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MIB-Inquiry-Infographic Android Application and Its Impact on Students' Critical Thinking Skills during the COVID-19 Pandemic

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Abstract: Momentum-impulse requires critical thinking skills, and teaching should be encouraging for students. Critical thinking skills can be fostered through inquiry-based learning. During the COVID-19 pandemic, familiar learning media were used for students. Therefore, it is necessary to develop creative learning media. This developmental research aimed to create a momentum-impulse e-book based on inquiry supported by infographics (MIB -In-graph) to enhance students' critical thinking skills. The developmental model was a 4D model with field testing, i.e., a pretest-posttest control group design with three classes. Descriptive analysis showed that MIB-In-graph, an Android application, received a good average rating in content, worksheets, and forms. Students' responses were very positive. Mixed design ANOVA showed that the mean score of students' critical thinking skills increased significantly from the pretest to the posttest in each class and students' critical thinking skills in the experimental class was more salient than control class 1 and control class 2. The highest difference in mean scores was in the experimental class. The differences were influenced by various factors such as learning approaches, media use, pictures, and collaboration.

Keywords: *Critical thinking skill, infographic, inquiry, momentum-impulse e-book.*

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Introduction

Momentum impulse is a subtopic of mechanics and a fundamental concept in physics (Denny et al., 2020). However, the momentum impulse is still difficult for some students to learn (Wirjawan et al., 2020). Students have difficulty qualitatively interpreting momentum when applied to everyday physics problems (Denny et al., 2020) because momentum-impulse requires higher-order thinking skills (Eveline et al., 2019). It has been found that students need higher-order thinking skills to solve problems in everyday life and progress in the science and technology (Muskita et al., 2020). Momentum impulse is challenging because students do not use higher-order thinking skills when solving problems by applying the concept of momentum in everyday life.

The ability to think critically is one of the higher-order thinking skills (Fikri et al., 2020). The ability to think critically is a skill that students must have in learning (Pantiwati et al., 2023). Active learning can motivate students' critical thinking skills (Hidayat et al., 2023). Inquiry is needed in the classroom to enhance students' critical thinking skills (Verawati et al., 2019). As the impulse is a part of science, learning in a scientific context can be used as a basis for inquiry in everyday life (Pursitasari et al., 2020). Creativity is necessary to complete the inquiry learning model (Wahyudi et al., 2019) and prevent students from practicing their critical thinking skills on impulse topics monotonously.

Inquiry learning requires teaching materials such as textbooks (Pursitasari et al., 2020). Students' reading interest in science books (physics) is relatively low (Djajadi & Rauf, 2020). Learning how to present physics textbooks is necessary to develop (Mansyur et al., 2020) because most physics textbooks are dominated by words, which is exhausting for

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students (Apriyanti et al., 2020). In books, attention to visual and verbal aspects can create a pleasant atmosphere in understanding physics concepts (Haroky et al., 2019). Combining pictures and words makes information easier to understand (Winarto et al., 2018). In addition, children and adolescents prefer to read picture books rather than less attractive textbooks (Maharani et al., 2019). Physics textbooks can be presented differently than usual by including interesting pictures to enhance critical thinking as a tool of inquiry-based stimulus learning.

The momentum-impulse that is considered complicated by students is to understand the nature of momentum as a vector quantity (Wirjawan et al., 2020), the application to daily life (Denny et al., 2020), the relationship between the forces acting on the particles and the changes in momentum, and to draw a diagram of the changes in momentum, since the material presented is based only on theory (Rosa et al., 2018). This concept is complex for college students and is suitable for infographics (Naparin & Saad, 2017). The concepts of momentum and impulse are especially close to students' daily life (Himawan & Ariswan, 2021; Wirjawan et al., 2020). Thus, researchers can investigate how the concept is translated into an infographic (Naparin & Saad, 2017). However intense and complicated it is to understand information, infographics simplify and convey information with a layout different from any other type of visualization (Ozdamli et al., 2016). Infographics in physics subjects have not been widely used (Apriyanti et al., 2020).

Consistent with the need to provide students with real and active experiences through the inquiry process (Fatmawati & Rustaman, 2020), building mindsets and knowledge in inquiry (Gunawan et al., 2020) has a positive impact on 21st-century critical thinking skills (Kravchenko et al., 2023), the need for creativity and innovation in creating contexts that are easier for students to understand (Yuberti et al., 2019) by simplifying the concept through infographics (Aldalalah, 2021). The innovative physics textbook on momentum and impulse introduces inquiry-based learning and infographics to improve students' critical thinking skills.

The generation known as Gen-Z spends countless hours in the digital world through various electronic devices (Widodo et al., 2020). During the COVID-19 pandemic, innovative approaches should deliver learning materials beyond textbooks (Juanda et al., 2021). The infographic media needed can be displayed on a smartphone (Apriyanti et al., 2020). Especially Indonesian students are addicted to smartphones (Safitri et al., 2019). Using a smartphone as a medium is an innovation (Nikmah et al., 2019). Smartphones are a medium of independent learning, anywhere, anytime, and flexible (Apriyanti et al., 2020). During the COVID-19 pandemic, online learning has become necessary, with smartphone devices being the primary solution (Rizal et al., 2020). Therefore, this article aims to develop physics learning media. This book uses infographics to present inquiry-based momentum-impulse learning and examine its effect on high school students' critical thinking skills.

Literature Review

Inquiry-Based Learning

The inquiry learning model actively builds students' knowledge (Gunawan et al., 2020; Hastuti et al., 2020). Inquiry learning involves steps that encourage students to explore their curiosity, conceptualize ideas, collect and analyze data, and draw conclusions. To effectively teach physics, it is important to use infographics organized to align with the stages of the inquiry learning model (Baglama et al., 2017).

Table 1. Conceptualization of the Inquiry Learning Model

No	(Suchman, 1961)	(Tsivitanidou et al., 2018)	Conceptualization
1	Episode Analysis 1. Identify objects (and system objects) 2. Verify the state of the object at the start of the demonstration	Initiation Phase 1. Problem-based approach (opening phase) 2. Considering pupils' preconceptions (dialogical and interactive; dialogic and non-interactive)	Problem Presentation: Presenting open-ended question stimuli to see students' perspectives in understanding a phenomenon
2	Determination of relevance Collect data through a series of experiments	Practicing phase: 1. Planning 2. Making hypotheses 3. Collecting Information 4. Executing the Inquiry	Data collection and analysis of investigation results (experiments)
3	Induction of relational constructs Discover the principles and physical relationships that govern the changes that occur.	Review phase 1. Comparing results to the scientific view 2. Creating models 3. argumentation 4. Reinforcing the scientific view	Reflection on the results of data and material analysis

The inquiry is a learning model that provides better results for students (Hernawati et al., 2018). The conceptualization of the inquiry learning model in Table 1 shows the steps of inquiry: problem-solving, hypothesizing, gathering information and conducting inquiry, comparing the results to the physics view, and summarizing and interpreting. These

five steps of inquiry learning are applied to how students collect data or developmental evidence from student worksheets. The student worksheets are included in the e-book (MIB -In-graph). The conducted methods for developing, assessing, and testing momentum-impulse worksheets can be read in our previous article (Baihaqi et al., 2021).

