students' Critical Thinking Skills". Based on the research that has been done, the results show that the average posttest and N-Gain cognitive and critical thinking abilities of classes that receive ethnoscience learning are better than classes that receive conventional learning. The purpose of this study is to produce an E-module of buffer solutions based on integrated problem-based learning with ethnochemistry to improve students' critical thinking skills and analyze the level of validity, practicality, and effectiveness of the E-module on students' critical thinking skills.

Method

This type of research is Research and Development (R&D) with a 4-D development model (Thiagarajan & Semmel, 1974). This 4-D model consists of four stages of development, namely definition, design, development, and dissemination (Arkadiantika et al., 2020). The first stage consists of 5 parts, namely: front-end analysis; student analysis; task analysis; concept analysis; and formulation of learning objectives. The second stage is design, namely designing an E-module of buffer solutions based on problem-based learning integrated with ethnochemistry.

The third stage is development, activities carried out in the development stage are validity, practicality, and effectiveness testing. The validity test consists of two parts, namely construct validity and content validity. The validity test was carried out by 3 lecturers and 2 chemistry teachers with the aim of revealing the validity of the developed buffer solution E-module. Criticism, input, and suggestions from the validators became the material for revising the developed E-module. The practicality test was carried out by giving a practicality test questionnaire to 2 chemistry teachers and 32 students. Effectiveness testing was conducted using a quasi-experimental research design with an unequal control group type. and the sampling technique used was Random Sampling, where the samples used for the experimental group and the control group were taken randomly from a certain population (Sugiyono, 2017). The research design can be seen in Table 1.

Table 1. An unequal control group type

Group	Pretest	Treatment	Posttest
Experimental	E1	X	E2
Control	K1	-	K2

(Sugiyono, 2013)

Information:
E1 = Pretest for the experimental class
K1 = Pretest for the control class
X = Treatment in the form of an E-module of buffer solutions based on integrated ethnochemical PBL given to the experimental group
E2 = Posttest administered to the experimental group
K2 = Posttest administered to the control group

The final stage is dissemination. This stage involves using the developed tool on a broader scale, for example, in other classes, other schools, or by other teachers. The instruments used in this study were teacher interview sheets, student questionnaires, validity questionnaires, and practicality questionnaires. Effectiveness was assessed using objective questions that have been tested for their effectiveness in measuring students' critical thinking skills.

Data were obtained from product validity tests, and the results were analyzed using Aiken's V formula, as shown in Equation 1.

$$V = n\,(c-1)\sum s \quad (1)$$

Where:
s = r- Io

The data generated from the practicality test was analyzed using the formula as shown in Equation 2 (Arikunto, 2021).

$$p = \frac{f}{N} \times 100\% \quad (2)$$

Description:
p = final score
f = score obtained
N = maximum score

The effectiveness of the E-module is seen by comparing the results of students' critical thinking abilities in the experimental class and the control class which are then analyzed using the N-Gain test as shown in Equation 3 (Hake, 1998).

$$N_{Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{100 - \text{Pretest Score}} \quad (3)$$

To determine whether the e-module significantly impacts students' critical thinking skills, a t-test was conducted, requiring prior normality and homogeneity tests.

The normality test used the Liliefors test. The homogeneity test used the Fisher F-test, as shown in Equation 4.

$$F = \frac{\text{Big Variance}}{\text{Small Variance}} \quad (4)$$

Hypothesis testing is carried out using the independent sample t-test as shown in Equation 5.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (5)$$

Where:

$$S = \sqrt{\frac{(n_1 - 1)\,S\frac{1}{1} + (n_2 - 1)\,S\frac{2}{2}}{n_1 + n_2 - 1}} \quad (6)$$

Information:
$\bar{X}_1$ = Average value of the experimental class
$\bar{X}_2$ = Average value of the control class
S = Combined standard deviation of both class
n_1 = Number of students in the experimental class
n_2 = Number of students in the control class
S_1^2 = Variance of the experimental class
S_2^2 = Variance of the control class

The test criteria is to accept H0 if t < t1-α where t1-α is obtained from the distributed list t with df = (n1+n2-2) (Sudjana, 2005).

