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Constructing Assessment for Evaluating Critical Thinking and Creative Problem-Solving Skills in the Lesson on Soundwave

Sri Zakiyah[1], Irma Rahma Suwarma[1*], Dadi Rusdiana[1]

[1] Department of Physics Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.

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Corresponding Author:
Irma Rahma Suwarma
irma.rs@upi.edu

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Abstract: The objective of this article is to develop an instrument that can be used to assess the ability to solve creative problems (CPS) and critical thinking (CT) in the context of sound waves. This work is a component of our research on developing a teaching material that includes assessment as a component of the final product. The objective of this instrument is to evaluate students' critical thinking (CT) and critical problem-solving (CPS) abilities both before and after implementing the recently developed mobile learning teaching resources. To construct the instrument, we adhere to the Facione and Osborn-Parness frameworks for CTs and CPSs. Validity testing and reliability testing comprise this instrument development process. We utilize Cronbach's Alpha to assess reliability and the content validity index to assess validity. According to the content validity index results, four of the six items in the CT instrument were determined to be valid. Conversely, the empirical validation test of the creative problem-solving skills instrument demonstrated that the results were valid and suitable for use. The Cronbach's Alpha results also indicated that both tools accurately evaluated students' creative problem-solving and critical reasoning abilities.

Keywords: Assessment; Creative problem-solving; Critical thinking

Introduction

Mastering critical thinking and creative problem-solving is crucial for the current generation in the fourth industrial revolution. These skills are highly demanded in managerial, professional, and technical roles, which are rapidly evolving (Deming, 2017; Fleaca & Stanciu, 2019; Mardis et al., 2018; OECD, 2014a). Therefore, it is crucial for students to cultivate creative problem-solving abilities in order to confront and surmount intricate obstacles that lack obvious solutions, both in their daily lives and in their future endeavors.

Proficient students in critical thinking can evaluate and examine the provided phenomena and facts while offering appropriate arguments within the context of the topic being investigated (Hyytinen et al., 2014). Critical thinking skills and problem-solving abilities are tightly interconnected. In the PISA assessment, students are required to distinguish between facts and opinions when understanding problem situations. They also need to identify relationships between variables when formulating solutions. When choosing a strategy, they must consider cause and effect. Finally, when reflecting on the results, they are expected to critically evaluate assumptions and alternative solutions (OECD, 2014b). Problem-solving abilities can enhance individuals' ability to actively interact in society by facilitating their adaptation to new situations, promoting lifelong learning, and effectively applying acquired information (OECD, 2014b).

An approach to enhance students' critical thinking and creative problem-solving abilities involves instructing them using mobile learning resources (Dasilva et al., 2019; Fan et al., 2023; Husna & Kuswanto, 2018; Ismail et al., 2017; Wongwatkit et al., 2017). Components in learning materials are learning instructions, achieved competencies, the content, supporting information, exercises, work instructions

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(student worksheets), evaluation, and answers to the test results (Depdiknas, 2008). Thus, the evaluation aspect of learning materials aims to assess how learning objectives have been achieved following the learning process (Prastowo, 2013). Consequently, it is crucial to develop precise measuring tools to assess the extent to which the mobile learning teaching materials undergoing development have succeeded in enhancing critical thinking skills and creative problem-solving abilities. Regrettably, there is a dearth of research examining instruments that assess creative problem-solving skills as a component of critical thinking abilities. The objectivity and validity of the assessment results will be significantly impacted by selecting the appropriate assessment instrument, thereby enabling the acquisition of objective and valid information regarding the achievement of learning objectives.

Moreover, the appropriate tool can significantly impact the efficacy of utilizing mobile learning to hone the targeted skills. Errors in choosing and using assessments might lead to inaccurate information about learning and educational achievements (Setiadi, 2016). Previous research shows several researchers conducting development research in creating instruments for measuring critical thinking but still limited to measuring creative problem-solving. For example Desnita (2022), Noris et al. (2024), Rizki et al. (2021), and Tiruneh et al. (2017) create an instrument for CTs in the lesson of waves, biology, chemical balance, and electricity and magnetism, respectively. Furthermore, in previous works, we found some limitations regarding instruments to measure CTs in the lesson on sound waves. As part of our research on developing mobile learning teaching materials to enhance critical thinking skills and creative problem-solving abilities, we created an instrument to gather data on students' CTs and CPS abilities before and after using the mobile learning materials.