Infographics

Infographic material is generally easier to understand and more satisfying for students (Ozdamli et al., 2016). Visual communication with infographics can present many pages (Alqudah et al., 2019). Infographics are unique because they combine beautiful visualizations in an impressive way as learning tools. Infographics are graphical representations of data used to present information more clearly (Terabe et al., 2020). Guidelines for making good infographics (Dalton & Design, 2014) are (a) setting clear goals, (b) the format to be represented, (c) relevant to the audience, (d) meaningful, (e) focusing on effectiveness, (f) effective narrative to convey data and knowledge, (g) ensure that the design of the infographic is good, (h) original content and presentation, (i) persuasive title, (j) conducting research, (k) trusted sources, (l) cohesive source, and (m) there is an outreach plan.

Infographics were widely disseminated during the COVID-19 pandemic; for example, the COVID-19 vaccine, vaccination series, myths, and mask-wearing consistently performed better on Instagram, Facebook, and Twitter platforms (Rotolo et al., 2022). Infographics could increase health education awareness (Piil et al., 2023). During the COVID-19 pandemic, infographics provided accurate information to the public (Kemp et al., 2022). In this development research, infographics help to convey momentum-impulsive content in Android applications. Improved design and easy readability of infographics can increase readers' interest (Terabe et al., 2020). Image design in the Android-based media (Astiningsih & Partana, 2020) supports stories in infographics. Like comics with character and image recognition (Lesmono et al., 2018), infographics with character recognition were at the beginning of e-books. Infographic innovations focus on conveying visual messages (Piil et al., 2023). The right images can encourage students to learn concepts (Sutarto et al., 2018).

Electronic Book

Textbooks must have an effect as a medium to raise awareness of the thinking (Sholehhudin et al., 2020). E-books have greatly increased in popularity. Fojtik (2015) indicated that the advantages of e-books include (a) easier purchase and distribution, (b) easy storage and backup, (c) the ability to adjust the font size, (d) adding text to multimedia, (e) readable on different devices, and (f) the ability to have a large number of devices in an e-book, .exe format for storage on CD/flash/micro SD, .zip format for quick emailing, .app format for use on I-Phone, android, I-Pad, and tablets (Perdana et al., 2021).

Previously, we developed inquiry-based worksheets for momentum-impulse learning during the COVID-19 pandemic (Baihaqi et al., 2021). Considering the pandemic conditions, the videos were advantageous as a data source, which allowed experiments to be carried out in a short learning period. Videos could be a tool for teaching real phenomena in scientific concepts and a modification of inquiry learning (Nurohman et al., 2021). Learning using applications during the COVID-19 pandemic increased the needs of students (Ikonnikova et al., 2022). However, the student worksheet was less attractive to students when using a smartphone (Lesmono et al., 2018). Mobile tools such as Android, iOS, and computers prepared according to students' needs contribute to motivation and reduce learning anxiety (Figueiredo, 2023). Therefore, we conducted this research in an e-book format and provided the worksheets as an Android application (.apk). This feature allowed students to play the video with the data source for the lab directly in the Android application, separately from the worksheets.

Critical Thinking Skills

Elements of critical thinking include interpretation, analysis, evaluation, inference, and self-regulation (Choiriyah et al., 2022). Other researchers use elements of critical thinking, including focus, reason, conclusion, situation, clarity, and summary (Hidayat et al., 2023). Table 2 contains the conceptualization for developing critical thinking questions.

Table 2. Conceptualization Critical Thinking Skill Indicators

No	(Ennis, 1996)	(Watson & Glaser, 2002)	Conceptualization
1	Clarity	Recognition Assumption	Clarity Assumption
2	Situation	Interpretation	Interpretation
3	Focus	Inferences	Inferences
4	Inferences		
5	Reason	Deduction	Reason
6	Overview	Evaluation of argument	Evaluation

Methodology

Research Design

The researcher adapted and used the 4D development model in this research. It aims to answer the question, "Is the momentum-impulse e-book based on the inquiry learning model assisted by infographics feasible?". The 4D model is shown in Table 3. The field test design was a pretest-posttest control group design. The field test design is presented in Table 4.

Table 3. 4D Model for Momentum-Impulse E-Book Based on Inquiry Assisted by Infographic (MIB-In-graph)

No	Development Stages	Steps	Result
1	**Define**	Front end analysis	Interview report with high school teacher: There were doubts that students' critical thinking skills could improve during limited study time and online-offline learning facilities during the COVID-19 pandemic.
		Student analysis	Classroom observation report: Students choose an Android app over print, web, or PC books.
		Task analysis	Determination of the dependent variable (critical thinking)
		Concept analysis How do we convey momentum?	An object of mass *m* moving with velocity *v* has momentum.
		How do we convey impulse?	The initial momentum of a moving object changes when the object gets a force at a certain time interval
		How do we convey the momentum-impulse relationship?	If there are two moving objects collide with no force on them.
		How do we convey momentum conservation law?	If there are two moving objects collide with no force on them.
		How do we convey the type of collision?	Collisions between 2 moving objects are affected by the coefficient of restitution of objects.
		Keywords: moving object	
		Concept map: use moving objects as initial events to convey the goal concept	
		Learning indicator specifications	Indicators of achievement of basic competencies in lesson plan
2	**Design**	Create product	Grids, designs, and Android apps MIB-In-graph
		Make critical thinking skill test instrument	
		Make validation sheets	Validation sheet of MIB-In-graph and validation sheet of critical thinking skill test instrument
3	**Develop**	Expert appraisal	The finished product of the MIB-In-graph and critical thinking skill test sheet
		Developmental testing	Empirical test: report on the feasibility of critical thinking skill test items Field test: report on improving student critical thinking skills with MIB-In-graph
4	**Disseminate**	Publications	National and/or International Journal

Table 4. Pretest-Posttest Control Group Design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control 1	O_1	X_2	O_2
Control 2	O_1	X_3	O_2

With:

O_1: *Pretest* critical thinking skills

O_2: *Posttest* critical thinking skills

X_1: Physics learning activities on momentum-impulse material using MIB-in-graph

X_2: Physics learning activities on momentum-impulse material using momentum-impulse book assisted by an android simulation game of *Tulup*

X_3: Physics learning activities on momentum-impulse material using a physics textbook for class 10 at one of the Islamic senior high schools in Malang

Sample and Data Collection

The participants were 45, 45, and 44 students from grade 10 science 1, 2, and 3 in one of the Islamic high schools in Malang. The participants were 258 students from three high schools in Malang who were in class 11 and had received momentum-impulse material. Researchers used a cluster sampling technique to select the participants for the field test and the empirical test as strata were not considered in drawing the sample members. The instruments used for data collection were:

1. The MIB-In-graph assessment sheet consisted of an assessment table of book content, presentation, and the Android application format of the book. The teacher's book assessment sheet contains a score table for book content, syllabus, lesson plans, and four inquiry-based worksheets. Both were submitted to six validators (three high school physics teachers with a master's degree in physics education, a physics education lecturer with a master's degree, and two physics education lecturers with a doctoral degree).
2. The student response questionnaire contained 32 statements, seven items on media operation, and nine items on design/appearance. Nine items on readability of the material and seven on interest in the MIB -In-graph android application.
3. The question of critical thinking skills arose from the relationship between an operative verb, indicators of critical thinking, and the momentum-impulse concept. Operational verbs are 'implemented' and 'present.' Both are operational verbs in the basic competencies of the 2013 curriculum for momentum-impulse material. Critical thinking indicators were five indicators that had resulted from conceptualization (Table 2). The indicators for critical thinking questions were developed as essay questions. Fifteen essay questions were created with levels ranging from C3-C6 in bloom taxonomy (3 items as anchor items, the other 12 items divided into two packages as A and B). The distribution of critical thinking questions is shown in Table 5.

