# IBMR-based physics e-book: Enhancing multi-representation and problem-solving ability

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**Abstract**
Problem-solving and multi-representation abilities are essential competencies for 21st-century students, especially in physics. The use of teaching materials based on effective learning models and technology can enhance these abilities. This study aims to: develop an IBMR-based physics e-book (Investigation Based Multiple Representation) that is deemed feasible by experts, and evaluate its effectiveness in improving students' problem-solving and multi-representation abilities. This study employs the ADDIE development model, which includes analysis, design, development, implementation, and evaluation. A total of 48 students from a state Islamic senior high school (MAN) in Yogyakarta were randomly selected as research subjects. Data collection instruments included validation sheets, questionnaires, and tests for multi-representation and problem-solving abilities. Feasibility analysis was conducted descriptively, practicality and student response tests used ideal standard deviation, test instrument validation used Aiken's V equation and item analysis using Item Response Theory (IRT), and effectiveness testing used MANOVA. The results showed that the IBMR-based physics e-book is feasible for use in physics learning, with validator assessments in the "Feasible" category and student responses in the "Very Good" category. Although it was not effective in improving multi-representation abilities, this e-book significantly enhanced problem-solving abilities, particularly in the evaluation aspect and the indicator of converting verbal representations to pictorial forms

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## 1. Introduction

The rapid development of information and communication technology in the 21st century demands changes in various aspects of life, including education (Rahmatullah et al., 2022). Education is required to facilitate and ensure that students can learn and innovate, be proficient in the use of technology and information, and possess the skills to live in the 21st century (Akour & Alenezi, 2022; Iivari et al., 2020; Qureshi et al., 2021). These skills include creativity, collaboration, communication, critical thinking, problem-solving, digital literacy, and citizenship (Voogt & Roblin, 2012).

Problem-solving ability are one of the fundamental abilities that students must possess to face increasingly complex challenges (Gunawan et al., 2020; Susanti et al., 2021). According to the 2022 Programme for International Student Assessment (PISA), Indonesia ranks among the bottom 12 countries in ASEAN (OECD, 2023). PISA assesses the extent to which students can apply their knowledge to solve problems, rather than merely testing their mastery of mathematics and science content (Novita et al., 2012). These results indicate that Indonesian students' problem-solving abilities, particularly in science, remain low (Hasibuan et al., 2019; Santika et al., 2020). Previous research findings reveal that students' physics problem-solving ability are categorized as low, with an average score of 1.31 (Prahani et al., 2021). Another study shows that 92% of students have low problem-solving abilities, with scores ranging from 0 to 50 (Rachmawati et al., 2022).

Problem-solving skills can be enhanced through physics education. This aligns with one of the main objectives of physics education at the high school level. Physics education aims to develop reasoning and analytical thinking skills, explain various natural phenomena using physics concepts and principles, and solve everyday problems(Badan Standar Nasional Pendidikan, 2014). However, research indicates that students' problem-solving skills in physics are still low, with an average score of 1.31 in the low category (Prahani et al., 2021).

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Additionally, multi-representation skills are crucial in physics as they support problem-solving (Ubaidillah, 2019). These skills help students better understand concepts and theories and enhance critical thinking through various forms of representation such as words, images, diagrams, and mathematical equations (Hidayah et al., 2022; Ningrum et al., 2015). However, research shows that students' multi-representation skills are also low, with an average percentage of 40-45% in each mode of representation (verbal, image, graphic, and mathematical) (Am & Istiyono, 2022).

Newton's laws, which are fundamental in physics, involve many physics concepts and the use of vector principles and force diagrams (Eriyanti & Rosiningtias, 2023). Difficulties in describing phenomena, connecting them to concepts, and applying them in various real-life cases pose challenges for students (Fadlli et al., 2019). Research indicates that in Newton's laws, students' multi-representation and problem-solving skills are still low. Students' representation skills are below 50% for all modes of representation, with graphic representation being the lowest at 18%(Furqon & Muslim, 2019). Additionally, 67% of students still experience difficulties in problem-solving (Ronita & Putra, 2024).