Method

Participant

The validation stage included three experts: two physics education lecturers and one physic teacher. The reliability test relied on 47 class XI high school students from a state school in South Sumatra Province. Figure 1 illustrate the research flow.

CTs and CPSs Framework

Facione (2020) states that six indicators are core critical thinking skills: interpretation, analysis, inference, evaluation, explanation, and self-regulation. The critical thinking framework refers to Facione (2020), excluding self-regulation. Table 1 summarizes the indicators and sub-indicators of critical thinking.

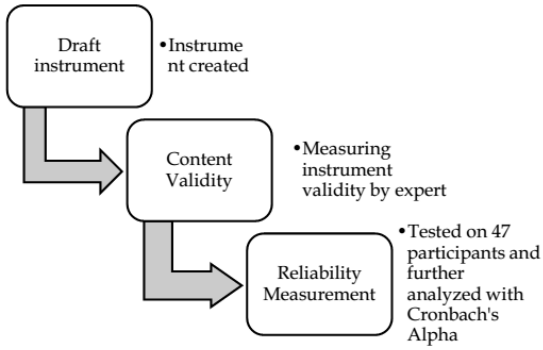


Figure 1. Research flow

Table 1. Critical Thinking Skills Indicators

CTs Indicators	CTs Sub Indicators
Interpretation	Categorize
	Decode significance
	Clarify meaning
Analysis	Examine ideas
	Identify arguments
	Identify reasons and claims
Inference	Query evidence
	Conjecture alternatives
	Draw logically valid or justified conclusions
Evaluation	Assess credibility of claims
	Assess quality of arguments that were made using inductive or deductive reasoning
Explanation	State results
	Justify procedures
	Present arguments

Various specialists have developed numerous frameworks for innovative problem-solving abilities. Treffinger et al. (2008) introduced the concept of CPS as a model comprising three primary elements: comprehending difficulties or problems, generating ideas, and planning for execution. Meanwhile, Parnes (1988) discovered that CPS is a recurring process because of the ongoing issues that occur from the actions and solutions implemented by people. The stages of the CPS process are referred to as the Osborn-Parnes CPS process (Evans, 1997; Isaksen, 2023; Parnes, 1988; van Hooijdonk et al., 2020) and are briefly outlined in Table 2.

The Osborn-Parnes CPS process, which encompasses five four-part components—fact finding, problem finding, idea finding, and solution finding—will be employed to evaluate the creative problem-solving abilities of participants in this study. The research did not prioritize the acceptance finding step due to its consideration of the inherent complexity of the CPS. The stage of acceptance finding is arduous and time-consuming, as students must carefully select a solution that does not give rise to further issues. Furthermore, they must exert considerable effort to persuade others that the chosen proposal deserves acceptance and implementation.

Table 2. Creative Problem-Solving Framework

CPSs Indicators	Definition
Fact finding	Using available data or information to identify facts about the scenario
Problem finding	Various methods of problem identification to generate multiple problem statements.
Idea finding	Ideas for potential solutions to rising problem statements
Solution finding	Evaluation of solution implications and repercussions during ideation for problems
Acceptance finding	Preparation for implementation comprises establishing a good plan, refining, testing, and implementing it.

Grid for Instrument Arrangement

Participants will be required to answer 14 essay questions that assess their critical thinking skills and 2 essay questions that evaluate their creative problem-solving ability. The selection of the essay format (extended written response) is motivated by its qualities that are well-suited for assessing proficiency in knowledge, logical thinking, and the ability to generate outputs (Chappuis & Stiggins, 2019). Table 3 and Table 4 provide a concise summary of the grid matrix that outlines the indicators for creative problem-solving skills (CPSS) and critical thinking skills (CTS).