Result and Discussion

Definition

Based on the front-end analysis stage, the following results were obtained: the teaching materials used by teachers in chemistry lessons, particularly for buffer solutions, do not yet implement a problem-based learning model; in explaining chemistry material, no approach has been used that links the material to local culture (ethnochemistry) in the learning process.

In the task analysis stage, an analysis of learning outcomes for the buffer solution material was conducted. The learning outcomes analyzed were those for Phase F, where students are required to understand the concept of solutions in everyday life. The learning objectives are for students to be able to analyze the working principles of buffer solutions in maintaining pH, calculate the pH of buffer solutions, and analyze the role of buffer solutions in everyday life. The concept analysis stage was conducted based on the established learning objectives.

Design

Based on the problems identified in the definition stage, a buffer solution e-module was developed based on problem-based learning integrated with ethnochemistry. An example of the buffer solution e-module that was developed is as follows:

Student Orientation to the Problem

In this stage, students read the discourse presented in the e-module, which contains contextual ethnochemistry discourse on the buffer solution material. An example of this stage is shown in Figure 1.

1. ORIENTASI PESERTA DIDIK PADA MASALAH

- Wawasan Etnokimia 1
  Perhatikan Gambar berikut ini!

Sungai Batanghari

Gambar 2. Sungai Batanghari
Sumber: https://news.detik.com/berita/

Sungai Batanghari merupakan sumber air baku yang ada di Provinsi Jambi. Zona tengah sungai Batanghari terdiri dari empat Kabupaten yaitu, Kabupaten Batanghari, Kabupaten Bungo, Kabupaten Tebo dan Kabupaten Sarolangun memberi pasokan air baku yang berlimbah untuk daerah hilir sungai Batanghari. Disamping itu, masyarakat yang bermukim di sepanjang daerah pengaliran sungai Batanghari memanfaatkan air sungai untuk keperluan mandi dan minum, mencuci serta keperluan rumah tangga. Masalah kualitas air sungai Batanghari sungguh memprihatinkan, adanya potensi pencemaran air yang disebabkan oleh berbagai aktivitas penduduk seperti keramba ikan, pembuangan sampah ke sungai, aktivitas pertanian, air buangan limbah industri dan limbah pengolahan hasil pertanian dan perkebunan serta terdapat kegiatan perusak lingkungan perambahan hutan (Gusri et al., 2022).

Secara alami, sungai Batanghari memiliki kemampuan alami untuk menstabilkan pH air sungai tersebut melalui sistem penyangga karbonat (H_2CO_3/HCO_3^-). Air sungai Batanghari mempunyai pH yang reLatif tetap di sekitar 6-8,5. Jika air sungai Batanghari kemasukan zat yang bersifat asam, maka ion H^+ dari asam tersebut akan bereaksi dengan

7

Figure 1. Student orientation to problems

Organizing Students for Learning

In this stage, students gather information related to the buffer solution material. An example of this stage can be seen in Figure 2.

ion HCO_3^-, adapun persamaan reaksinya sebagai berikut :

$$H^+_{(aq)} + HCO_3^-{}_{(aq)} \rightleftarrows H_2CO_{3(aq)}$$

(Sudarmo, 2014)

Nah bagaimana prinsip kerja larutan penyangga karbonat di Sungai Batanghari jika kemasukan zat yang bersifat basa? berikan persamaan reaksinya? Diskusikan bersama anggota kelompokmu!

