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Development of PBL-Based Interactive Physics E-Books to Improve Students' Critical Thinking Abilities and Digital Literacy

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ABSTRACT
This research is development research using the ADDIE model with the stages of analyze, design, develop, implementation and evaluation. The research design used is Quasi Experimental Design. This research was conducted at SMA N 1 Ngaglik Sleman, Yogyakarta. This research aims to: (1) produce interactive physics e-book media based on problem based learning that is suitable for use in high school physics learning; (2) determine the practicality of using interactive physics e-book media based on problem based learning in improving students' critical thinking skills and digital literacy on temperature and heat material; (3) determine the effectiveness of using interactive physics e-book media based on problem based learning in improving students' critical thinking skills and digital literacy on temperature and heat material; and (4) describe the results of measuring students' critical thinking abilities and digital literacy. The data analysis technique uses Quest for empirical testing of the question instrument, N-gain, and effect size testing using GLM. The research results show that the interactive physics e-book media based on problem-based learning that was developed is feasible, practical, able to improve critical thinking skills and digital literacy. This al is based on N-gain and is supported by the GLM results in the effect size test which shows that students' critical thinking skills and digital literacy are in the strong category.

INTRODUCTION

In this digital era, technology is developing rapidly so that technology is also utilized by educators [1]. Ideally, the use of technology not only involves educators but students can also use it, especially as a facility for independent learning activities [2]. The use of media during learning also provides new experiences for students so that it is hoped that students can be more active and enthusiastic in the classrom. Learning by utilizing technology requires students to have knowledge and skills in the fields of technology, media and information. In utilizing technology, every student must also have a critical attitude in filtering correct information so as not to be exposed to hoaxes or fake news. Therefore,

students must have a good critical attitude in utilizing technology to search for information during learning.

The importance of digital literacy includes digital knowledge, skills in using media and a good attitude in using digital media. Digital literacy involves various abilities such as the ability to understand, analyze and transmit information [3]. Digital literacy has several skills combined into one, such as information, media and communication literacy in the media. However, in reality, students' digital literacy is still low, this was proven through initial observations in the field. The use of smartphones at SMA N 1 Ngaglik shows that 61.33% of students use smartphones more often to play games and social media and the rest to access information related to lessons or assignments. In line with research conducted that 95% of teenagers with student status have smartphones and access them, and 45% of them said that they are almost always online and very rarely review lessons outside of school [4]. This is also confirmed by evidence from the 2020 APIJI survey which states that there are four main reasons for Indonesian people to access the internet, namely social media, message communication, online shopping and games. The problem with digital literacy is that students use technology in the form of smartphones mostly to access social media and games rather than using it for learning activities. In addition, students use the internet freely to access assignment answers without synthesizing the information. This makes students lazy and choose to spend the remaining time playing, relaxing and even considering the assignment to be something that can be completed at any time without correcting whether it is right or wrong. Research shows that students' low digital literacy with a score of 32.81 is included in the low category which includes the application and use of digital literacy in learning activities [5].

With good digital literacy skills, a person also needs critical thinking skills to find out the truth of the information sought or received [6]. Critical thinking skills emerge when someone obtains new information from the literacy process that has been carried out. Then one information is connected to other information so that it is continuous. Someone who has critical thinking will learn from experience, for example observing something as a form of investigation, examining evidence, exploring alternatives, arguing, testing conclusions, rethinking assumptions, and reflecting on the entire process [7]. Critical thinking ability is a thinking ability that not only requires the ability to remember but also the ability to analyze, synthesize and evaluate [8]. Critical thinking needs to be sharpened so that students are able to solve problems [9]. Critical thinking skills are also very important because they provide students with the opportunity to learn through experimentation [10].

Based on information obtained from interviews by the Physics teacher at SMA N 1 Ngaglik, students' critical thinking abilities have never been measured using tests in the form of essay questions. The questions that teachers usually use are only taken from the internet and replaced with numbers. The questions prepared by the teacher are not yet based on HOTS questions. The teacher stated that students' critical thinking skills still needed to be improved because during learning only a few actively asked questions and several other students fell short of the specified KKM score. This is reinforced by the 2018 PISA results which show that Indonesia's science achievement score is 396 out of a total score of 489. This shows that the average critical thinking ability of Indonesian students is still low. PISA results can be used to determine students' level of critical thinking because the questions contained in PISA are a collection of HOTS questions that encourage students to have the ability to solve problems, think critically, think creatively, reason and make decisions.