Table 5. Distribution of Critical Thinking Questions

Aspects of Critical Thinking	Question Item Number
Clarity Assumption	1,6,11
Interpretation	2,7,13
Inferences	3,10,12
Reason	5,8,14
Evaluation	4,9,15

4. The validation sheet for critical thinking questions contained two assessment tables. The first table included the indicators for critical thinking questions and the level of each item in an aspect of critical thinking. The validator gave a value between 1 and 4. Meanwhile, the second table assessed content, construction, and language items. If these three aspects were met, the validator gave a check mark; otherwise, a cross if these aspects were not met.

Analyzing of Data

The research procedure and analysis of data are explained as follows:

1) MIB-In-graph was developed through 4D stages, as shown in Table 1.
2) MIB-In-graph in ".apk" format was distributed to the six validators (3 high school physics teachers with teaching experience of more than five years, a physics education lecturer with teaching experience of less than one year, and two physics education lecturers with teaching experience of more or less ten years) along with the assessment sheet to obtain product feasibility results.
3) MIB-In-graph was revised according to suggestions from validators.
4) The MIB-in-graph feasibility analysis was carried out by calculating the four scale categories through the descriptive analysis presented in Table 6.

Table 6. Product Eligibility Criteria

Eligibility Criteria	Category
X ≥ 75	Very valuable
62,5 < X ≤ 75	Worthy
50 < X ≤ 62,5	Not feasible
X ≤ 50	Very unworthy

5) Instruments and assessment sheets for critical thinking questions were given to the six validators and revised according to their suggestions.

6) The content validity of critical thinking questions was calculated using Aiken's V equation.

7) The empirical test was used to determine the quality of critical thinking items. This empirical test includes validity and reliability. Rasch modeling analysis was used for the validity test. The items are considered valid if the infit mean square value is 0.77-1.30 (fits the Rasch model). For reliability, researchers used classical test theory (CTT) analysis KR-20. The items were distributed to 258 students. The students' responses were entered into the program QUEST. QUEST provides an output in the form of a 'Summary of Item Estimates' showing the values of the mean square value of infit, the mean square value of outfit, the mean square value of infit, and the mean square value of outfit. This result was described as the validity of the critical thinking items. Another output is the 'internal consistency,' which indicates the reliability value of the test instrument, classically calculated with the reliability index KR -20.

8) A pretest-posttest control group design was used to compare the books among the three classes. The difference in learning activities is shown in Table 7.

Table 7. Comparison of Learning Activities in the Three Classes

Class	Teacher Activities	Student Activities
Experiment Book: MIB-In-graph Android Application Learning Model: *Inquiry*	(*Problem approach*) Shows momentum infographics about a bowling ball hitting the pins and cars at different speeds hitting a tree.	Pay attention to reading short stories in infographics on each android.
	Guide students in groups. Presenting the problem approach in the form of a game of marbles and physical quantities in the game.	Make groups of 2-3 children. Fill in the table of physical quantities in the game of marbles in the worksheet and ask questions.
	(M*aking hypotheses*) Presenting and stimulating students' opinions about the difficulty of marbles, cars, or objects with difficulty stopping motion.	Exploring different arguments in filling in the making hypotheses part in worksheets.
	(*Collecting information and Executing the Inquiry*) Playing the momentum practicum data source video as marbles being pushed with different strengths.	Playing the video in the MIB-In-graph, filling in the data table in the student worksheet based on observations of the marbles' motion throughout the video, such as distance and travel time, and then calculating the speed and momentum of the marbles.
	(*Comparing Results to The Physics View*) Directing students to form a graph of the relationship of velocity and momentum.	Formulate the momentum equation. Associating the results of video observations, data processing of momentum results, and their relationship with momentum infographics.
	(*Summarizing and Interpreting*) Guiding students to conclude.	Take turns to state the conclusion
	*In the next meeting, students practice momentum critical thinking questions related to events in infographics and worksheets.	

Table 7. Continued

Class	Teacher Activities	Student Activities
Control 1 Book: Momentum-impulse book-assisted simulation of *Tulup* game (Putranta, 2019) Learning model: *Guided Inquiry*	(*Orientation*) Demonstration of target shooting using a game of *Tulup.*	Observing the demonstration.
	Divide students into groups of 4-5 children. (*Formulating problems*) Guiding students to identify events and formulate physics problems in demonstrations	Sit in groups. Describe the formulation of the problem based on the events in the demonstration using a guided inquiry-based student worksheet.
	(*Formulate hypotheses*) Guiding students to make hypotheses. Directing student predictions to focus on learning objectives.	Formulate hypotheses.
	(*Collecting data*) Guiding students in using Android simulation.	Using an android simulation of *Tulup* game.
	Guiding students and helping determine variables, preparing work steps if obstacles exist.	Determine the independent, dependent, and control variables in the simulation that has been designed.
	Ask students to adjust the work steps arranged with references in the momentum-impulse book.	Develop work steps. Perform simulations according to their respective designs
	(*Test hypotheses*) Supervise learning activities.	Analyze physics events during the simulation.
	Invite students to conclude universally and clarify student answers.	Draw conclusions based on simulations, investigations, and universal momentum material.
	*The next meeting was spent practicing scientific literacy and HOTS questions related to *Tulup* (traditional game in Indonesia, like shooting) games.	
Control 2 Book: Physics package book from school Learning: *Constructivism approach*	(*Apperception*) Conduct a review related to Newton's Second Law regarding changes in momentum.	Listen and understand the teacher's explanation.
	(*Knowledge Construction*) Explaining the Law of Conservation of Momentum and Types of Collisions. Directing students to convey ideas related to collisions between two objects.	Listen and understand the teacher's explanation. Convey ideas related to collisions between two objects.
	Demonstrate a collision between two objects.	Watch demonstration.
	Directing students to do a simple experiment, namely dropping two different types of balls, recording with a cellphone, and then using a video editor application to check the position and time. Directing students to fill in the coefficient of restitution table.	Do a simple experiment. Fill in their answer based on data they got before from the video.
	(*Concept Application*) asks students to conclude the results of a simple experiment.	Infers the energy lost in objects during collisions.
	*Practice questions in the next meeting only amount to 1 question (according to the book's contents).	

9) The details regarding pretest and post-test analysis are presented in Table 8.