2. Mengorganisasi Peserta Didik untuk Belajar

Duduklah berdasarkan anggota kelompok yang telah ditentukan oleh guru untuk mendiskusikan:
1. Perbedaan larutan penyangga asam dan penyangga basa
2. Prinsip kerja larutan penyangga

3. Membimbing Penyelidikan Individual maupun Kelompok

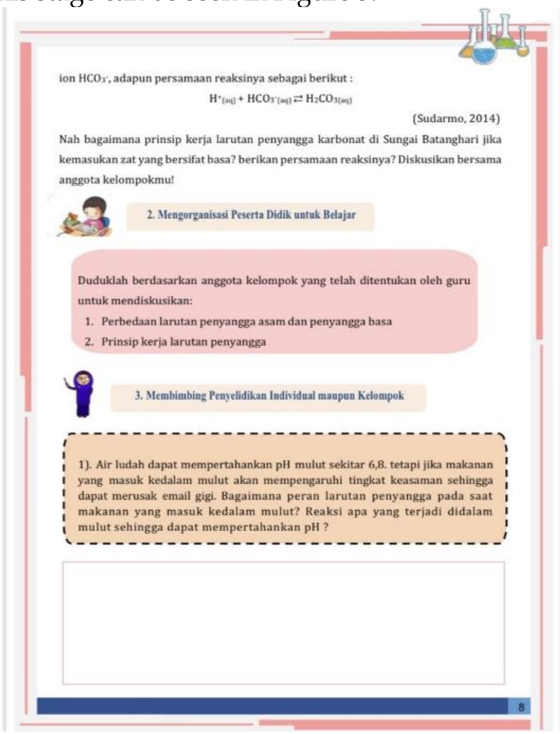
1). Air ludah dapat mempertahankan pH mulut sekitar 6,8. tetapi jika makanan yang masuk kedalam mulut akan mempengaruhi tingkat keasaman sehingga dapat merusak email gigi. Bagaimana peran larutan penyangga pada saat makanan yang masuk kedalam mulut? Reaksi apa yang terjadi didalam mulut sehingga dapat mempertahankan pH ?

8

Figure 2. Organizing students to learn

Guiding Individual and Group Investigations

In this stage, students collect data by conducting investigations or experiments to find solutions to the problems presented in the previous stage. An example of this stage can be seen in Figure 3.



ion HCO_3^-, adapun persamaan reaksinya sebagai berikut :

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8

Figure 3. Guiding individual and group investigations

Developing and Presenting Work

In this stage, students present work that aligns with the results of their problem-solving by filling in the answers on the student worksheet. An example of this stage can be seen in Figure 4.

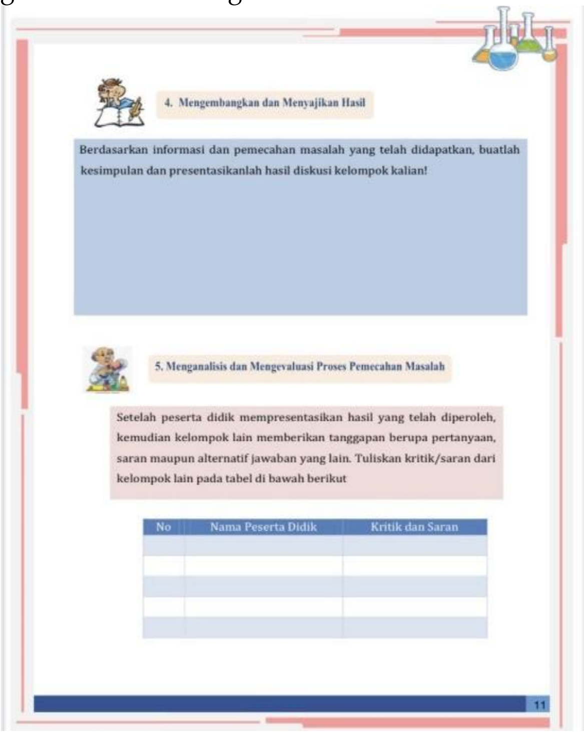

Figure 4. Develop and present work results

Analyzing and Evaluating Problem-Solving Results

In this stage, students evaluate the investigation and the process used in solving the problem. An example of this stage can be seen in Figure 5.