The low problem-solving and multi-representation skills of students can be attributed to various factors, such as students' interest, material characteristics, learning activities, and teaching strategies chosen by teachers(Hijriani & Amiruddin, 2021; Sari et al., 2020). Teacher-centered teaching strategies that emphasize quantitative aspects often hinder students' ability to use multi-representation (Murshed et al., 2021). The lack of understanding of physics concepts and the insufficient facilitation of multi-representation and problem-solving teaching also contribute to this issue (Faradila et al., 2022; Pebriana et al., 2022). Students tend to memorize solutions rather than understand them and more frequently use mathematical representations compared to image and verbal representations in solving problems(Harra Hau et al., 2020; Tenzin, 2019). Multi-representation and problem-solving skills can be improved through appropriate learning models. One such model is the Investigation Based Multiple Representation (IBMR), developed by (Siswanto, 2019). The IBMR learning model is designed to enhance students' representation and problem-solving skills in physics with a student-centered approach supported by constructivist learning theory, where students build their own knowledge (Dibyasakti et al., 2013). The IBMR model consists of five phases: orientation, investigation, multi-representation, application, and evaluation. Through this model, students are trained to solve problems by stimulating higher-order thinking processes such as analysis and reasoning, and using various representations (Setyarini et al., 2021).

In addition to learning models, teaching materials also play a crucial role in the success of learning (Safitri et al., 2022). Teaching materials integrated with technology, such as e-books, can help improve students' multi-representation and problem-solving skills (Hammond & Flook, 2020). Multimedia features in e-books, such as images, videos, and simulations, facilitate students' understanding of physics concepts and support problem-solving through examples and practice questions (Cheng et al., 2019).

The combination of quality teaching materials and appropriate learning models can enhance students' understanding, motivation, and skills in learning (Masrifah et al., 2018). The use of e-books combined with the IBMR model has the potential to improve students' multi-representation and problem-solving skills. Learning will be more directed and structured if the developed e-book refers to the appropriate teaching methods or models(Ndoa & Jumadi, 2022). Previous research by (Jatmiko et al., 2024) and (Liputo & Purwaningsih, 2022) showed positive results in the use of the IBMR model and digital books. Therefore, further studies are needed on the development of IBMR-based physics e-books to improve students' multi-representation and problem-solving skills.

## 2. Method

This research is a development study (R&D), adopting the ADDIE model with five stages: analyze, design, develop, implement, and evaluate (Branch, 2009). The stages and processes in the research are illustrated in Figure 1.