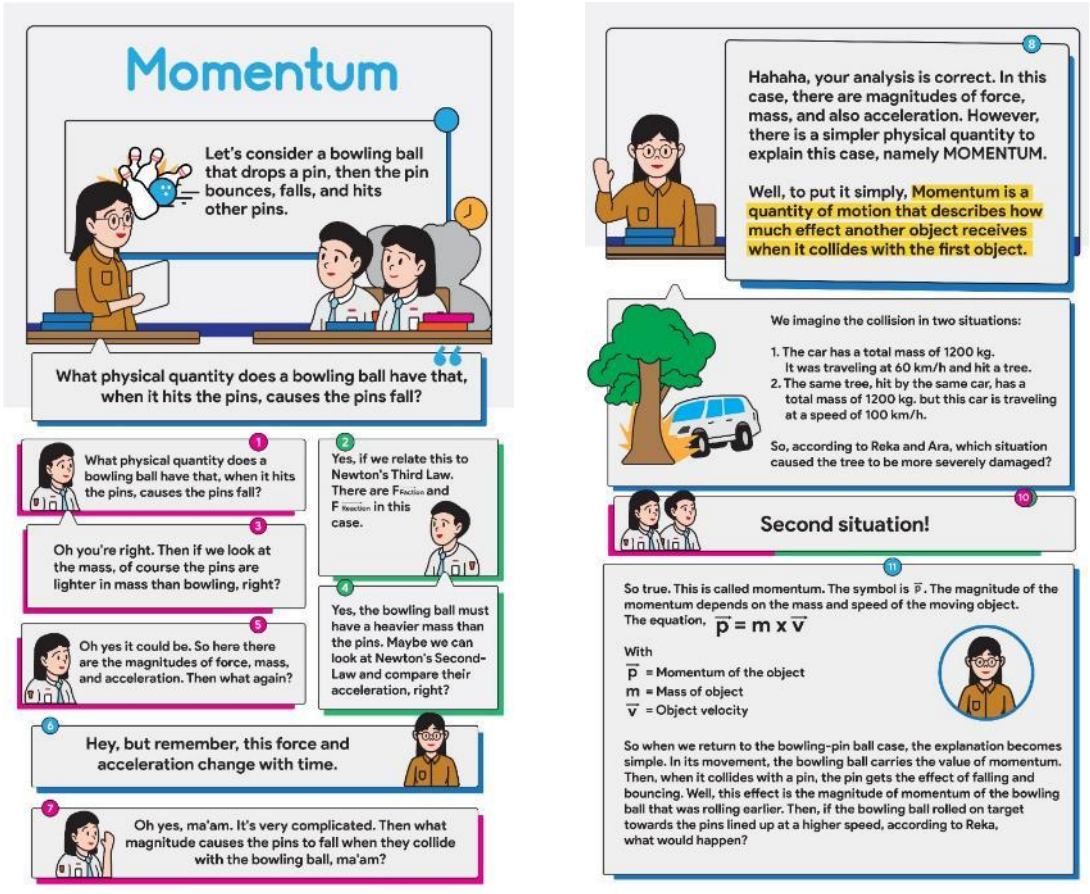
Table 8. Data Analysis Technique for Pretest and Posttest of Critical Thinking Skills

One between subject factor group	: 3 levels (experiment, control 1, control 2)
One within subject factor time	: 2 levels (pretest and posttest)
Data analysis technique	: Mixed Design ANOVA with the SPSS program help
Mixed Design ANOVA	
Basic assumptions	Explanation
1. Data is normally distributed; use the Shapiro-Wilk technique	Small sample, i.e., <50 students in each class (experiment, control 1, and control 2)
2. Homogeneous variance	Levene's test
Procedure for concluding with Mixed Design ANOVA to answer the research question	
Research questions	Explanation
a. Whether students in different groups increased their critical thinking skills over time	If the *p* value in Tests of Within-Subject Effects showed significant difference in time, then see the Pairwise Comparisons table
b. Whether such an increasing was more salient in some groups than others i.e. whether there was an interaction between group and time	If the *p* value in Tests of Between Subject Effects showed significant difference in group, then see the Multiple Comparisons table

10) Student response questionnaires for the MIB-In-graph Android application were distributed to the experimental class, and the results were analyzed using a four-point assessment scale.

Findings/Results

The implementation of learning short stories on momentum is shown in Figure 1. Short stories in infographics can teach students about the momentum (Sholehhudin et al., 2020). Physics stories with digital themes can serve as distance learning tools (Lashari et al., 2022). The analysis of MIB -In-graph android application feasibility by experts and students' responses is shown in Table 9.



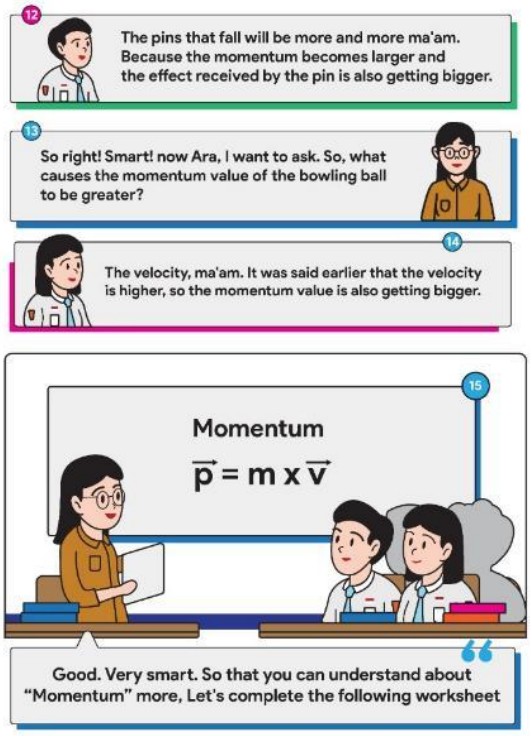


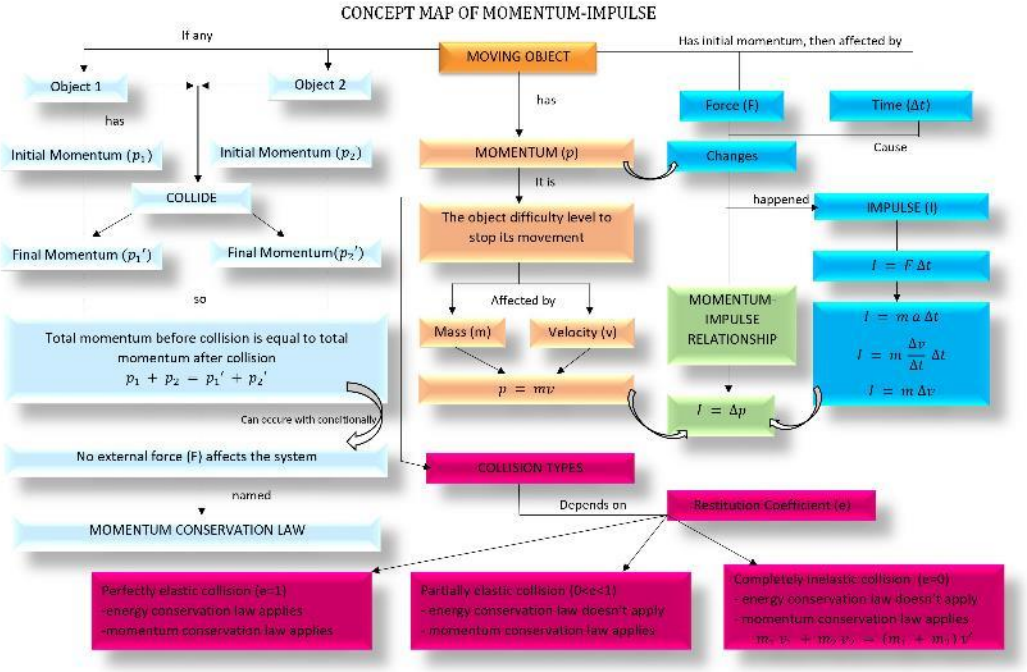
Figure 1. Momentum Infographic on e-Book

