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Physics Workbook using Multimodal Representation on Simple Harmonic Motion Topic

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Abstract: This study aimed to produce teaching materials in workbooks using multimodal representations, which can effectively improve problem-solving and critical-thinking skills. The research method used is the research and development (R&D) method. Test the quality of the workbook developed through validation by three expert lecturers and ten teachers and test the legibility of the main ideas of the discourse by ten high school students. Meanwhile, to test the effectiveness of this research workbook using design randomized control group pretest-posttest design to 70 high school students, 35 each in the control class and 35 in the experimental class. The test results of students' problem-solving and critical-thinking skills were analyzed quantitatively using the N-gain and t-test with the help of SPSS. Based on the main idea's quality and understanding tests, the feasibility percentage of the workbook was 76.35% in the feasible category. Moreover, the effectiveness test results show that workbooks using multimodal representations significantly improve students' problem-solving skills and critical-thinking skills compared to worksheets that can be used in schools.

Keywords: Critical Thinking; Problem Solving; Workbook

Introduction

One of the efforts made by Indonesia in facing the global challenges of the 21st century is to improve the quality and results of human work through the educational process. Education in the 21st century is essential to ensure students have learning and innovation skills, skills in using information technology and media, and can work and survive by using 21st-century life skills known as 4C (critical thinking, creative, communication and collaboration) (Weng et al., 2022; Liana & Sugiarti, 2022; Sari & Ariswan, 2021; Dervic et al., 2018; Prayogi et al., 2018). Physics is a branch of science that underlies the development of advanced technology and is the basis for studying the harmonization of nature (Nasir, 2017). Physics learning is a forum for cultivating thinking skills in solving problems in everyday life (Ubaidillah & Wilujeng, 2019).

However, in reality, students still need to improve in learning science. Based on data Organization for Economic Cooperation and Development's (OECD), Program for International Student Assessment (PISA) in 2018, Indonesia's children's scientific literacy scores they were decreased by seven compared to 2015, where the respective scores were 403 and 396 out of a maximum score of 500. This condition placed Indonesia in 73rd place out of 79 participating countries (OECD, 2018). Preparing questions on the scientific literacy test in PISA emphasizes skills in solving science problems related to everyday life and drawing conclusions based on evidence to understand and make decisions about science (Kartimi & Winarso, 2021), (Rusilowati, 2018); likewise, according to the results of an international study regarding the cognitive abilities of students, namely Trends in Mathematics and Science Study (TIMSS). TIMMS 2015 results in the field of science show that Indonesia obtained a score of 397, below the international average score of 500, where Indonesia is ranked 44th out of 47 participating countries (Martin et al., 2016). The low results of PISA and TIMSS for

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Indonesian children show that physics learning does not emphasize problem-solving skills and critical thinking skills. This is also supported by the results of a preliminary study conducted at a school in Bandung. In the initial examination, two types of tests were carried out, namely, tests of critical thinking skills and problem-solving skills. The critical thinking skills test results tested on 30 students still needed to be higher. The overall maximum score is 69.2, the minimum score is 15.8, and the average score is 47. Likewise, with the whole problem-solving skills test, the maximum full is 68.4, the minimum score is 17.4, and the average score is 49 out of 100. These results still need to be closer to what was expected.

Achieving good learning competencies is, of course, carried out with the right learning process and also in building student concepts. In this case, correct mastery of physics content can be done through mastery of physics concepts using multimodal representations (Treagust & Duit, 2017; Siswanto et al., 2018). Multimodal representation explains a topic or sub-topic by integrating a mode of verbal representation (text/narration) with one or more modes of visual representation so that a comprehensive written description is produced (Treagust & Duit, 2017). The use of multimodal representation is well-developed for problem-solving skills and critical thinking skills (Wei et al., 2022). Several studies state that students' difficulty in solving problems is a need for understanding related to interpreting various modes of representation such as graphics, mathematical equations, text, and computer simulations (Carli et al., 2020; Wawro et al., 2020; Campos et al., 2020; Burkholder et al., 2020; Ryan & Schermerhorn, 2020). Several other studies have stated explicitly that graphical representations are the most difficult for students to understand compared to other representations, and this has an impact on understanding the wrong concept (Rončević et al., 2019; Skrabankova et al., 2020; Santosa, 2022).