The solution to the problem of students' low critical thinking and literacy skills is to develop a learning media that combines the use of technology in the form of smartphones, computers and laptops. A form of technology-based learning media that is efficiently used by students and teachers when learning is smartphones/cellphones [11]. This is because almost all students nowadays already have cellphones/smartphones. Learning media in the form of cellphones/smartphones are used by teachers and students as tools to help achieve effective learning goals. In accordance with 21st century learning which cannot be separated from digital developments, students are required to be able to operate and utilize technology in learning [12]. Forms of using technology in learning can be seen in the form of e-books or digital books that have been implemented. Existing e-books or digital books will be modified

both in terms of appearance and book content to provide new learning for teachers and students. The use of e-books in learning is expected to have a positive impact on students. It is not enough just to use learning media, but learning must be based on the right learning model, one of which is the PBL model. Learning carried out using this model emphasizes building skills related to decision making, discussion, finding solutions to problems, gathering information [13].

When using learning media and choosing a learning model, you must adapt it to the subject and material that will be delivered. Physics is one of the science subjects studied since elementary education. The expected ability from learning physics is that students are able to understand nature and the world around them [14]. Learning physics is synonymous with problems that link physics concepts to mastering knowledge in the form of facts [15]. One of the materials in physics lessons that has quite a lot of concepts is temperature and heat. Students are often confused and make mistakes in determining substances that release or receive heat, and are confused if more than two types of substances or objects are used, for example water, calorimeter and ice. Apart from that, students also do not understand the application of heat transfer in everyday life which is in accordance with the concept of heat transfer. This is in line with interviews conducted with students who said that the material on temperature and heat was difficult to understand because there were so many formulas, even the physics grades of almost a class were below the KKM, and the delivery of concepts by teachers that were not well understood and the media and facilities were less supportive. , so that when learning takes place many students are not active.

Based on the description above which is supported by the results of observations and previous research, the appropriate and interesting solution for conducting research is development of PBL-based interactive physics e-books to improve students' critical thinking and digital literacy abilities.

METHOD

This research was carried out at SMA Negeri 1 Ngaglik, Sleman Regency, Yogyakarta, odd semester of the 2023–2024 academic year. The sampling technique used in this research was random. Thus, class XI MIPA 1 with a total of 35 students and class XI MIPA 2 with a total of 36 students were obtained as samples. This research uses research and development methods (R & D) [16]. The research design used in this research is the ADDIE Model (Analysis-Design-Development-Implementation-Evaluation) [17]. In this research, we have reached the final stage of evaluation. The research design used is non-equivalent one test post test control group design and the research design used can be described in table 1.

Table 1. Experimental Design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control	O_3	X_2	O_4

Data collection techniques are carried out by surveys and tests. The survey was through a validation questionnaire for critical thinking ability test instruments and digital literacy skills as well as through a student response questionnaire to the PBL model interactive physics e-book. While testing through pretest and posttest students' critical thinking abilities and digital literacy. However, before analyzing the data, the data is first converted into interval data using the MSi method. Then data analysis is carried out such as product and instrument feasibility using equation:

$$P = \frac{f}{N} \times 100\% \quad (1)$$

Description:
P : percentage of assessment
f : score obtained
N : maximum score

The criteria for the feasibility level of teaching material [18], are shown in Table 2.

Table 2. Four Scale Ideal Standard Assessment Criteria

Quantitative Score Range	Category
$X \geq X_i + 1.0\ SB_i$	Very Feasibility
$X_i + 1.0\ SB_i > X \geq X_i$	Feasibility
$X_i > X \geq X_i - 1.0\ SB_i$	Moderate
$X < X_i - 1.\ 0SB_i$	Not Feasibility

Then an analysis of the empirical validity of the instrument was carried out. Testing the empirical validity of the instrument items used the Quest application. Then the output of the quest test results is interpreted based on the average value of INFIT Mean of Square (INFIT MNSQ). Next, the reliability analysis using the Quest application refers to the summary item estimates and reliability of estimate sections [19]. After carrying out feasibility tests and empirical tests, extensive field test analysis was carried out. By analyzing the N-Gain value and effectiveness analysis. N-Gain analysis is carried out using the equation:

$$< g > = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \quad (2)$$

description:
$< g >$ = N-Gain score
S_{post} = Post-test score
S_{pre} = Pretest score
S_{max} = Maximum score

The results of the N-gain analysis are interpreted using the categories of n-gain calculation results [20] shown in table 3.