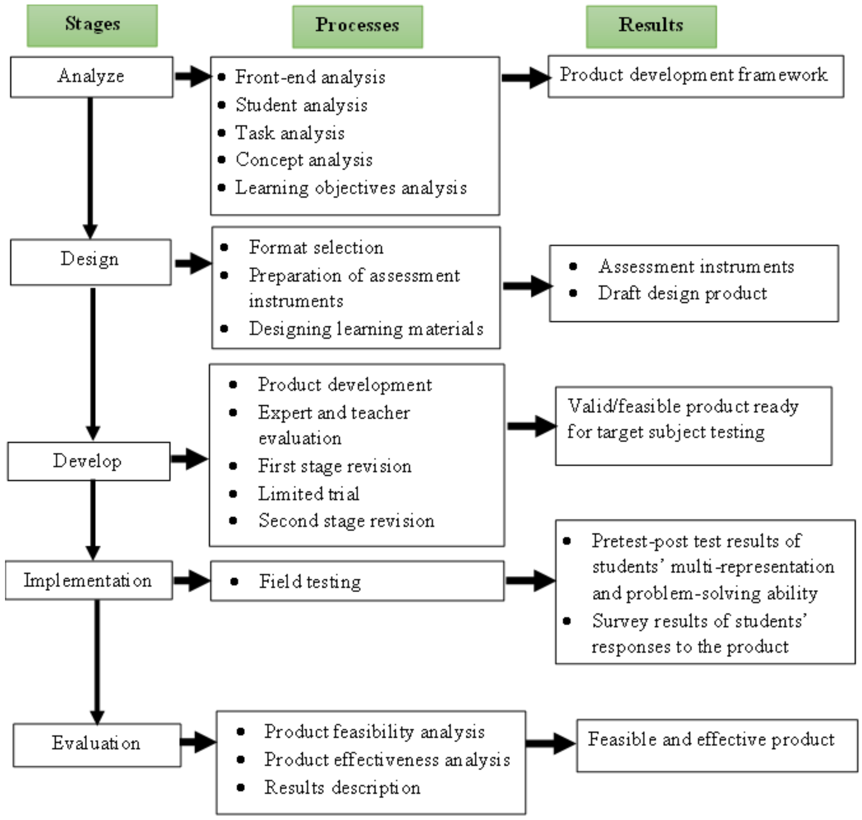


**Figure 1.The stages and processes in the research**

This study was conducted at a Madrasah Aliah Negeri (MAN) in Yogyakarta. Two physics experts were involved to assess the feasibility of the developed product, while two physics teachers from the target school evaluated its practicality. The readability test of the product was conducted with 30 eleventh-grade MAN students, while the test instrument trial involved 250 eleventh-grade students from public high schools and Madrasah Aliah Negeri in the Yogyakarta area. The effectiveness test of the product involved 48 tenth-grade MAN students, divided into two groups: the experimental class (X-C) and the control class (X-D). Each stage of this research was designed to ensure that the developed product is not only feasible and practical but also effective.

This study used two types of data collection instruments, tests and non-tests. The non-test instruments included expert assessment questionnaires, teacher response questionnaires, and student response questionnaires. The test instruments consisted of problem-solving ability tests and multi-representation ability tests. The expert assessment instrument used a Guttman scale with two answer categories: "yes" if the criteria for each component appeared in the assessed physics e-book or "no" if the criteria did not appear for each assessed product component, where a score of 1 was given if the assessor answered "yes" and a score of 0 if the answer was "no". The teacher and student response questionnaires used a Likert scale with four answer categories: very poor (1), poor (2), good (3), and very good (4). The data obtained included quantitative data (scores) and qualitative data (comments and suggestions). The effectiveness of the developed product was tested through field trials on the actual target using essay-type tests consisting of 8 items to measure students' multi-representation and problem-solving abilities before and after the treatment. The trial design used a quasi-experimental method with a post-test pre-test non-equivalent control group design, as shown in the following Table 1.

**Table 1. Quasi-experimental design with posttest-pretest nonequivalent control group design.**

| Kelas | Pretest | Perlakuan | Posttest |
|---|---|---|---|
| Kelas Eksperimen | 01 | X | 02 |
| Kelas Kontrol | 03 | - | 04 |

The experimental class received treatment in the form of learning using an IBMR-based physics e-book with the IBMR model (X), while the control class used the Physics curriculum package book with conventional teaching methods such as lectures, discussions, and exercises (-). Before the treatment, both groups were given a pretest (O1 for the experimental class and O3 for the control class) to measure students' initial abilities. After the treatment, both groups were given a post-test (O2 for the experimental class and O4 for the control class) to measure changes in students' abilities after the treatment.

The data in this study were analyzed using descriptive and inferential statistics. Statistical software was used to calculate the mean, standard deviation, and percentage, which describe the results of expert assessments, teacher responses, and student responses. Descriptive analysis categorized the average score results based on predetermined intervals Table 2 and Table 3.

**Table 2. The feasibility score intervals**

| Score Interval | Percentage | Category |
|---|---|---|
| $(S_{min} + P) \leq S \leq S_{max}$ | 50%-100% | Feasible |
| $S_{min} \leq S \leq (S_{min} + P - 1)$ | 0% | Not Feasible |

(Widihastuti, 2007)

S represents the respondent's score, $S_{min}$ is the lowest score, $S_{max}$ is the highest score, $P$ is the interval class length

**Table 3. The score intervals for teacher and student responses**

| Respondent Score | Practicality Category | Readability Category |
|---|---|---|
| $X \geq \bar{X}_i + 1{,}0\ SB_i$ | Very Practical | Very Good |
| $\bar{X}_i < X \leq \bar{X}_i + 1{,}0\ SB_i$ | Practical | Good |
| $\bar{X}_i - 1{,}0\ SB_i < X \leq \bar{X}_i$ | Not Practical | Not Good |
| $X \leq \bar{X}_i - 1{,}0\ SB_i$ | Very Not Practical | Very Poor |

(Mardapi, 2012)

$X$ represents the average score, $\bar{X}_i$ is the ideal average...., $SB_i$ is the ideal standard deviation.