Table 9. Feasibility of MIB-In-graph Android Application

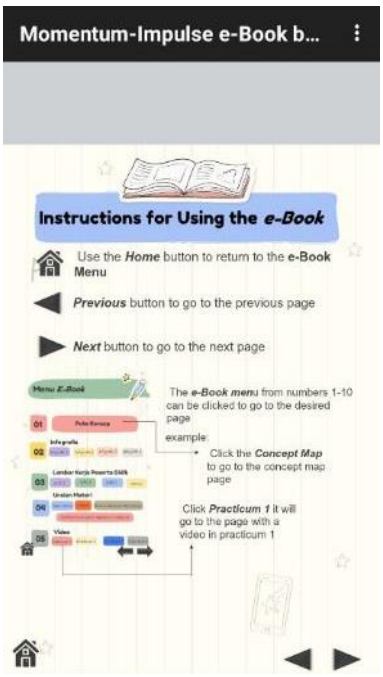
Component	Score	Component	Score
e-Book Content		**Worksheets**	
Cover-introduction	99.19	Momentum worksheet	96.63
Concept map	97.92	Momentum conservation law worksheet	96.53
Instructions	100	Restitution coefficient worksheet	97.22
Menu	100	Collision types of worksheets	96.23
Learning goals	100	**Worksheet package**	**95.17**
Topic description, the breadth, the depth, and the accuracy of the material	99.50	**MIB-In-graph Android App**	
Infographic 1	96.88	Presentation, layout, language	98.22
Infographic 2	100	Ease of use	98.33
Infographic 3	100	Application	97.22
Infographic 4	100	Independent learning media	93.33
Example of problems	100	**Average**	**96.88**
Exercises	100	**Companion of MIB-In-graph android application (Teacher's book)**	
Quiz	100	Cover	100
Summary, glossary, references	100	Foreword	97.22
Inquiry as basic	100	List of contents	100
Scientific approach	100	Syllabus	100
Average	**99.61**	Content Representation (CoRe)	95.08
Students' response		Preparation of indicators of basic competencies	98.61
Operational of media	82.38	Lesson plan	99.35
Design	83.43	Rubric of assessment	98.96
Material readability	84.72	References	100
Interested to e-Book	83.45	**Average**	**98.80**
Average	**83.50**		

Concept maps were included because concept maps helped to construct propositions and students' understanding of concepts (Silva et al., 2022) on momentum impulses. Concept analysis in Table 3 yielded a concept map in Figure 2a. Like

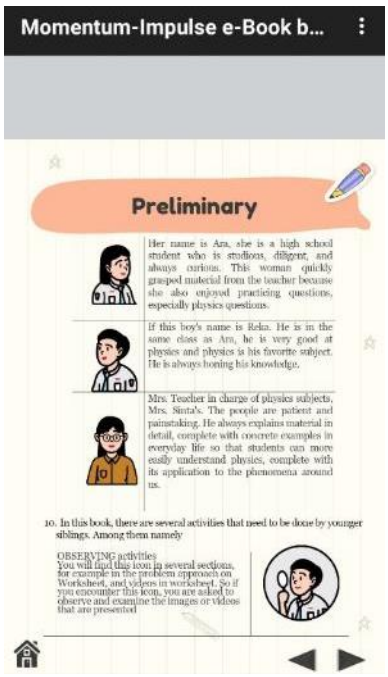
comics with character and image recognition (Lesmono et al., 2018), introducing characters in infographics was at the beginning of e-books (Figure 2c). The characters in the infographic illustrated the scientific approach. When facing a problem, students thought about finding strategies, determining steps, and re-checking the correctness of their problem-solving, including the steps of trying, reasoning, and concluding in a scientific approach (Pursitasari et al., 2020). The teacher's book fell into a very feasible category with a score of 98.90. Students can understand momentum-impulse concepts, teaching methods, and main ideas through CoRe (Nurmatin & Purwianingsih, 2017). CoRe received a score of 95.08. CoRe is a TPACK instrument needed in designing learning with technology integration in the 21st-century (Dewi et al., 2022). The lesson plan as a detailed version of CoRe (Purwianingsih et al., 2022) received a 99.35 score, reflecting a very good integration of TK, CK, and PK knowledge in the teacher's book. Details of the MIB-In-graph android application are presented in Figure 2.



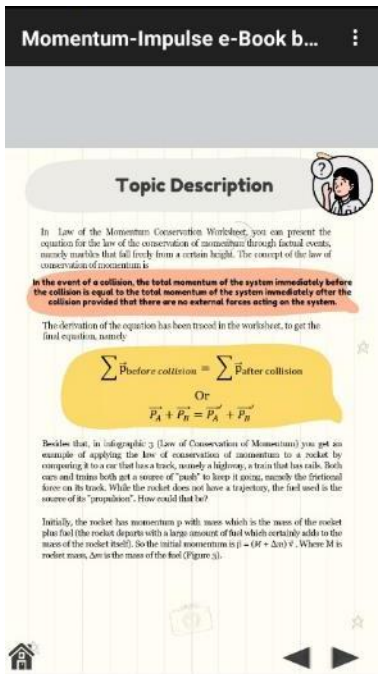
(a) Concept Map Zoomed



(b) Instructions for Use e-book



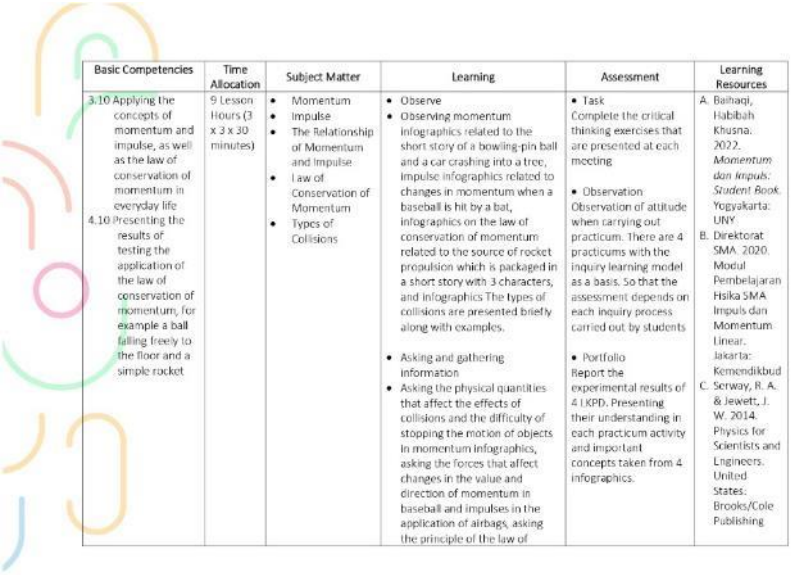
(c) Character Recognition in Infographics