Table 3. Grid for CPSS Instrument

Question Indicator	CPSs Indicators	Question Number	Qty
Developing strategies to address noise pollution issues.	Identifying facts and information from the discourse given (fact-finding).	1, 2	1
	Seeing problems in the piece of literature that was given (problem finding)		1
	Provide several possible answers to the issues that have been pointed out (idea finding)		1
	Looking for creative and effective ways to solve problems that have already been named (solution finding)		1
	Evaluate the chosen answer based on its flaws, benefits, and the amount of work that went into making it work (acceptance finding).		1

Table 4. Grid for CTS Instrument

CTs Indicators	Sub CTs Indicators	Details	Question Number
Interpretation	Categorize	Use criteria to group types into groups.	1
	Decode significance	Explain what it means.	6
	Clarify meaning	Explain what a statement means.	12
Analysis	Examine ideas	Review the ideas	4
	Identify arguments	Determine whether the case fits the issue being discussed	10
	Identify reasons and claims	Figuring out how the ideas and facts given fit together	7
Inference	Query evidence	Collect the essential details to arrive at a decision.	8
	Conjecture alternatives	Assume things	2
	Draw logically valid or justified conclusions	Draw conclusions	9
Evaluation	Assess credibility of claims	Assessing the credibility of a statement	13
	Assess quality of arguments that were made using inductive or deductive	Assess arguments made using inductive reasoning.	11
Explanations	State results	Explanation of the interpretation's results	14
	Justify procedures	Consider these things as a guide for judging the design of experimental methods.	5
	Presents arguments	Support a point with evidence.	3

Data Analysis Technique

Validity tests are conducted to evaluate the appropriateness of the instruments that have been developed. The assessment technique utilizes a content validity index derived from a validity sheet with six indicators, each rated on a five-point scale ranging from very suitable to not suitable. A minimum CVI score of 1 is required for a panel of three to five experts (Polit & Beck, 2006; Shi et al., 2012). Meanwhile, the reliability test is conducted by determining the Cronbach's Alpha coefficient. The obtained Cronbach's Alpha score will be referenced using Table 5.

Table 5. Cronbach's Alpha Level of Reliability (Rajalahti & Kvalheim, 2011)

Cronbach's Alpha Score	Level of Reliability
0.0 – 0.20	Less reliable
>0.20 – 0.40	Rather Reliable
>0.40 – 0.60	Quite reliable
>0.60 – 0.80	Reliable
>0.80 – 1.00	Very Reliable

Result and Discussion

Instrument Validity

Three validators evaluated the critical thinking ability instrument by assigning a score ranging from 5 to 1 (indicating extremely suitable, suitable, quite suitable, less suitable, and not suitable) on the validation form. The validation sheet comprises six items, which are divided into three primary aspects: content (items 1 and 2), construction (item 3), and language (items 4, 5, and 6). In addition to evaluating the elements included on the validation sheet, the validator also offers recommendations for enhancing specific queries formulated. The findings of the validator evaluation are presented in Table 6.

Table 6 presents the results, indicating that items 1, 2, 3, and 6 have valid I-CVI values, whereas items 4 and 5 need improvement. This is consistent with the advice of an expert to enhance sentence structure and grammar. Table 7 summarizes the enhancements made by incorporating comments from the experts.

Table 6. I-CVI Calculation for CT Assessment

Item	Expert 1	Expert 2	Expert 3	NA	I-CVI
1	3	5	4	3	1.00
2	3	4	4	3	1.00
3	4	5	4	3	1.00
4	0	5	3	2	0.67
5	4	0	4	2	0.67
6	4	5	4	3	1.00
S-CVI/Ave					0.89
TA					4.00

NA= Number of agreements
I-CVI= item-content validity index
TA= Total agreement
S-CVI/Ave= Scale-content validity index (average)