A good multimodal representation can be displayed in teaching materials. Teaching materials are essential to implementing learning in schools because it makes it easier for students to develop their competencies (Baifeto et al., 2022; Yulkifli et al., 2020). A workbook is one form of teaching material used in learning activities. Through workbooks, students are more active in building their knowledge, so they can think higher in processing existing material. For this reason, students need the ability to think critically, logically, and systematically in processing their knowledge. When students are given problems according to the material in teaching materials, they must be able to develop and master different representations (presentations) or multi-representational abilities to solve these problems (Rahmawati et al., 2022).

Learning by using a workbook allows students to learn individually. He knows actively without maximum assistance from a teacher. Based on previous research, teaching materials workbook reduce learning-oriented-teacher centres; students are more focused on finding concepts and more active in learning (Elise et al., 2015). Besides that, a workbook can increase students' intellectual potential, which in this case, is a learning goal (Ifeoma, 2013). Thus, in developing teaching materials in the form of a workbook for students, it is necessary to pay attention to the characteristics and needs of students in responding to the challenges of the 21st century. The author tries to make teaching material a workbook for students who can practice critical thinking and problem-solving skills by using multimodal representations on simple harmonic motion material. The selected simple harmonic motion material is considered difficult even though its application is very close to everyday life. In this material, many modes of representation can be implemented. The development of this workbook uses the Design Representational Approach Learning to Write (DRALW) development flow developed by (Sinaga et al., 2014).

Method

This research aims to produce teaching materials in the form of workbooks developed using multimodal representations, which can empirically improve students' problem-solving and critical-thinking skills. This Study includes Research and Development (R & D) (Borg & Gall, 2003). This development only reached stage 7, namely the revision of operational products. Figure 1 below presents the R&D research framework used.

At the field trial stage to measure the effectiveness of physics workbooks using multimodal representations developed with worksheets commonly used in schools, the subjects used were 70 class X students at one of the high schools in Bandung City. The subjects were divided into 35 students in the experimental class and 35 students in the control class. The sampling technique is purposive sampling. The research design pattern used is a randomized control group pretest-posttest design (Sugiyono, 2017).