Table 3. N-Gain Assessment Criteria

N-Gain Index	Category
$g > 0{,}70$	Height Increase
$0{,}30 \leq g \leq 0{,}70$	Medium Increase
$g < 0{,}3$	Low Increase
$g = 0$	No Increase Occurred
$-1{,}00 \leq g < 0{,}00$	There was a decline

After that an effectiveness analysis was carried out. This analysis was carried out after passing the prerequisite tests, namely normality, homogeneity, linearity, multicollinearity. After the prerequisite tests were met, a hypothesis test was carried out to determine the differences between the experimental class and the control class, improvements, and the influence of PBL-based physics interactive e-books on students' critical thinking abilities and digital literacy. Decision making is based on the significance value of the variable which can be seen in the Partial Eta Squared value [21]. Decision making is based on table 4.

Table 4. Partial Eta Squared Interpretation Criteria

Effect Size	Category
$0,0 \leq f < 0,10$	Weak
$0,11 \leq f < 0,25$	Currently
$0,26 \leq f < 0,4$	Strong
$0,4 \leq f$	Very Strong

RESULTS AND DISCUSSIONS

Teaching Material Development Results

1. Analysis Stage

This stage is carried out by direct interviews by physics subject teachers and students, observing learning activities in the classroom [22]. The things carried out at the analysis stage are: (1) needs analysis aims to identify problems found in research schools such as learning media, learning models, and learning tools; (2) student analysis is designed to identify students' abilities, participation, learning styles, interests and attitudes towards using cellphones/smartphones during learning activities. The aim of this analysis is to ensure that the e-book media developed is relevant to students; (3) material analysis identifies the material concepts of temperature and heat contained in the media and model to be used. Then prepare a concept map, formulate learning objectives through the use of learning media adapted to the chosen model.

2. Design Stage

The teaching material design stage begins with creating an initial design in the form of a storyboard to make it easier to use the teaching material [23]. The design in the form of a storyboard is done manually. At this stage, learning objectives are designed based on temperature and heat material. Then prepare an outline book, compiling the contents of the learning material based on problem based learning. The results of this stage are a framework for the teaching materials that will be developed. At this stage the researcher also designed a feasibility test and readability test sheet.

3. Development stage

At this stage, e-book media begins to be developed according to the results of analysis and design. The main stage begins with preparing the initial product, including preparing the concept of temperature and heat material, LKPD, preparing lesson plans, as well as evaluating critical thinking skills and digital literacy [24]. Then select the e-book format which includes 6 main menus, namely; (1) cover, containing the title, curriculum logo, illustration image, music icon, and playback icon; (2) Material Menu, contains material containing PBL syntax, LKPD, hypothesis sheets, images, animations, videos, physics information related to temperature and heat material; (3) Simulation Menu, contains a temperature conversion experiment simulation; (4) Fun-Quiz menu, containing multiple choice questions that correspond to indicators of critical thinking skills and digital literacy; (5) Assignment Menu, containing independent practice questions to be done as additional assignments; (6) Closing menu, containing the developer profile and bibliography for preparing e-books. After the media is prepared, an assessment is carried out to determine the suitability of the media. The feasibility test was carried out by an expert validator with the validation results shown in table 5.

Table 5. Media Feasibility Results by Media and Material Experts

No.	Expert Validator	Indicator Aspects	Score	Category
1	Media	Visual and Audio	89,10	Very Feasible
2		Software Engineering	84,66	Feasible
3	Learning Materials	Learning	85,66	Very Feasible
4		Material or Content	86,05	Very Feasible

After the e-book media passes the feasibility test by a team of expert validators with various suggestions and comments, it is declared that the media is suitable for use. The form of an e-book can

be seen in the following image.