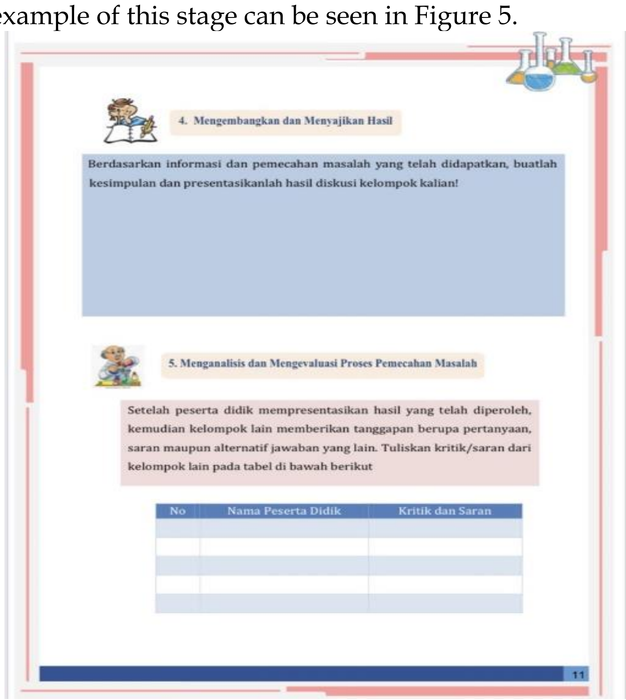

Figure 5. Analyze and evaluate problem solving results

Development

Validity Test

The construct validity test comprises components of content, language, presentation, and graphics. The content validity test examines the e-module's content's suitability to the problem-based learning syntax and its relevance to chemistry. The validator's critiques, input, and suggestions serve as input for revising the module under development (Pebrianti et al., 2024). Based on data analysis, the construct and content validity tests were each 0.88 in the valid category. Therefore, it can be concluded that the developed buffer solution e-module is valid in terms of both construct and content. The results of the construct validity test are shown in Table 2, and the content validity test is shown in Table 3.

Table 2. Construct validity analysis results

Rated aspect	Value V	Validity Category
Content component	0.87	Valid
Language component	0.93	Valid
Presentation component	0.87	Valid
Graphic component	0.88	Valid
Average v score	0.88	Valid

Table 3. Content validity analysis results

Rated aspect	Value V	Validity Category
Content alignment with *PBL* syntax	0.88	Valid
E-module content alignment with chemistry	0.88	Valid
Average V Score	0.88	Valid

Practicality Test

The practicality test of the electronic buffer solution module based on PBL integrated with ethnochemistry was measured by giving a practicality questionnaire to two chemistry teachers and 32 grade XII students who had studied the buffer solution material. The practicality analysis was based on the guidance and information, the appropriateness of the e-module content, the e-module design, and the pedagogical impact. According to Gede & Widharma (2021), practicality testing is important to determine whether the developed e-module is effective and practical for students and teachers or vice versa. The average practicality score for the buffer solution e-module by teachers and students was 88.33 and 84.93%, respectively, categorized as very practical. These results indicate that the developed buffer solution e-module is valid and practical for use as a teaching material in chemistry learning on buffer solutions. Its effectiveness in improving students' critical thinking skills can be further tested. The results of the e-module practicality data analysis are shown in Table 4.

Table 4. Results of data analysis on the practicality of e-modules by teachers and students

Rated aspect	Teacher (%)	Student (%)	Practicality Category
Guidelines and information	80.00	83.00	Very Practical
E-Module content suitability	91.66	83.30	Very Practical
E-Module design	93.33	88.50	Very Practical
pedagogical Effects	83.33	-	
average V score	88.33	84.93	Very Practical

Effectiveness Test

This stage aims to determine the effectiveness of the developed e-module by comparing the critical thinking skills of students in the experimental and control classes. The research data was obtained after conducting research at SMAN 1 Bungo, with grade XI D as the experimental class, who were treated using the buffer solution e-module based on problem-based learning integrated with ethnochemistry.