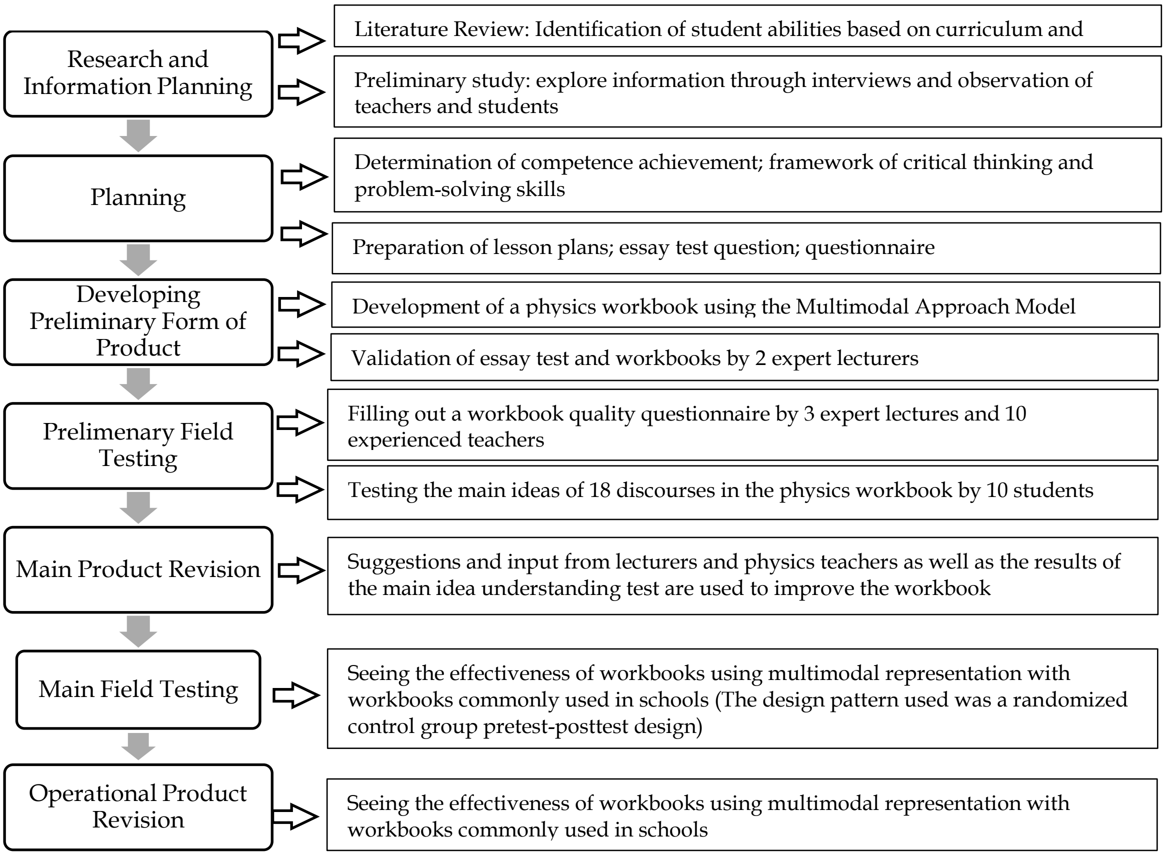


Figure 1. Research Framework

Table 1. Pretest-posttest control group design

Class	Pre-test	Treatment	Post-test
Experiment	O_1, O_2	X_1, Y_1	O_1, O_2
control	O_1, O_2	X_2, Y_1	O_1, O_2

Description:

- O_1 : Provision of problem-solving skills test questions
- O_2 : Giving critical thinking skills test questions
- X_1 : Learning using workbook problem-solving orientation and critical thinking developed using multimodal representations
- X_2 : Learning to use worksheets that are at school
- Y_1 : Project-based learning model with strategic problem solving

Research Instrument

The instruments used to see an overview of the feasibility of the workbook being developed are the workbook quality test instrument and the instrument to test the understanding of the main ideas of the discourse. The workbook quality test uses a questionnaire instrument consisting of 20 assessment aspects divided into three components, namely 1) compatibility between essential competencies and indicators, 2) compatibility between presentation and content writing, and 3) suitability of student activities. Three expert lecturers and ten high school physics teachers with more than five years of teaching experience carried out this quality test instrument. The quality test instrument is a rating scale-type questionnaire with 1-4 answer intervals. The questionnaire answer intervals comprised very inappropriate, inappropriate, appropriate, and very appropriate categories. Then, the instrument for understanding the main ideas of the discourse is used to see the legibility of the developed workbook, which includes writing the main ideas and supporting sentences in the 18 discourses contained in this workbook. Another instrument was developed to get an overview of students' problem-solving skills and improvement of critical thinking skills. The problem-solving skills test instrument consists of 6 essay questions classified by Rosengrant (Rosengrant et al., 2007) with four stages: describing the problem, simplifying the problem, describing the physical form, and solving the problem mathematically. The critical thinking skills test instrument consists of 10 essay questions classified by Ennis (Ennis, 2009): primary classification, basic decision-making, inference, advanced classification, strategy, and tactics.

Analysis Data

Based on the quality test data and comprehension tests on the developed workbooks, then averaged, the feasibility category of the teaching materials can be obtained. The quantitative data obtained in this study were then analyzed descriptively based on the eligibility categories of the textbooks listed in Table 2.

Table 2. Workbook feasibility assessment criteria

Percentage of assessment	Criteria of Legibility
90% < x ≤ 100%	Very feasibly
75% < x ≤ 90%	Feasibly
60% < x ≤ 75%	Feasibly enough
≤ 60%	Less feasibly

Meanwhile, to determine the increase in problem-solving skills and critical thinking skills due to the use of workbooks, it is analyzed using the normalized gain through the equation:

$$\langle g \rangle = \frac{\langle posttes \rangle - \langle pretest \rangle}{100 - \langle pretest \rangle} \quad (1)$$

The average N-gain value obtained is then interpreted into the criteria according to Hake (Richard R. Hake, 1999) in Table 3.

Table 3. Gain Criteria

Value <g>	Criteria
$\langle g \rangle \geq 0{,}7$	high
$0{,}7 > \langle g \rangle \geq 0{,}3$	medium
$\langle g \rangle < 0{,}3$	low

Result and Discussion

Workbook Due Diligence

The assessment of the developed workbook consists of 20 assessment aspects which include compatibility between essential competencies and indicators, compatibility between presentation and content writing, and suitability of student activities. The research results can be seen in Table 4.