Fig 1. *E-book application display*

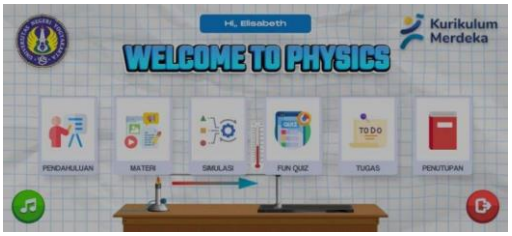

Fig 2. *The main page of the e-book application*

Fig 3. *Display of material contents*

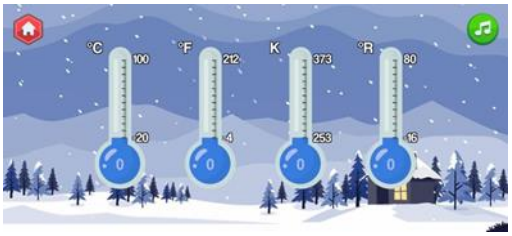

Fig 4. *Simulation display*

Fig 5. *Fun-Quiz View*

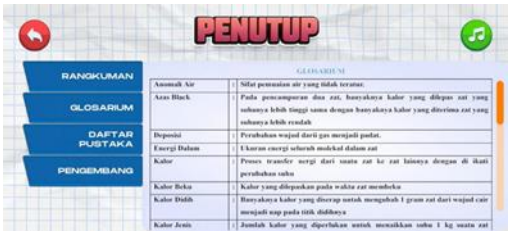

Fig 6. *View of the e-book's final cover*

Next, a feasibility test was carried out on learning tools in the form of LIP (Learning Implementation Plan), CTA (Critical Thinking Ability) and Digital Literacy Instruments. The results of the feasibility test for learning devices can be described as follows:

Table 6. LIP Feasibility Analysis Results

No.	Learning Media	Indicator	Score	Category
1	Learning Implementation Plan	Learning Implementation Plan identity	100	Very feasible
		Formulation of Indicators and Learning Objectives	82,30	Feasible
		Learning Activities	77,97	Feasible
		Language	89,83	Very feasible
2	Critical Thinking Skills Pretest Questions	Material	82,20	Feasible
		Construction	82,17	Feasible
		Language	95,57	Very feasible
3	Critical Thinking Skills Posttest Questions	Material	81,91	Very feasible
		Construction	81,82	Very feasible
		Language	88,34	Very feasible
4	Digital Literacy Instrument	Contents	91,25	Very feasible
		Construction	82,89	Very feasible
		Language	93,65	Very feasible

Based on the results of the feasibility test, all research equipment ranging from media, learning implementation plan, to test instruments were declared suitable for use in conducting research. Based on the results of the feasibility test, all research equipment starting from media, RPP, to testing instruments was declared suitable for use in conducting research. Next, a limited trial was carried out on the test instrument to determine the suitability and reliability of the instrument. Limited test results can be seen in Figure 7.

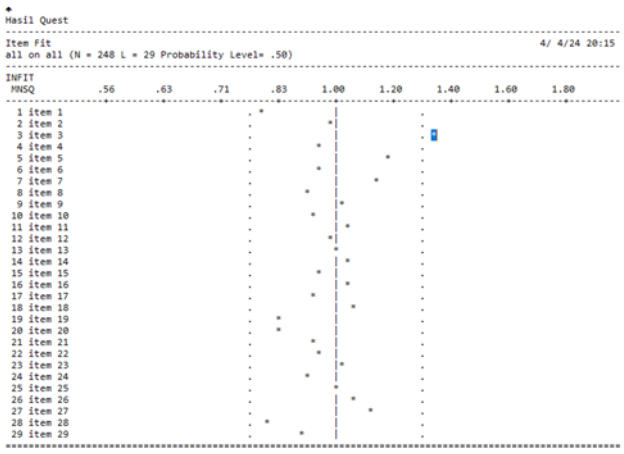

Fig 7. *Instrument Limited Test Output Results*

Based on the Quest output results, there are 28 critical thinking ability questions that were designed to have a mean squared infit value between 0.77 - 1.33, so it was concluded that the questions designed were included in the valid category and matched the rush model/PCM. However, there is one item in question number 3 that is invalid and does not fit the rush model because the outfit t value is more than 1.33 so it is not included in the valid category and does not fit the rush model [19]. Next, to find out the reliability of the question items, look at the Quest output section in the item estimate summary and case estimate summary sections. The results of the reliability of the unlucky item output can be seen in table 7.