The theoretical validity of the test instrument was assessed using Aiken's V based on expert judgment. The empirical validity and reliability of the multi-representation and problem-solving ability test instruments were analyzed using the QUEST program. An item is considered valid if the INFIT Mean of Square (INFIT MNSQ) value is within the range of 0.77-1.33 and the outfit t value is ≤ 2. Item reliability is assessed from the reliability of item estimate, reliability of case estimate, and internal consistency with the following reliability categories: >0.80 (very reliable), 0.60-0.80 (reliable), 0.40-0.60 (fairly reliable), 0.20-0.40 (somewhat reliable), <0.20 (less reliable) (Arikunto, 2009). The analysis results showed that the test instruments used were valid and fairly reliable.

The effectiveness of the test in evaluating multi-representation and problem-solving abilities was analyzed using a 5-point scoring rubric for each correct answer. MANOVA analysis (significance 0.05) was used to determine the effect of the treatment on the improvement of abilities. Effect size was calculated to show the effective contribution of the IBMR-based e-book in enhancing these abilities, with partial eta square (Wilks' lambda) categories as follows: 0.00–0.10 (small), 0.11–0.25 (medium), 0.26–0.40 (large) (Cohen et al., 2000).

The achievement of each ability indicator was analyzed using descriptive statistics, including the mean, standard deviation, and percentage of student scores categorized according to the criteria in Table 4.

**Table 4. The score intervals for students' multi-representation and problem-solving abilities.**

| No | Score Interval | Category |
|---|---|---|
| 1 | $M_i + 1{,}5SB_i < \theta$ | Very Good |
| 2 | $M_i + 0{,}5SB_i < \theta \leq M_i + 1{,}5SB_i$ | Good |
| 3 | $M_i - 0{,}5SB_i < \theta \leq M_i + 0{,}5SB_i$ | Fair |
| 4 | $M_i - 1{,}5SB_i < \theta \leq M_i - 0{,}5SB_i$ | Very Poor |
| 5 | $\theta > M_i - 1{,}5SB_i$ | Very Good |

(Azwar, 2022).

# 3. Results and Discussion

## 3.1. Analiysis Result

The front-end analysis was conducted through literature review, observation, and interviews at the target school. The results indicated that the physics learning process in the classroom still uses conventional methods such as lectures and discussions. Teaching materials commonly used by teachers, such as self-made material summaries, have not integrated technology like E-books. It was found that the use of smartphones is allowed in learning, although sometimes it becomes a hindrance, it also provides benefits such as quick access to educational resources. The main obstacles in learning physics are low conceptual understanding and low learning interest. Based on these results, the development of more innovative and technology-utilizing teaching materials, such as IBMR-based physics E-books, is highly necessary.

The main subject in this study is Newton's laws, which include the concepts of force, mass, and acceleration. These concepts are interrelated and form the basis of Newton's laws. This material was chosen because it is one of the fundamental topics in physics that is widely applied in daily life. Interviews with teachers revealed that students still find it difficult to understand this material. It was found that MAN uses the Merdeka Curriculum, but there are challenges in its implementation. One challenge is the difference in understanding and applying the curriculum by teachers, such as teaching Newton's laws in class X, which should be taught in class XI, so the learning outcomes follow the physics learning outcomes of class XI (phase F). Subsequently, learning objectives were formulated in accordance with the expected learning outcomes and competency indicators in this study, namely multi-representation ability and problem-solving ability.

## 3.2. Design Result

The design phase resulted in a draft design of the IBMR-based physics E-book, which includes selecting the format, creating grids and product designs, and preparing the learning implementation plan (Teaching Module). The IBMR-based Physics E-book covers Newton's Laws (Newton's First, Second, and Third Laws). The material was developed with attention to problem-solving and multi-representation ability indicators. The presentation format of this E-book is adapted to the IBMR learning model, which consists of five phases: orientation, investigation, multi-representation, application, and evaluation. The components of the E-book include the cover, title page, table of contents, preface, usage instructions, book content presentation, IBMR-based physics learning, IBMR model syntax, prerequisite understanding, Learning Objectives Flow or ATP and keywords, concept maps, learning, summaries, remedial and enrichment, learning reflection, bibliography, glossary, and developer profile. The teaching module is prepared according to the Merdeka Curriculum format, and the learning steps are adjusted to the IBMR model phases. Subsequently, assessment instruments were prepared, including the feasibility and effectiveness assessment of the IBMR-based E-book in improving problem-solving and multi-representation abilities. These instruments include draft grids and product feasibility assessment sheets validated by experts, as well as responses from teachers and students. The test used is an essay question consisting of pretest and post-test to measure students' understanding more accurately.