Table 4. Data on Workbook Quality Test Results by Lecturers and Teachers

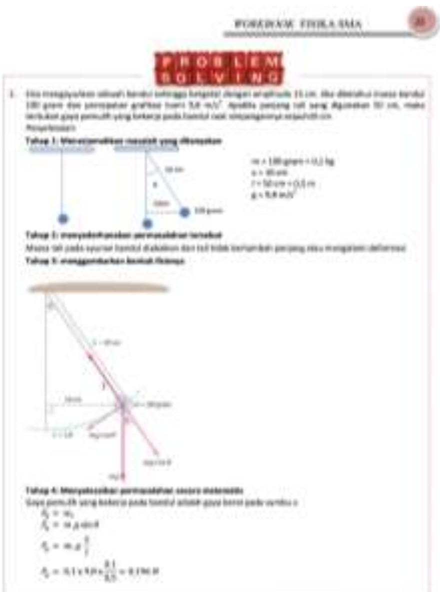
Assessment Aspects	Percentage (%)
Conformity between Basic Competencies with indicators or objectives	78
Conformity of each hand with the activity description and content	78
Compatibility of Basic Competency with breadth and depth of content	83
Accurate content, free from misconceptions	83
The structure and organization of the material are arranged in a logical and coherent manner	83
Each concept is represented by at least two modes of representation, namely verbal and one of the visual modes	85
The presentation style of content and activities is interesting to read	88
The written language used is easy to understand	80
The scientific terms used are well known by the target audience, and the scientific terminology is used appropriately	73
The description of the teaching material is related to the previous knowledge and experience of students	80
Activity description on workbook encourage the development of scientific reasoning	85
Activity description on workbook build conceptual understanding	85
Activity description on workbook enable students to investigate science concepts in depth	83
Activity description on workbook practice aspects of critical thinking skills	80
Activity descriptions in the workbook practice problem solving skills using multimodal representations	85
Learning activities and evaluation according to indicators/objectives	78
Evaluation questions/ practice questions contained in the teaching material are in accordance with the subject matter	75
Example questions on workbook it uses complete, sequential, and systematic problem-solving stages so as to train aspects of problem-solving skills	85
Practice questions or evaluation questions are formulated clearly so as not to confuse students	78
Teaching materials (science textbooks/workbooks) use symbols and International Units consistently.	85

Table 4 shows the percentage of the workbook quality assessment for each assessment aspect. The highest rating on the style aspect of content exposure and activities is interesting to read, reaching 88%. The lowest rating on the element of the scientific terms used is well-known by the target audience, and scientific language is used correctly, getting a percentage of 73%. Thus, in this aspect, it would be even better to use terms easily recognized by the audience. Based on the data in Table 4, the average assessment of the workbook quality reached 81.3% with very suitable criteria. Some aspects that still need to be improved should be improved for better results based on the comments and suggestions given by the validator.

The developed workbook has four activity sections: Experiment, Critical Thinking, Problem-Solving, and Exercise. In experimental Activities found in a workbook, students face real-world problems asked to solve through experiments. Each question in the practical activity directs students to be able to think critically. Critical thinking activities here are in the form of application in life, where students are asked to express ideas/ideas and opinions about the truth of the discourse in the workbook. Address on the application in life can be in the form of applications in technology or natural phenomena.

Furthermore, the activity in Problem Solving is studying physics problems equipped with answers using problem-solving stages. At the same time, Exercise Activities are in the form of tasks completed in problem-solving steps. Table 5 shows snippets of the activities in the developed workbook.

Table 5. A snippet of the display of activities in the workbook

Activity's view	
Activities "Experiments"	Activities "Critical Thinking"
	
Activities "Problem-Solving"	Activities "Exercise"
	

Furthermore, the test data for understanding the discourse's main ideas and supporting sentences are grouped by sub-chapter groups, including spring vibrations, pendulum swings, simple harmonic motion equations (displacement, velocity, acceleration, and energy), and damped harmonic motion. In this workbook, there are 18 discourses. The research results in Table 6.