(d) Topic description for momentum conservation law

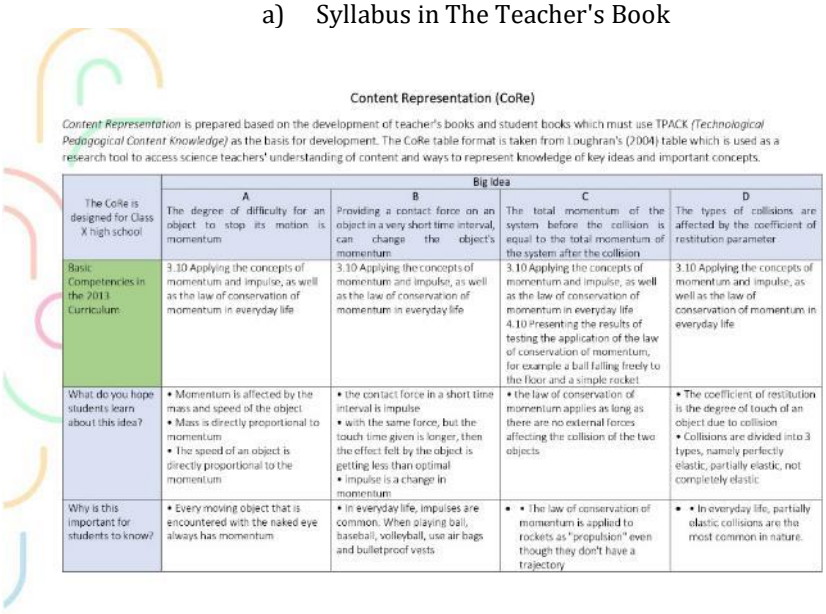
Figure 2. Screenshots of The MIB-In-graph Android Application

Learning activities require supporting aspects such as lesson plans, learning evaluations, and videos (Asri et al., 2020), which in this development are packaged in a teacher's book. Several layouts for teacher books are presented in Figure 3.



Basic Competencies	Time Allocation	Subject Matter	Learning	Assessment	Learning Resources
3.10 Applying the concepts of momentum and impulse, as well as the law of conservation of momentum in everyday life 4.10 Presenting the results of testing the application of the law of conservation of momentum, for example a ball falling freely to the floor and a simple rocket	9 Lesson Hours (3 x 3 x 30 minutes)	• Momentum • Impulse • The Relationship of Momentum and Impulse • Law of Conservation of Momentum • Types of Collisions	• Observe • Observing momentum infographics related to the short story of a bowling-pin ball and a car crashing into a tree, impulse infographics related to changes in momentum when a baseball is hit by a bat, infographics on the law of conservation of momentum related to the source of rocket propulsion which is packaged in a short story with 3 characters, and infographics The types of collisions are presented briefly along with examples. • Asking and gathering information • Asking the physical quantities that affect the effects of collisions and the difficulty of stopping the motion of objects in momentum infographics, asking the forces that affect changes in the value and direction of momentum in baseball and impulses in the application of airbags, asking the principle of the law of	• Task Complete the critical thinking exercises that are presented at each meeting • Observation Observation of attitude when carrying out practicum. There are 4 practicums with the inquiry learning model as a basis. So that the assessment depends on each inquiry process carried out by students • Portfolio Report the experimental results of 4 LKPD. Presenting their understanding in each practicum activity and important concepts taken from 4 infographics.	A. Baihaqi, Habibah Khusna. 2022. *Momentum dan Impuls: Student Book*. Yogyakarta: UNY B. Direktorat SMA. 2020. Modul Pembelajaran Fisika SMA Impuls dan Momentum Linear. Jakarta: Kemendikbud C. Serway, R. A. & Jewett, J. W. 2014. Physics for Scientists and Engineers. United States: Brooks/Cole Publishing

a) Syllabus in The Teacher's Book



Content Representation (CoRe)

Content Representation is prepared based on the development of teacher's books and student books which must use TPACK *(Technological Pedagogical Content Knowledge)* as the basis for development. The CoRe table format is taken from Loughran's (2004) table which is used as a research tool to access science teachers' understanding of content and ways to represent knowledge of key ideas and important concepts.

The CoRe is designed for Class X high school	Big Idea			
	A The degree of difficulty for an object to stop its motion is momentum	B Providing a contact force on an object in a very short time interval, can change the object's momentum	C The total momentum of the system before the collision is equal to the total momentum of the system after the collision	D The types of collisions are affected by the coefficient of restitution parameter
Basic Competencies in the 2013 Curriculum	3.10 Applying the concepts of momentum and impulse, as well as the law of conservation of momentum in everyday life	3.10 Applying the concepts of momentum and impulse, as well as the law of conservation of momentum in everyday life	3.10 Applying the concepts of momentum and impulse, as well as the law of conservation of momentum in everyday life 4.10 Presenting the results of testing the application of the law of conservation of momentum, for example a ball falling freely to the floor and a simple rocket	3.10 Applying the concepts of momentum and impulse, as well as the law of conservation of momentum in everyday life
What do you hope students learn about this idea?	• Momentum is affected by the mass and speed of the object • Mass is directly proportional to momentum • The speed of an object is directly proportional to the momentum	• the contact force in a short time interval is impulse • with the same force, but the touch time given is longer, then the effect felt by the object is getting less than optimal • impulse is a change in momentum	• the law of conservation of momentum applies as long as there are no external forces affecting the collision of the two objects	• The coefficient of restitution is the degree of touch of an object due to collision • Collisions are divided into 3 types, namely perfectly elastic, partially elastic, not completely elastic
Why is this important for students to know?	• Every moving object that is encountered with the naked eye always has momentum	• In everyday life, impulses are common. When playing ball, baseball, volleyball, use air bags and bulletproof vests	• • The law of conservation of momentum is applied to rockets as "propulsion" even though they don't have a trajectory	• • In everyday life, partially elastic collisions are the most common in nature.

b) Content Representation (CoRe) in The Teacher's Book

Figure 3. Display of a) Syllabus and b) CoRe in Teacher's Book

Aiken's V analysis of the substance, construct, and language components is presented in Table 10. Each item received a value of V > 0.08, which means they had high validity so that all items can be tested empirically on students. The empirical test results for critical thinking items are presented in Table 11.

Table 10. Aiken's V Analysis for Every Item of Critical Thinking Skill Test

Question Item Number	Aiken's V score	Interpretation
Item 1	0.958	High validity
Item 2,3,4,5,6,7,8,9,10,11, 12, 13, 14, 15	1.000	High validity

Table 11. Results of the Empirical Test (Validity and Reliability)

Determination of the overall fit of the item				
Fit Statistics	**Value and Standard Deviation**	**Range**	***Rasch* model provisions**	**Information**
Infit Mean Square	0.99 and 0.22	0.77 to 1.21	0.77-1.30	Compatible with *Rasch models*
Outfit Mean Square	0.90 and 0.20	0.70 to 1.10	0.50-1.50	Compatible with *Rasch models*
Determination of INFIT MNSQ (fit item) for each critical thinking item				
Question Items	**Items in Instruments**	**INFIT MNSQ**	**Status**	**Information**
1	Anchors (2)	0.45	Unwell	Not used
2	Anchors (7)	1,12	fit	Valid
3	Anchors (14)	1.31	fit	Valid
4	1 Package A	0.98	fit	Valid
5	4 Package A	1.04	fit	Valid
6	6 Package A	1.15	fit	Valid
7	9 Package A	1.14	fit	Valid
8	11 Package A	0.94	fit	Valid
9	13 Package A	1.07	fit	Valid
10	3 Package B	1.09	fit	Valid
11	5 Package B	1.07	fit	Valid
12	8 Package B	1.20	fit	Valid
13	10 Package B	1.20	fit	Valid
14	12 Package B	0.99	fit	Valid
15	15 Package B	1.10	fit	Valid
Internal Consistency		0.75	High reliability	

Based on the empirical test, the 15 critical thinking items fit the *Rasch model*. However, when looking at each item, item 1, the anchor item, did not fit the *Rasch model*, so it was discarded, and only the remaining 14 items were used for the pretest and posttest. The reliability results in the QUEST program also show that critical thinking items have high reliability so that they can provide sufficient and steady information as expected. The normality and homogeneity tests were carried out to fulfill basic assumptions for the Mixed Design ANOVA analysis. The results are shown in Table 12.