## 3.3. Development Result

The product developed is an IBMR-based physics E-book with Newton's Laws material. After the design phase, the draft design was developed into a product draft. The IBMR-based physics E-book was created in a flipbook format with HTML, so it can be accessed online on the Heyzine platform using devices such as smartphones, laptops, and computers through provided links/barcodes. Additionally, the IBMR-based physics E-book was also developed by adding Google Drive links to facilitate communication between teachers and students, allowing students to submit various assignments and teachers to provide feedback. The e-book enables students to interact directly with the material being studied, supplemented with various related cases to enhance problem-solving ability. The visual content like images and videos presented in the e-book helps clarify the material and supports students in improving their multi-representation ability. This makes learning more engaging and helps students easily understand concepts.

The material presentation is structured based on the IBMR model syntax. In the orientation phase, learning objectives and physics phenomena are presented in video form (Figure 2).

Figure 2. Orientation Phase Display

In the investigation phase, guidelines for investigative activities, both direct and virtual experiments as shown in Figure 3. The investigation phase also includes the presentation of materials with various representations (images, text, mathematical equations) are provided, along with videos to facilitate concept understanding (Figure 4).

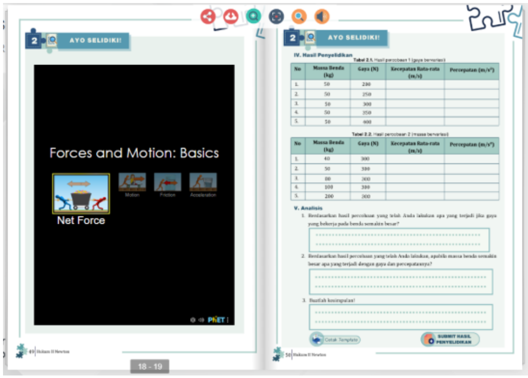

Figure 3. Investigation Phase Display, presenting experimental guidelines

Figure 4. Material Presentation Display

In the Multiple representation phase, worksheets are provided to guide students in creating various representation modes of the concepts studied and the results of the investigations conducted (Figure 5). This phase emphasizes enhancing multiple representation ability by giving students ample opportunities to build and use representations.

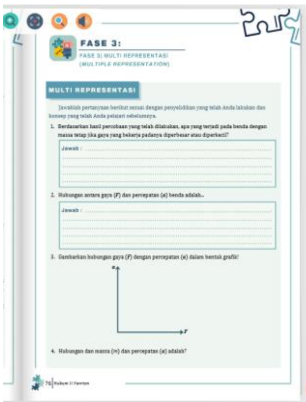

Figure 5. Multi-Representation Phase Display

The application and evaluation phase shown in Figure 6 and Figure 7. The application phase presents various problem-solving questions in different representations. This phase focuses on improving physics problem-solving skills through the application of the created multi-representations. Finally, the evaluation phase provides answer keys to check students' work.


**Figure 6. Application Phase Display**


**Figure 7. Evaluation Phase Display**

The lesson plan and product draft created must undergo validation by experts in terms of content and construction. The content aspect is reviewed for its alignment with the material and concepts as well as the expected learning outcomes, ensuring the e-book content is scientifically accurate and relevant to the learning objectives. The construction aspect of the IBMR-based physics e-book is assessed based on the conformity of the e-book components with the previously designed layout. The results of expert validation are shown in Table 5 and Table 6.

**Table 5. The validation results of the lesson plan components**

| components of a lesson plan | Total Score | | S | Category |
|---|---|---|---|---|
| | Expert 1 | Expert 2 | | |
| General Information | 12 | 12 | 12 | Feasible |
| Core Components | 6 | 6 | 6 | Feasible |
| Attachments | 4 | 4 | 4 | Feasible |
| Average | | | 22 | Feasible |