Table 6. The Results of Understanding Discourse Idea

Sub subject	Percentage (%)
Spring Oscillation	80.0
Spring Oscillation	57.5
Spring Oscillation	77.5
Spring Oscillation	60.0
Spring Oscillation	70.0
Swing pendulum	72.5
Swing pendulum	82.5
Swing pendulum	77.5
Swing pendulum	60.0
Swing pendulum	82.5
Swing pendulum	82.5
Deviation in SHM	60.0
Velocity and acceleration in SHM	60.0
Energy in SHM	80.0
Energy in SHM	80.0
Energy in SHM	82.5
Damped Harmonic Motion	60.0
Damped Harmonic Motion	60.0

Table 6 shows the percentage of understanding the main ideas of the discourse. The highest level of legibility of the main idea is found in discourses 7, 10, 11, and 16 on the subject of pendulum swings and energy in simple harmonic motion. The lowest readability level on spring vibration material in discourse two is 57.5%. Students need to fix sentences or words that are considered difficult by students for discourse two so that students easily understand them. Overall, the average understanding of the main ideas for the 18 discourses reached 71.4% in the high category.

Based on the quantitative data of the quality and workbook readability tests, the feasibility percentage was 76.35% in the feasible category. Suitable teaching materials (one of them a workbook) must meet several requirements, including: (1) the concepts are explained correctly and clearly, (2) the explanation is successive both inductively and deductively, (3) the depth and breadth of content according to the level of development of students, (4) can integrate verbal and visual representations, (4) can encourage readers to want to read more about the information conveyed, and the use of punctuation and sentence structure must comply with grammatical rules (Sinaga et al., 2014).

Data on Student Problem-Solving Skill Results

The data obtained on the pre-test, post-test, and calculations N-gain problem-solving skills of students in the experimental and control classes are presented in Table 7.

Table 7. Student Problem-Solving Ability Test Data

Class	The Number of students	<*Pretest*>	<*Posttest*>	<*g*>	Category
Experiment	35	30.6	59.7	0.42	Medium
Control	35	28.2	47.5	0.27	Low

From Table 7, the average test of students' problem-solving skills in the pre-test for the experimental class was 30.6, and for the control class was 28.2. The initial difference in the experimental class was 2.4, higher than the control class. Then the students are given the test again after learning is complete. The average test score of students' problem-solving skills in the post-test for the experimental class was 59.7, and the control class was 47.5. The difference in post-test results for the experimental class was 12.2, which was higher than the control class. The findings obtained from the calculation results in N-gain for the experimental class of 0.42 and the control class of 0.27. Based on Hake's (Richard R. Hake, 1999) categorization, the results for the experimental class were included in the medium category, and the control class was included in the low category. These findings indicate that the value of problem-solving skills in the experimental class after learning has better results than in the control class.

Furthermore, Statistical tests were conducted to see significant differences in problem-solving skill improvement between students who used workbooks using multimodal representations oriented to problem-solving skills with students using worksheets commonly used in schools. First, the gain normality test was carried out to test the students' problem-solving skills, as shown in Table 8

Table 8. Normality test results gain students' problem-solving skills

Data Source	Class	Sig.*	Decision
Gain	Experiment	0.590	Normal
	Control	0.779	Normal

The Shapiro-Wilk normality test statistical process with SPSS 23 was carried out for problem-solving skills data. Based on Table 8, it can be seen that the significance value of the data gain for the experimental class of 0.590, where this value is greater than the α value (0.590 > 0.05), so it is concluded that the data is normally distributed. For the significance value of the data gain, the control class is 0.779, which is also more significant than the α value (0.779 > 0.05), so it can be concluded that the data is normally distributed. Because both data are normally distributed, the next step is to do a homogeneity test.

The homogeneity test was carried out with the help of IBM SPSS 23 use test Levene. The results of the homogeneity test of students' problem-solving skills tests are presented in Table 9.

Table 9. Homogeneity test results of students' problem-solving skills

Data Source	Sig.	Decision
Gain	0.716	Homogeneous

In Table 9, the significance value of the data gains 0.716 (significance > 0.05), so it can be concluded that the sample comes from homogeneous data. Based on data from normality test results and homogeneity test, hypothesis testing was carried out using parametric statistical tests (t-test) using IBM SPSS 23. The results of hypothesis testing are shown in Table 10.

Table 10. Hypothesis test results gain problem-solving skills

Data Source	Class	Sig.*	Decision
Gain	Experiment Control	0.000	There are significant differences

Based on Table 10, the analysis results to test the data hypothesis N-gain problem-solving skills show a significance of 0.000. The significance value is smaller than the α value (0.000 <0.05), so it is concluded that applying workbook physics using multimodal representation in the learning process can significantly improve students' problem-solving skills compared to worksheets in schools.