Table 7. Quest Output Results Reliability of Question Items

Reliability	Output	Catogory
Item Estimates	0,70	High Reliability
Case Estimate	0,73	High Reliability

Based on the output results above, it shows that the critical thinking ability questions have high reliability and are good for use in field trials. This is in accordance with the reliability value which is at 0.60 - 0.80, which is included in the high category [25]. After all learning tools for research are deemed feasible and have passed limited testing, field trials or implementation of the media that have been developed are carried out.

4. Implementation Stage

At this stage, large-scale trials or applications of the products that have been developed are carried out. This implementation was carried out to determine the effectiveness of PBL-based interactive physics e-books to improve students' critical thinking and digital literacy skills in the process before and after using the developed e-books [26]. The results of this implementation will be analyzed for its effectiveness in improving critical thinking skills and digital literacy. The implementation results can be reviewed in the results of the N-Gain Test analysis of critical thinking skills and digital literacy in the experimental class and control class in the table 8 table 9.

Table 8. Critical Thinking Ability N-Gain Score

No	Component	Experimental Class		Control Class	
		Pre	Post	Pre	Post
1	Number of students	35	35	36	36
2	Average value	61,57	89,06	75,77	83,25
3	N-Gain	0,71		0,31	
4	Category	High		Low	

The N-Gain results in table 8 show that the N-Gain score in the experimental class is 0.71 higher compared to the N-Gain score in the control class which is 0.31. This proves that learning carried out with PBL-based interactive physics e-books is better at improving critical thinking skills compared to conventional learning with available teaching materials. Learning activities that contain PBL syntax can guide students to think critically and can improve students' critical thinking abilities. Every problem available in the e-book is directed at the critical thinking process. This aims to be able to develop and improve students' critical thinking abilities.

Table 9. Digital Literacy N-Gain Score

No	Component	Experimental Class		Control Class	
		Pre	Post	Pre	Post
1	Number of students	35	35	36	36
2	Average value	61,51	87,51	69,44	78,97
3	N-Gain	0,67		0,28	
4	Category	Currently		Low	

The N-Gain results in table 26 show that the N-Gain score for the experimental class is 0.67 higher

compared to the N-Gain score for the control class of 0.28. This proves that learning carried out with PBL-based interactive physics e-books is better at increasing students' digital literacy compared to conventional learning with available teaching materials. Learning activities that utilize technology such as e-books that contain PBL syntax can guide students to carry out digital literacy well.

5. Evaluation Stage

This stage contains the results of the summative evaluation obtained from the results of field trials based on the results of the pretest and posttest of students' critical thinking abilities and digital literacy. All data obtained must first undergo prerequisite tests such as normality, homogeneity, linearity and multicollinearity tests [27]. After that, the data was analyzed and further tests were carried out including hypothesis testing using GLM (General Linear Model) and effect size testing.The results of hypothesis testing and effect size can be seen in the table 10.

Table 10. Variable Increase Hypothesis Test Results

Variable	I	J	Mean Difference	Sig.
Critical Thinking Ability	Experiment	Control	1,226	0,000
	Control	Experiment	-1,226	0,000
Digital Literacy	Experiment	Control	8,901	0,000
	Control	Experiment	-8,901	0,000

Based on the test results, the significance value for critical thinking skills was 0.00 < 0.05, meaning there was a significant increase between critical thinking skills and digital literacy in each class. In the experimental class for critical thinking skills, the mean difference value was positive, while in the control class it was negative. This means that the use of PBL-based e-books has a better effect compared to the use of learning media in the control class in the form of regular printed books. Furthermore, in digital literacy between the experimental class and the control class, the mean difference value for the experimental class was positive and the control class was negative. This shows that the use of PBL-based e-book media is able to increase students' digital literacy compared to using regular books in the control class. Next, to see the effectiveness of media on critical thinking skills and digital literacy, you can see the graphic Figure 8.