**Table 6. The validation results of the IBMR-based physics e-book components.**

| Physics E-Book Component Based (IBMR) | Total Score | | S | Category |
|---|---|---|---|---|
| | Expert 1 | Expert 2 | | |
| Cover | 5 | 5 | 5 | Feasible |
| Title Page | 4 | 4 | 4 | Feasible |
| Table of Contents | 1 | 1 | 1 | Feasible |
| Preface | 1 | 1 | 1 | Feasible |
| Usage Instructions | 2 | 2 | 2 | Feasible |
| Book Content Presentation | 1 | 1 | 1 | Feasible |
| Material: IBMR-Based Physics Learning | 1 | 1 | 1 | Feasible |
| IBMR Model Syntax | 1 | 1 | 1 | Feasible |
| Prerequisite Understanding | 1 | 1 | 1 | Feasible |
| Learning Objectives Flow or ATP and Keywords | 2 | 2 | 2 | Feasible |
| Concept Map | 1 | 1 | 1 | Feasible |
| Learning | 10 | 10 | 10 | Feasible |
| Material Summary | 1 | 1 | 1 | Feasible |
| Remedial and Enrichment | 1 | 1 | 1 | Feasible |
| Learning Reflection | 1 | 1 | 1 | Feasible |
| Bibliography | 1 | 1 | 1 | Feasible |
| Glossary | 1 | 1 | 1 | Feasible |
| Author Profile | 1 | 1 | 1 | Feasible |
| Average | | | 36 | Feasible |

Based on the expert validation data calculations for the IBMR-based teaching module Table 6, all components of the teaching module received a "Feasible" category with an average score of 22 (100%). The expert validation data calculations for the IBMR-based physics e-*book*. Table 6**.** *showed* that all components of the e-book received an average score of 36 (100%) with a "Feasible" category. It is concluded that both the teaching module and the IBMR-based e-book are feasible for use in the learning process. Subsequently, an analysis of the practicality assessment by teachers was conducted, and the results are presented in Table 7.

**Table 7. The results of teacher responses**

| Aspect | Score | | x̅ | Category |
|---|---|---|---|---|
| | Teacher 1 | Teacher 2 | | |
| Ease of Use | 4,00 | 4,00 | 100 | Very Practical |
| Usefulness | 4,00 | 4,00 | 100 | Very Practical |
| Presentation | 4,00 | 4,00 | 100 | Very Practical |
| Average | 4,00 | 4,00 | 100 | Very Practical |

The practicality assessment by teachers Table 8. indicated that the IBMR-based physics e-book in terms of depth, ease of presentation, and usefulness received an average score of 100 with a "Very Practical" category. After the product was deemed feasible by experts, a limited readability test was conducted on 30 students of class XI MAN. The results of the readability test (Table 8) are shown in Table 8.

**Table 8. The results of student responses in the limited test**

| Aspect | $\bar{x}$ | Category |
|---|---|---|
| Perceived Ease of Use | 49,57 | Very Good |
| Attractiveness | 51,01 | Very Good |
| Usefulness | 49,34 | Very Good |
| Satisfaction | 48,43 | Very Good |
| Presentation | 81,89 | Very Good |
| Content | 56,60 | Very Good |
| Language | 50,48 | Very Good |
| Attitude | 63,44 | Very Good |
| Average | 56,35 | Very Good |

Table 8. shows that the average score for all assessment aspects was 56.35% with a "Very Good" category. The development phase results in a feasible product draft ready for implementation in the actual target.

## 3.4. Implementation Results

Field testing was conducted to implement the IBMR-based physics e-book in two class X MAN groups: an experimental class with 22 students (X-C) and a control class with 26 students (X-D). The trial lasted for three sessions. The average pretest and posttest scores for multi-representation and problem-solving abilities in both classes are shown in Table 9.

**Table 9. Pretest-Posttest Results**

| Descriptive Statistics | | | | |
|---|---|---|---|---|
| | Experiment | | Control | |
| | Pretest | Post-test | Pretest | Post-test |
| Multi Representation Ability | 41.59 | 45.68 | 17.88 | 40.58 |
| Problem Solvinng Ability | 18.18 | 33.18 | 20.96 | 24.04 |
| | N= 22 | | N=26 | |

Additionally, student feedback on the IBMR-based physics e-book was collected through questionnaires at the end of the learning sessions. The results are shown in Table 10, indicating positive responses with an average score of 47.46 for all aspects, categorized as "very good."