Each indicator of problem-solving ability achievement was analyzed based on the pre-test, post-test, and N-gain scores. The ability of each indicator of student problem-solving in the experimental class and control class is shown in Table 11.

Table 11. Data on pre-test, post-test, and N-gain scores for each student's problem-solving indicator

Indicator	Experiment Class					Control Class				
	<*Pretest*>		<*Posttest*>		*N-gain*	<Pretest>		<Posttest>		*N- gain*
	Score	%	Score	%		Score	%	Score	%	
Describe the problem	208	33.0	394	62.5	0.44	196	31.1	307	48.7	0.26
Simplify the problem	143	22.7	340	51.0	0.37	167	25.5	243	38.6	0.16
Describes physical form	193	30.6	392	62.2	0.46	173	27.5	319	50.6	0.32
Solving problems mathematically	227	36.0	419	66.5	0.48	178	28.3	328	52.1	0.33

These results indicate that the use of the use workbook physics developed by the author can further improve students' physics problem-solving skills compared to learning using worksheets that students at school commonly use.

Data on Critical Thinking Skills Results

The data obtained on the pre-test, post-test, and calculations N-gain students' critical thinking skills in the experimental class and the control class are presented in Table 12

Table 12. Student Critical Thinking Ability Test Data

Class	The number of students	<*Pretest*>	<*Posttest*>	<*g*>	Category
Experiment	35	43	73	0.53	Medium
Control	35	40	58	0.30	Low

From Table 12, the average test of students' critical thinking skills pre-test for the experimental class was 43, and for the control class was 40. The initial difference in the experimental class was three higher than the control class. Then the students are tested again after the learning activities have been completed. The average test score of students' critical thinking skills in the post-test for the experimental class was 73, and for the control class was 58. The difference in the post-test results for the experimental class was 15 higher than the control class. The findings obtained from the calculation results N-gain for the experimental class of 0.53 and the control class of 0.30. Based on Hake's (Richard R. Hake, 1999) categorization, the results for the experimental class were in the medium category and the control class in the low category. These findings indicate that the value of critical thinking skills in the experimental class after learning has better results than in the control class. The improvement of each aspect of critical thinking skills in simple harmonic motion material can be seen in Figure 2.

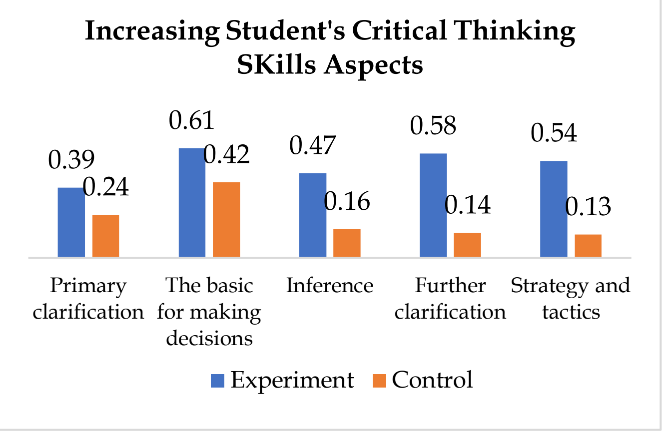


Figure 2. Diagram of Increasing Student's Critical Thinking Skills Aspects

From the diagram in Figure 2, it can be seen that the increase in aspects of primary clarification, the basis for making decisions, inference, further clarification, and strategy and tactics of the experimental class increased higher than that of the control class.

Furthermore, based on the N-gain data, a statistical test was carried out to see the increase in students' critical thinking skills. First, a normality test for the essential gain of thinking skills is performed, which is shown in Table 13.

Table 13. Normality test results gain critical thinking skill

Data Source	Class	Sig.*	Decision
Gain	Experiment	0.540	Normal
	Control	0.071	Normal

Statistical tests were carried out to see the normality of data on students' critical thinking skills using IBM SPSS 23, namely by testing Shapiro-Wilk. Based on Table 13, the significance value of the data gain for the experimental class of 0.540 is greater than the α value (0.540 > 0.05), so it is concluded that the data is normally distributed. For the significance value of the data gain, the control class is 0.071, which is also more significant than the α value (0.071 > 0.05), so it can be concluded that the data is normally distributed. Furthermore, the homogeneity test was carried out with Levene's test. The results of the homogeneity test of students' critical thinking skills tests are presented in Table 14.