A pretest was administered to students in both sample classes before the start of the lesson to determine their initial abilities. The lesson was conducted in each class according to the specified teaching materials, followed by a posttest using the same questions. Improvements in students' critical thinking skills were analyzed using the N-Gain test. The results of the N-Gain analysis are shown in Table 5.

Table 5. N-Gain analysis results of sample classes

Class	N-Gain	Category
Experimental	0.71	Tall
Control	0.46	Currently

Based on the analysis results, the data obtained that the N-Gain value in the experimental class and the control class was 0.71 and 0.46 in the high and medium criteria. The results of the data analysis can be seen that the N-Gain value for the experimental class was higher than the control class with a difference of 0.25. To determine whether the E-module of buffer solutions based on ethnochemical integrated problem-based learning has a significant effect on students' critical thinking skills, a hypothesis test was conducted. Before conducting the hypothesis test, a normality test and a homogeneity test were first conducted. The results of the normality test can be seen in Table 6.

Table 6. Normality test analysis results

Class	L_{count}	L_{table}	Category
Experimental	0.14	0.15	Normal
Control	0.14	0.15	Normal

As seen in Table 6 above, the normality test using the Liliefors table at a significance level of 5% indicates that the data are normally distributed. Next, a homogeneity test was performed. The results of the homogeneity test can be seen in Table 7.

Table 7. Results of homogeneity test analysis

Class	N	F_{count}	F_{table}
Experiment	36	1.55	1.77
Control	36		

Based on the normality and homogeneity tests, it can be concluded that both sample classes are normally and homogeneously distributed. The results of the data analysis indicate that the hypothesis test was conducted using an independent sample t-test. The assessment criteria are if the calculated $t_{value} > t_{table}$ then the HO is rejected, whereas if the calculated $t_{value} < t_{table}$ then the HO is accepted. The results of the hypothesis test are as shown in Table 8.

Table 8. Hypothesis test results

Class	n	α	$\bar{X}$	S^2	T_{count}	t_{table}
Experimental	36	0.05	71.68	53.87	8.52	1.66
Control	36	0.05	46.68	258.24		

Table 8 shows that $t_{count} > t_{table}$, so H0 is rejected and H1 is accepted, meaning the research hypothesis is accepted, namely the critical thinking ability of students in phase F XI.D SMAN 1 Bungo who used the buffer solution module E based on Problem-Based Learning integrated with ethnochemistry is significantly higher than the control class that did not use the buffer solution module E. The increase in critical thinking ability of the experimental class is due to students who learned with the buffer solution module E based on Problem-Based Learning integrated with ethnochemistry, because the integration of local wisdom of Jambi Province, such as the Batanghari River which contains buffer solutions can help students in building the concept of buffer solutions through real-world phenomena they are familiar with, thereby improving students' critical thinking skills. In addition, local wisdom makes learning more applicable because it prioritizes the usefulness of concepts owned by students and is strengthened by scientific discoveries related to local culture (Asda et al., 2023).

This research is limited to the development stage only, problems according to the steps in the E-module.

Conclusion

An electronic module (E-module) for ethnochemical-based buffer solutions integrated with Problem-Based Learning (PBL) to improve critical thinking skills in 11th-grade students at SMAN 1 Bungo was developed through research and development using a 4D development model. The validation results of the E-module construction and content were 0.88. The practicality of the E-module by teachers and students was 88.33 and 84.93%, respectively, which was categorized as very practical. The N-Gain analysis obtained in the experimental and control classes was 0.71 and 0.46, respectively, which represented high and medium criteria. The results of hypothesis testing showed that t count > t table, meaning that the critical thinking skills of students at SMAN 1 Bungo who used the product were higher than those of students in the control class who did not use the product. It is recommended to conduct further research to develop an electronic module based on Problem-Based Learning (PBL) integrated with ethnochemistry in other chemicals, so that the integration of local wisdom in chemistry learning can be applied more widely.

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Contributing Authors

Nadia and Desy Kurniawati developed the research instrument, guided the research process, and wrote the article; Alizar and Budhi Oktavia validated the module.

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Conflict of Interest

The authors declare no conflict of interest.

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