**Table 10. Student Response Results**

| Aspect | $\bar{x}$ | Category |
|---|---|---|
| Perceived Ease of Use | 45,47 | Good |
| Attractiveness | 39,90 | Very Good |
| Usefulness | 37,30 | Very Good |
| Satisfaction | 40,10 | Very Good |
| Presentation | 70,67 | Good |
| Content | 45,92 | Very Good |
| Language | 43,67 | Very Good |
| Attitude | 58,29 | Good |
| Average | 47,67 | Very Good |

Effectiveness testing was conducted. Before performing the MANOVA test, prerequisite tests for normality using the Shapiro-Wilk test and homogeneity using Levene's test and Box's M test were conducted to ensure the collected data met the requirements for further testing. The results of the prerequisite tests can be seen in Table 11. Normality Test Results, Table 12. Homogeneity Test Results, Table 13. Box's M Homogeneity Test Results.

**Table 11. Normality Test Results**

| Tests of Normality | | | |
|---|---|---|---|
| | Group | Shapiro-Wilk Statistic | Sig. |
| Pre-Multi representation Ability | Experiment | .931 | .127 |
| | Control | .937 | .115 |
| Post-Multi representation Ability | Experiment | .953 | .361 |
| | Control | .970 | .624 |
| Pre-problem solving Ability | Experiment | .937 | .170 |
| | Control | .938 | .120 |
| Post-Problem-Solving Ability | Experiment | .943 | .228 |
| | Control | .942 | .151 |

**Table 12. Homogeneity Test Results**

| Test of Homogeneity of Variance | | |
|---|---|---|
| | Levene Statistic | Sig. |
| Pre-Multi representation Ability | .028 | .868 |
| Post-Multi representation Ability | .200 | .657 |
| Pre-problem solving Ability | 1.553 | .219 |
| Post-Problem-Solving Ability | .088 | .768 |

**Table 13. Box's M Homogeneity Test Results**

| Box's Test of Equality of Covariance Matricesa | |
|---|---|
| Box's M | 16.312 |
| Sig. | .141 |

The prerequisite test results showed that the significance value (Sig.) for all data in the Shapiro-Wilk test was > 0.05, indicating that the data for problem-solving and multi-representation abilities were normally distributed. The homogeneity test showed that the significance value (Sig.) for all data on problem-solving and multi-representation abilities was > 0.05, and the output of Box's Test of Equality of Covariance Matrices showed a significance value (Sig. 2-tailed) of 0.141 > 0.05, indicating that the data for problem-solving and multi-representation abilities in the experimental and control classes were homogeneous. Table 14. Show MANOVA Test Results.

**Table 14. MANOVA Test Results**

| Variables | Group | Sig. | Partial Eta Squared |
|---|---|---|---|
| Multi Representation Ability | Experiment | 0,238 | .030 |
| | Control | 0,000 | .531 |
| Problem Solving Ability | Experiment | 0,001 | .201 |
| | Control | 0,452 | .012 |

The results of the multivariate testing showed that partial eta square (Wilks' lambda) was used to review the contribution of treatment effectiveness to the improvement of abilities, determining the effective contribution of the IBMR-based physics e-book in enhancing students' multi-representation and problem-solving abilities. In the experimental class, the multi-representation ability showed a significance value > 0.005, thus H0 was accepted with an eta square value of 0.030 (30%). In contrast, in the control class, the significance value was < 0.005, thus H0 was rejected with an eta square value of 0.531 (53.1%). This indicates that the treatment in the control class was more significant in improving multi-representation ability compared to the experimental class, with the effectiveness percentage in the control class categorized as "high" and in the experimental class categorized as "low." For problem-solving ability, in the experimental class, the significance value was < 0.005, thus H0 was rejected with an eta square value of 0.201 (20%). In the control class, the significance value was > 0.005, thus H0 was accepted with an eta square value of 0.012 (12%). This means that the treatment in the experimental class was more significant in improving problem-solving ability compared to the control class, with the effectiveness percentage in the experimental class categorized as "medium" and in the control class categorized as "low."

Table 15. shows the level of students' abilities in multi-representation and problem-solving for each indicator. The multi-representation ability of students in the experimental class was superior in three out of four measured indicators. Meanwhile, the problem-solving ability of the experimental class was superior in all measured indicators. Table 15.