Table 7. Sample Question – Revising the Narration

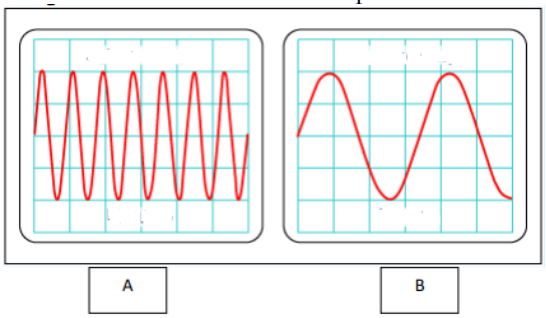
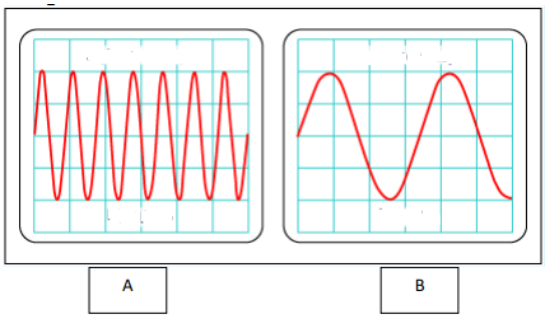
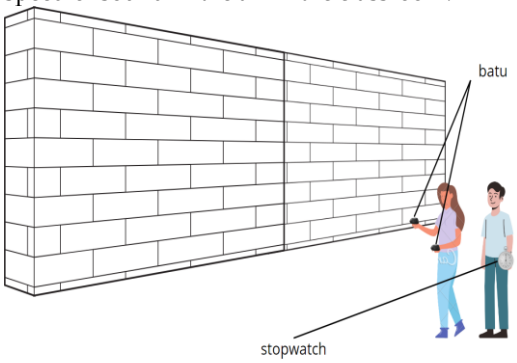
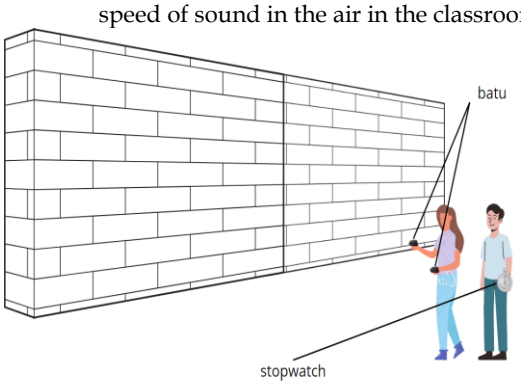
Before revision	After revision
When an object vibrates, it produces sound waves. The sound changes when an object vibrates rapidly. An oscilloscope was used to visualize these two wave pictures for both treatments.  How are the waves in pattern A different from those in pattern B? Please provide your conclusion.	When an object vibrates, it produces sound waves. The rhythm or vibration pattern will influence the music that is created. The following is a visual representation of two images of sound waves captured using an oscilloscope for two treatments.  How are the waves in pattern A different from those in pattern B? Please provide your conclusion.

Table 8. Sample Question – Revising the Ambiguous

Before revision	After revision
Two pupils devised the following system to measure the speed of sound in the air in the classroom. 	Two pupils devised the following system to measure the speed of sound in the air in the classroom. 

Before revision	After revision
One of the students hit both stones at once. Meanwhile, another student used a stopwatch to determine when the sound reflected off the wall was heard. Before the trial, their physics teacher evaluated the experimental plan. According to the teacher, the experiment would provide erroneous measurements because it was conducted in the classroom. Explain why you believe the teacher's assertion is correct.	One of the students is holding two stones, one in each hand. The pupil then struck the stone close to another stone. Meanwhile, another student used a stopwatch to determine when the sound reflected off the wall was heard. Before the trial, their physics teacher evaluated the experimental plan. According to the teacher, the experiment would provide erroneous measurements because it was conducted in the classroom. Explain why you believe the teacher's assertion is correct.

An expert offered an opinion on a question due to the unclear linguistic structure. The question includes an image depicting a girl holding two stones, and the accompanying text explains that the stones were struck. Experts offer recommendations to elucidate the direction in which the stone is struck. The outcome of modifying unclear sentences in the questions is outlined in Table 8.

Furthermore, the CPS instrument undergoes a validity test where a score is assigned using a 5-level Likert scale (ranging from very suitable to not suitable) on the validation sheet. The validation sheet comprises six items, which are categorized into three primary aspects: content (items 1 and 2), construction (item 3), and language (items 4, 5, and 6). In addition to evaluating the elements included on the validation sheet, the validator also offers recommendations for enhancing the questions that have been formulated. The findings of the validator evaluation are presented in Table 9.

Table 9. I-CVI Calculation for CPS Assessment

Item	Expert 1	Expert 2	Expert 3	NA	I-CVI
1	4	5	4	3	1.00
2	4	5	4	3	1.00
3	4	5	4	3	1.00
4	4	5	3	3	1.00
5	4	5	4	3	1.00
6	4	5	4	3	1.00
S-CVI/Ave					1.00
TA					6.00

The CPS instrument is declared valid under the results summarized in Table 7. Nevertheless, there are a few minor enhancements from the expert, including the narration of query sentences and errors in word usage. The improvements before and after the improvements are summarized in Table 10.