Table 12. Normality and Homogeneity Test for Critical Thinking Skills Variable

Shapiro-Wilk Normality Test				**Homogeneity Test**		
Test	**Class**	**Statistics**	***p***	**Test**	**Levene's Statistics**	***p***
Pretest	Experiment	.960	.125	**Pretest**	2,756	.067
	Control 1	.958	.108			
	Control 2	.960	.131			
Posttest	Experiment	.949	052	**Posttest**	1,761	.176
	Control 1	.974	.430			
	Control 2	.952	.065			

p value in the normality table, $p \geq .05$ so that it can be said that the data was normally distributed. Levene's statistical analysis shows $p \geq .05$ means there were similarities in the variance of the critical thinking variable, or the data was homogeneous. Since the conditions of normality and homogeneity are met, we can read the results of Mixed Design ANOVA as shown in Table 13.

Table 13. The Output of Mixed Design ANOVA

Mauchly's Test of Sphericity				
Within Subject Effects		Mauchly's W	df	*p*
time		1.000	0	.
Test of Within-Subject Effects				
	Source		df	F	*p*
Time	Sphericity Assumed		1	6685.512	.000
	Greenhouse-Geisser		1.000	6685.512	.000
Time*group	Sphericity Assumed		1	75.726	.000
	Greenhouse-Geisser		1.000	75.726	.000
Tests of Between-Subject Effects					
Source	Mean Square		df	F	*p*
Group	420.526		2	2.784	.000

Table 13. Continued

Pairwise Comparisons			
(I)Time	(J)Time	Mean difference (I-J)	*p*
Pretest	Posttest	-16.573*	.000
Posttest	Pretest	16.573*	.000
Multiple Comparisons			
(I)group	(J)group	Mean difference (I-J)	*p*
Experiment	Control 1	3.333	.036
	Control 2	4.068*	.029
Control 1	Experiment	-3.333	.036
	Control 2	.7355	.069
Control 2	Experiment	-4.068	.029
	Control 1	-.7355	.069

In Table 13, the value of *p* on *Mauchly's Test of Sphericity* is unavailable. This result is because there are only two levels of measurement, namely pretest and posttest. This result means that there is only one set of difference scores and nothing to compare those difference scores against to indicate a violation of sphericity. However, *p* It can be assumed <.005, which means sphericity is not met. So, the reference for reading the data is the *Greenhouse-Geisser* value from the *Tests of Within-Subject Effects*. The box time explained that there was difference in time because the *p* value less than .001 indicates that there are changes over time in critical thinking skills across the whole sample ($F(1,131) = 6685.512$, $p < .001$). Time*group box explained the interaction. The F value is significant because $p<.001$ indicates that the changes of critical thinking skills over time are not equivalent across the three group. *Tests of Between Subject Effects* showed if there are significant differences between the groups. The group differences in critical thinking skills averaged across time are significant ($F(2,131) = 2.784$, $p<.001$). The main effect for time and the main effect for group were significantly different. *Pairwise Comparisons* showed that critical thinking skills of all students increased significantly from pretest to posttest. *Multiple Comparisons* compared critical thinking skills in each group averaged across time. The experiment class had significantly higher critical thinking skills than the control class 1 and control class 2 because the *p* value are less than .05. The control class 1 and control class 2 were not significantly different because the $p= .069$ which is more than .05. A plot of the interaction was showed in Figure 4. The mean scores of all three groups are similar at the pretest. The mean scores increase over time, more so for those in the experimental group.

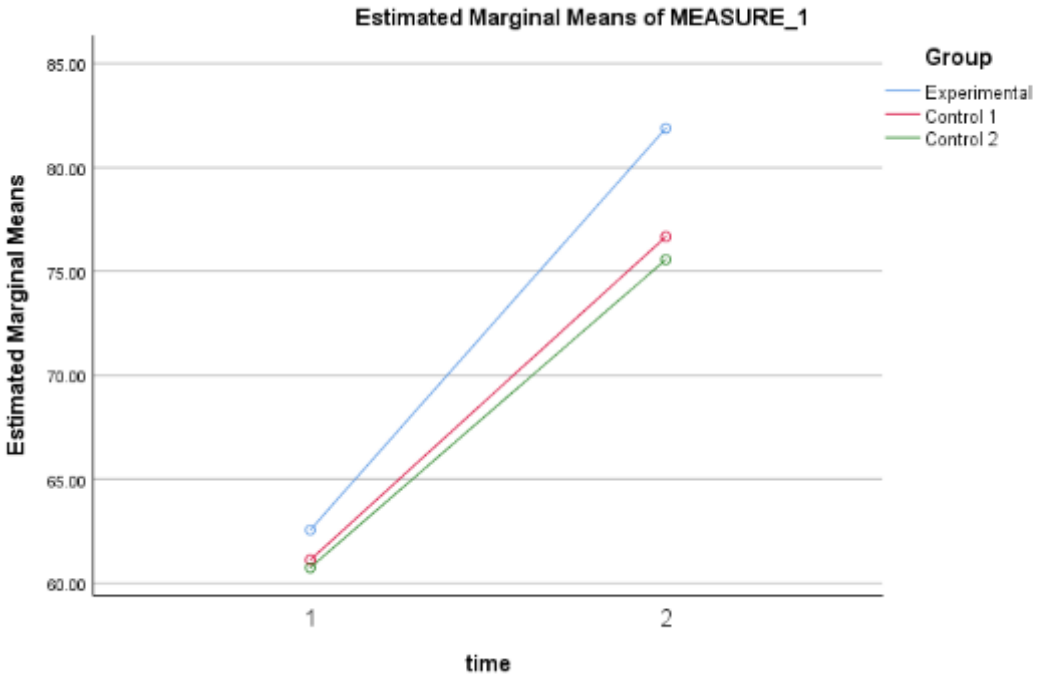


Figure 4. Plot of Critical Thinking Skills

Discussion

The factors causing the different increases in mean scores for critical thinking skills across classes can be described as follows. The first factor is the learning approach. The books in experimental and control class 1 were developed based on the requirements of the 2013 curriculum. The 2013 curriculum in Indonesia requires a scientific approach. On the

other hand, the books in control class 2 had a constructivist approach to learning. The process of the scientific approach, such as observing, asking, reasoning, and testing, contains assumptions and is close to constructivist learning. The scientific approach in the 2013 curriculum is part of what constructivism proposes (Waseso, 2018).