**Table 15. Achievement Results of Students' Multi-Representation Abilities**

| Variabels | Indicator | Group | % | Category |
|---|---|---|---|---|
| Multiple Representation | Converting pictorial representations to verbal | Experiment | 58% | Fair |
| | | Control | 54% | Fair |
| | Converting verbal representations to pictorial | Experiment | 63% | Good |
| | | Control | 55% | Fair |
| | Converting verbal representations to graphical | Experiment | 51% | Fair |
| | | Control | 47% | Fair |
| | Converting pictorial representations to mathematical | Experiment | 16% | Very Poor |
| | | Control | 32% | Poor |
| Problem Solving | Identifying problems | Experiment | 61% | Good |
| | | Control | 59% | Good |
| | Determining strategies | Experiment | 43% | Fair |
| | | Control | 37% | Poor |
| | Solving problems | Experiment | 59% | Good |
| | | Control | 19% | Very Poor |
| | Checking and evaluating | Experiment | 76% | Very Good |
| | | Control | 45% | Fair |

## 3.5. Evaluation Results

The evaluation phase provides information regarding the feasibility, practicality, and effectiveness of the IBMR-based physics e-book in enhancing students' problem-solving and multi-representation abilities. Feasibility was assessed through expert validation and student responses, practicality through teacher responses, and effectiveness through pre-test post-test analysis. The results showed a significant improvement in students' abilities after using this e-book. The evaluation also reviewed the research objectives that were not achieved as a basis for future research.

The development of the IBMR-based physics e-book (Investigation, Multi-Representation, and Application) has resulted in a product that is feasible and practical to use. In terms of effectiveness, this e-book is more effective in enhancing students' problem-solving abilities compared to their multi-representation abilities. The IBMR model has proven to help students better understand and solve physics problems.

The improvement in students' multi-representation abilities was not significant, possibly due to the lack of habit in using various representations in physics learning (Arzak & Prahani, 2023). Learning with the IBMR-based e-book involves students through the phases of investigation, multi-representation, and application, each providing experimental guidelines, worksheets, and case examples. The use of various representations in physics learning poses its own challenges. Students need to learn the format and operators of representations, find relationships between representations and the concepts they represent, and learn the relationships between various representations (Ainsworth, 1999). Errors in translating one representation to another may occur (Adu Gyamfi et al., 2012). These findings indicate that students' success in problem-solving does not solely depend on multi-representation abilities. Other factors such as students' initial abilities and mathematical skills also play important and more dominant roles in solving problems (Faradila et al., 2022; Gagatsis & Shiakalli, 2004; Ince, 2018; Pebriana et al., 2022).

However, the ability to convert verbal representations to mathematical in the experimental class obtained the lowest average score (16%). Students still struggle to present concepts in symbolic form, possibly because they are not yet able to choose the appropriate concepts to present mathematical equations(Delice & Sevimli, 2010; Theasy et al., 2018). Overall, the IBMR-based e-book has a positive impact on improving students' multi-representation abilities. This e-book helps students better understand the material and provides practice through the provided worksheets.

The use of the IBMR-based Physics E-book for each problem-solving ability indicator in the experimental class showed that the highest average score was obtained for the problem evaluation indicator (76%), while the lowest average score was for the strategy determination indicator (43%). This research result is consistent with the findings of (Rachmawati et al., 2022) which showed that the strategy determination step obtained the lowest results. Students need to write in detail the problem-solving strategies used (Mustajab et al., 2020), The development of this e-book has significant implications for physics education, helping teachers deliver material and facilitate learning, and encouraging students to become more active and independent learners.

## 4. Conclusion

The conclusion of this study indicates that the IBMR-based Physics E-book (Investigation Based Multiple Representation) is feasible for use in learning. Based on the expert assessment data analysis, this product received a "feasible" category with an "Excellent Agreement" level of expert consensus. Additionally, student responses in the field test were very positive, categorized as "Very Good." The MANOVA analysis results indicate that this E-book is effective in enhancing students' problem-solving abilities, with an effectiveness contribution of 50.1%, particularly in the "checking and evaluating" indicator. However, the E-book is less effective in improving students' multi-representation abilities, with an effectiveness contribution of 17.5%, although the highest improvement occurred in the ability to "convert verbal representations to pictorial forms."

Further research development can be conducted on a broader scale compared to this study. Broader development can be achieved in terms of the material used while still considering the basic competencies for students, the scope of the research area, and a wider class coverage. Additionally, deeper research development can be carried out by exploring variables that have not been investigated in this study but are relevant to the learning design using the Investigation Based Multiple Representation (IBMR) learning model.

## Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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