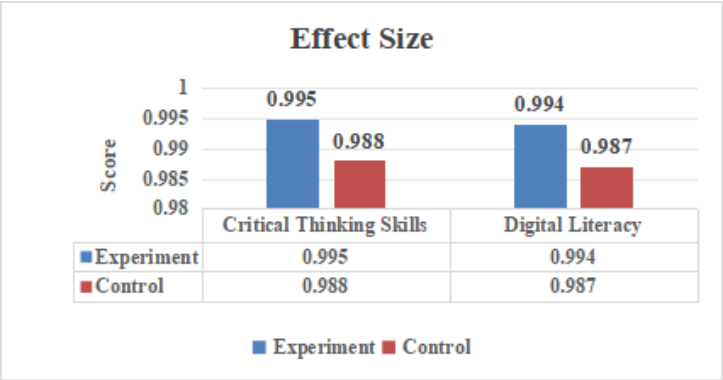

Fig 8. *Differences in Effect Size in Experimental Class and Control Class*

There are differences in the results of critical thinking skills and digital literacy in the two classes. This is supported by the results of the statistical analysis of the Manova test, the intercept significance of which is 0.000 < 0.005, so it can be concluded that there is an influence of interactive physics e-books based on problem based learning on students' critical thinking abilities and digital literacy. Apart from that, based on the results of the effect size test, it was also found that the eta square had a significance value of 0.403 > 0.400 which was included in the strong category [28] [29].

Description of Critical Thinking Ability and Digital Literacy Indicators between the Experimental Class and the Control Class

1. Interpretation

In the control class, students were presented with a picture and then students were asked to express a hypothesis about the event. On average, students only answered modestly with inaccurate answers or hypotheses. There are also students who answer briefly and are not related to the material. However, during learning activities students are allowed to access information from various media, but students are less likely to take advantage of this opportunity. Many students also use the internet to look for answers but do not filter the information properly so that the hypothesis they write is not accurate. Meanwhile, in the experimental class, students take advantage of the opportunity to access e-books and the internet and filter information and then solve the problem together with a group of friends. So that learning looks active due to students being enthusiastic about learning [30].

2. Analyze

In the control class and experimental class, questions were presented regarding the concept of expansion as well as examples of heat transfer in everyday life. In the control class, some students were able to answer correctly and some answered incorrectly. Meanwhile, in the experimental class, almost all students answered correctly due to team collaboration in accessing information using e-books [31].

3. Evaluate

Evaluating is the ability to judge the accuracy of a statement or statement by assessing the situation using logic and based on concepts. In both classes, a discourse was presented with certain temperature conditions, then students were asked to convert the temperature to another thermometer scale. The average of students answering questions like this is mostly correct, so the increase in the average is included in the high category [32].

4. Conclude

Students are given discourse related to expansion, heat and heat transfer in everyday life, students are asked to correctly conclude the relevant information. On average, students answered correctly by providing appropriate reasons and explanations. Therefore, it can be concluded that students really understand the conclusions that have been made [33].

5. Explain

In this indicator, questions are given about heat transfer by convection in everyday life, students are asked to explain and give reasons that are logical and based on concepts. Most of the students answered correctly, but some students still answered logically but not based on concepts. This is what makes the indicators explaining critical thinking abilities fall into the medium category. Therefore, it is necessary to further improve this indicator [34] [35].

CONCLUSION AND SUGGESTION

Conclusion

The development research that has been carried out can be concluded that the development of an interactive physics e-book based on problem based learning on temperature and heat material to improve critical thinking skills and digital literacy is declared feasible in the very good category. The development of an interactive physics e-book based on problem based learning on temperature and heat material to improve critical thinking skills and digital literacy was declared practical in physics learning with a very good category. The development of an interactive physics e-book based on problem based learning on temperature and heat material was declared effective in improving critical thinking skills and digital literacy. Learning using PBL-based interactive e-books can improve aspects or indicators of students' critical thinking abilities and digital literacy.

Suggestion

Based on the results of the discussion that has been presented, several suggestions can be outlined as follows; (1) Physics interactive e-books based on problem based learning need to be further developed by adding more trendy and interesting features by learning more deeply about application creation features (2) Interactive physics e-books based on problem based learning need to be developed in terms of appearance and content presented. It would be better to learn more interesting and varied designs.

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