Table 14. Homogeneity test results of students' critical thinking skill

Data Source	Sig.	Decision
Gain	0.343	Homogeneous

Table 14 shows the significant value of the data gain of 0.343 (significance > 0.05), which means that the sample comes from homogeneous data. Furthermore, hypothesis testing was carried out with parametric statistical tests (t-test) using the help of IBM SPSS 23. The results of hypothesis testing are shown in Table 15.

Table 15. Hypothesis test results gain critical thinking skills

Data Source	Class	Sig.*	Decision
Gain	Experiment	0.000	There are significant
	Control		differences

Based on Table 15, the analysis results to test the data hypothesis gain critical thinking skills show a significance of 0.000. The significance value is smaller than the α value (0.000 <0.05), so it is concluded that applying workbook physics using multimodal representation in the learning process can significantly improve students' critical thinking skills compared to worksheets in schools. In the *workbook* using skill-oriented multimodal representations, these critical thinking skills consist of practical instructional discourse (experimental activities), learning guiding discourse, and application discourse in life. Discourse on practicum instructions is made by considering the use of mode in its presentation. As a result, students better understand the practical instructions presented.

In addition, in application discourse in everyday life, students are trained to think critically to answer questions according to the problems presented. As a result, it is easier for students to understand the various phenomena presented in the application discourse. The use of multimodal in this discourse helps students to make it easier to understand the discourse to get a complete concept. A piece of information can only be interpreted in a context if complemented by other information, where an image must be associated with a verbal mode and vice versa (AM & Istiyono, 2022). Learning does not only prioritize the content of scientific facts and ideas through writing but can also be expressed in multimodal representations in the form of visuals and text (Yeşildağ Hasançevi & Günel, 2013). This multimodal approach stimulates critical thinking and accommodates multilingual expression and understanding. The use of various representations will enrich the learning experience of students. According to Treagust (Treagust & Duit, 2017), representation does not have to be tied to changing from one form to another in one way; it can be two ways or even multi-way.

In the workbook's practicum activities, students face Real World problems asked to solve through experiments. Each question in the practicum activity directs students to be able to express or analyze ideas/ideas in expressing their opinions to get solutions to specific answers with an analysis of evidence from the experiments carried out. This is in line with the statement by Wei (Wei et al., 2022) about critical thinking skills, namely analyzing ideas or ideas in a more specific direction, distinguishing sharply, selecting, identifying, studying, and directing them towards a more perfect one with multimodal representation. After reading the real-world problem-solving presented, students must answer the guiding questions to get specific conclusions. Following Saiful's opinion (Prayogi et al., 2018), one of the best approaches to developing critical thinking skills is to ask questions while guiding students to relate their thoughts to concepts they have previously possessed.

On application activities in life found in the workbook, students are also asked to express ideas/ideas and opinions about the truth of the discourse in the workbook. Discourse on the application in life can be in the form of applications in technology or natural phenomena. Critical thinking can reflect on the impact of technological developments, objectively weigh various values, and develop or choose the right solution (Al-Hashim, 2019) the demands of the material needed to give each case. Students read the application discourse presented, then asked for students' opinions about the level of trust in the advertisement given if the discourse is in the form of advertisements, asking students to analyze arguments from the discourse, hypothesize, or apply strategies and tactics, etc. Each question given directs students to think critically so that students understand the subject matter provided. Critical thinking skills are essential in helping students learn the subject matter (Pierce et al., 2013).

Conclusion

Based on the findings and discussion, the developed workbook is suitable for use in schools as teaching material for learning physics. This workbook is very good at training students' problem-solving and critical-thinking skills. Using workbooks also allows students to study independently, discuss with friends and understand the material clearly. To optimize the use of this workbook, it is suggested that researchers pay more attention to terms that students need to become more familiar with. For teachers who want to use this physics workbook, it is advisable to study it first, considering that no teacher's book is available in the results of this development. In addition, this physics workbook can be followed up by transmitting creativity in its development as one of the teaching materials through groups of physics teachers such as MGMP at the school, district, and even provincial levels. In the future, workbooks using this multimodal representation can be developed further based on student learning styles.

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Author Contribution

Metta Liana: Conceptualization, methodology, writing—original draft preparation, formal analysis, investigation, and visualization. Parlindungan Sinaga: supervision, validation, resources. Emiliannur: writing review, editing.

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The authors declare no conflict of interest regarding the publication of this paper.

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