Table 10. Sample Question – Revising Narration and Interrogative Sentence

Before revision	After revision
55 dB is the lowest amount of noise.	As the loudest amount of noise, 55dB is used.
You have chosen the best answer for the problem. What problems and issues do you think might come up when the solution is put into action? Explain how you plan to get stakeholders to accept and back your chosen solution.	You have chosen the best answer for the problem. What problems and issues do you think might come up when the solution is put into action? Make a plan for getting stakeholders to agree with and back the solution you choose.
You have chosen the best answer for the problem. What problems and issues do you think might come up when the solution is put into action?	You have chosen the best answer for the problem. What problems and issues do you think might come up when the solution is put into action?

Content, internal structure, response process, consequences, and relation to other variables are the five sources of validity evidence (Sireci & Faulkner-Bond, 2014). Content validity is the degree to which a measurement tool accurately represents the construct being measured. It is regarded as a critical piece of evidence that corroborates the validity of a measurement tool, such as a research instrument (Adom et al., 2020; Almanasreh et al., 2019). Previous works also conducted a validity test with several methods such as, Aiken's V (Azmi & Festiyed, 2023; Dirman & Mufit, 2022; Kharisma et al., 2024; Muharini & Rasmawan, 2024), Rasch Model (Manik et al., 2022; Sa'adah & Ikhsan, 2023), and product-moment correlation (Mulyana & Desnita, 2023). Our work enriches the validity method by using the content validity index.

Instrument Reliability

Once the prepared instrument has been validated, the subsequent stage involves assessing the reliability of the instrument. Reliability refers to the consistency and stability of measured values obtained from repeated measurements conducted under same conditions using the same measuring device (source). Reliability testing is conducted by providing questions to students for them to solve, using CTs (computerized tests) and CPSs

(computerized problem-solving systems). Once the data was collected, it was subsequently analyzed using SPSS software to calculate the Cronbach's Alpha score. The acquired findings for the critical thinking instrument and the CPS ability instrument were 0.476 and 0.926, respectively. These results indicate that the categories of quite reliable and very reliable were assigned to the instruments, as stated by Guilford (Ruseffendi, 2005).

The stability of the measuring instrument and its consistency over time are referred to as reliability. In other words, reliability is the instruments' capacity to produce consistent results when used at different times (Sürücü & Maslakçi, 2020). It is improbable that the same results will be obtained on each occasion, as there are variations in the population and the sample, as well as at the moment the measuring instrument is applied (Revelle & Condon, 2019). Nevertheless, a robust positive correlation between the results of the measuring instrument is a sign of reliability (Feng et al., 2021; Korpershoek et al., 2020). The measuring instrument's reliability is critical for the study's results to be appropriate. As a result, researchers must verify the reliability of the measuring instrument they employ.

A reliability test was also conducted in previous works to assess its consistency. The results are primarily determined by the researchers using Cronbach's Alpha formula. Various studies, including (Desnita, 2022; Noris et al., 2024; Rizki et al., 2021), have evaluated the instrument's reliability in the context of the lesson wave, biology course, and chemical balance, respectively. Additionally, our work contributes to the scarcity of resources in creative problem-solving, particularly by developing an assessment to measure it. Research has been conducted in the past on creative problem-solving through the development of learning products, including e-book (Sukma et al., 2023), student's worksheets (Fatmawati et al., 2023; Sulistiani et al., 2024), module (Fitri et al., 2023; Widya et al., 2023), and learning strategy (Fatmawati et al., 2022). In this way, our works offer complementary references for developing assessments that evaluate creative problem-solving abilities.

Conclusion

Essay questions can be devised to assess students' critical thinking and creative problem-solving skills in the context of sound wave material, enabling them to articulate their thoughts. After conducting an empirical validation test on the critical thinking skills instrument, it was found that 4 out of the six items were deemed valid. In comparison, the remaining two items needed revision to be used. On the other hand, the empirical validation test on the creative problem-solving skills instrument demonstrated that the results were valid and appropriate for use. Moreover, both tools accurately assessed students' critical thinking and problem-solving skills.

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Author Contributions
Conceptualizing research, I.R.S., D.R., S.Z.; designing, I.R.S. and S.Z.; collecting Data, S.Z.; analyzing data, I.R.S. and S.Z.; writing—original draft preparation, S.Z. writing—review and editing, I.R.S., D.R., S.Z.

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Conflicts of Interest
No conflict of interest.

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