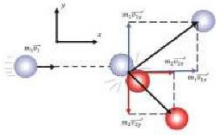
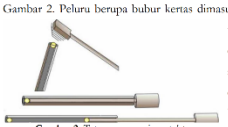
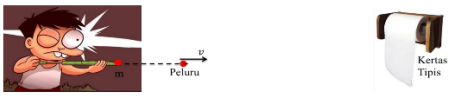
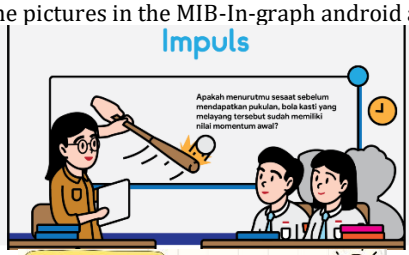
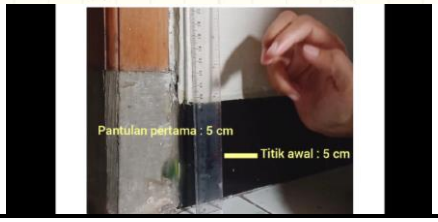
Hadjipanayi and Michael-Grigoriou (2020) used the constructivist learning approach to teach knowledge about asperser's syndrome to the experimental class that used virtual reality simulations and the control class that received expository narratives/articles. The results showed that the experimental group had more knowledge than the control group. The comparison in this study refers to the two different media, not the constructivist learning approach. In the scope of this study, it cannot be understood that the constructivist approach is worse at promoting students' critical thinking skills than the scientific approach. More specifically, constructivist learning requires media or instructional features. How to apply the constructivist approach in a particular learning model, teaching method, or media is not mentioned in the control group 2 physics book, not even in the teacher's book.

The second factor is the use of media. The Android simulation of *Tulup* games in control class 1 with virtual reality simulations in Hadjipanayi and Michael-Grigoriou's (2020) research was similar. While the physics book for control class 2 is an exposure article. The exponential article appears to be a concept of truth, like the physics book in control class 2 that presents Newton's Second Law for changes in momentum, momentum conservation law, and types of collisions with the concept of truth. At the same time, critical thinking is tolerance for ambiguity and initiative to find source evidence (Aston, 2023). So, control class 1 was superior in shaping students' knowledge through their android simulation of *the Tulup* game. Regarding the experimental class, Android is no longer an aid but the main media. Control class 2 used Android to record experiments and videos (see Table 7). At the same time, video data sources were provided in worksheets in MIB-In-graph. Existing videos helped to reduce the question "what" in remembering an image by students (Zandvakili et al., 2019). If there was a lack of laboratory equipment in school, learning media supported by technology that can be used include virtual laboratories (Lestari et al., 2023). The COVID-19 pandemic made it impossible for a long time to have a laboratory teaching when this research was being done. Thus, providing direct experience by providing video data sources as in the experimental class and simulating *Tulup* games in the control class 1 can help to learn quickly and effectively.

The third factor is the collaborative attitude of the students. Students become critical thinkers who ask more "why" and "how" questions, which significantly improves group collaboration (Zandvakili et al., 2019). The inquiry and guided inquiry models in experimental and control Class 1 required students to engage in group discussions. Inquiry is conceptualized as critical thinking as confirmation of the knowledge structure (Kaczko & Ostendorf, 2023). In group discussions about guided inquiry, better students helped weaker students (Rumain & Geliebter, 2020). Thus, these two classes outperformed the results of control class 2, which worked individually. While the control class 2 students always asked "what" questions, the other two classes were already at the "why" level. Conversational agents were also developed to promote complex thinking and knowledge sharing to promote group discussions when the teacher cannot always do this task (Nguyen, 2023). A conversational agent developed to replace teachers when they cannot guide the discussion illustrates the importance of collaboration in building critical thinking.

The fourth factor is pictures. Pictures help in forming meanings, reconstructing them, and helping individuals with their experiences to gain an understanding (Jimenez-Alonso & Bresco de Luna, 2022). Visual elements that students are already familiar with, such as shape, color, and environment, can produce longer discussions and emotional descriptions and arouse student interest in various subjects (Lopatovska, 2016). Student engagement with picture books refers to "critical thinking and book talk" while remaining focused on students (Papen, 2020). Students' experiences with using pictures in their books in each class are shown in Table 15. Even in MIB -In-graph, many other pictures provide experiences. Thus, the students in the experimental class had a richer experience with pictures than those in control class 1 and control class 2.

Table 15. The Use of Pictures in Each Book

Pictures	Use	Function
Pictures in the physics book that were used in the control 2 class		
	Describes the collision between two objects in the sub-material of the momentum conservation law	Forming meaning
	Explains the collision diagram in the sub-material of the collision	Forming meaning
	Provides an example of experimental display of the restitution coefficient done by students	Reconstructing understanding
Some pictures in the momentum-impulse book assisted by simulation of the Tulup game in control 1 class		
	Illustrates the Tulup game as an apperception of momentum material	Gives meaning to a familiar environment
	Provide an example of how to play Tulup as an apperception of momentum material	Reconstructing understanding, familiar shapes
	Illustrating a bullet in the Tulup game that pierces thin paper as a target	Provides meaning to a familiar environment
Some pictures in the MIB-In-graph android application are what they used in the experimental class		
	Depicts students and teacher discuss the initial ***momentum*** of a softball that flies before being hit, as an apperception of impulse sub-material (infographic 2)	Provides meaning to a familiar environment
	Provides an overview of slow and fast boxing punches in infographic two as impulse apperception	Reconstruct understanding, familiar environment
	Shows the motorbike's speed value when moving in a sharp turn and after passing a sharp turn from YouTube as a data source for impulse practice	Increase understanding, familiar environment, and real experience.
	Video footage of data source for the momentum conservation law practicum can be played directly in the book (android application)	Gain understanding, familiar environment, and real experience

Conclusion

Content development, worksheets, roles as Android applications, and the teacher's book from MIB-In-graph fell into the appropriate category for momentum-impulse learning. Critical thinking items met valid and reliable criteria to be used as pretest and posttest instruments. The mean critical thinking skills score increased significantly from the pretest to the posttest for all students. However, the mean score increase was not the same in each class. The experiment class using MIB-In-graph had significantly higher critical thinking skills than the control class 1 using a momentum-impulse book assisted by *Tulup* game android simulation and control class 2 using a physics book from school. The factors contributing to these differences include the unique learning approach, the use of media to convey knowledge, the importance of collaboration, and providing experiences to students with many pictures.

Recommendations

Future researchers can develop infographics in the form of short stories, as in this study. However, they can also apply them to other physics or elementary, junior high, and high school materials because infographics are very flexible. In addition, researchers can test the effect of the MIB-In-graph Android application on student independence. Physics teachers can use the MIB-In-graph Android application to teach momentum impulses after the pandemic to optimize critical thinking skills with independent learning media. Worksheets can be worked on in hands-on practice, not just by recording data via video, given that the pandemic is over. Researchers can explore other factors that might cause differences in the results of significant improvement in critical thinking skills in this study. Researchers in physics education can also compare many groups using different approaches and media to determine the most important factors influencing students' critical thinking about physics materials.

Limitations

This development research is limited to Android applications in the form of momentum-impulse material e-books. Physics materials at other high school levels are more numerous, and infographics can be used to develop other skills. The Android application enhanced the experimental class's critical thinking skills. However, it can also be tested to understand increased student independence during the COVID-19 pandemic, considering teaching a concept. Also, the questions developed to test critical thinking skills were limited to the class X SMA material of impulse-momentum.

Authorship Contribution Statement

Supahar: Guiding research, supervision. Habibah: Conceptualization, design, developing applications, carrying out field tests, analyzing, and writing development research results. Himawan: Created a momentum-impulse book assisted by a simulation of Tulup games to be used as a comparison in control class 2, reviewing. Ivandra: Reviewing. Farchan: Reviewing. Racy: Reviewing.

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