The effectiveness of a physics e-book on rotational dynamics of a traditional top game assisted by augmented reality to improve students' critical thinking skills and visual representations

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Received 25 May 2024; accepted 19 August 2024

This study aims to determine the effectiveness of the physics e-book of rotational dynamics in the traditional game of augmented reality-assisted tops in improving students' critical thinking skills and visual representation. This type of research is Research and Development (R&D) using the ADDIE development model, namely analyze, design, develop, implement, and evaluate. This research design is pretest-posttest control group. The subjects of this study included 3 expert lecturers and 2 teachers for product validation, 5 expert lecturers and 2 teachers for instrument content validity, 254 students for the empirical validity of the instrument, 6 students for the product readability test and 81 students for the implementation test. The data analysis technique of this research is to test the feasibility of the product using a standard scale, for the content validity of the instrument using Aiken's V, to analyse the items using the Partial Credit Model, and to test the effectiveness of the product using the general linear model (GLM). The results of this study indicate that the use of rotational dynamics physics e-books on traditional games of augmented reality-assisted tops is effective in improving critical thinking skills and visual representation of students with a large effect size category.

Keywords: Augmented reality; critical thinking; e-book; rotational dynamics; traditional top game; visual representation.

DOI: https://doi.org/10.31349/RevMexFisE.22.020205

1. Introduction

Critical thinking is one of the 4C skills needed for learners to face the challenges of the 21st century. The development of learners' critical thinking is the main goal of education today [1]. This is because learners' critical thinking skills are needed in everyday activities and have an impact on the success of learners academically and professionally in the future [2]. Students with high critical thinking skills are more likely to question, critique, and discuss environmental phenomena based on the scientific principles they've learned in physics [3,4]. Critical thinking habits play an important role in learners' developmental reasoning process to evaluate, decide, and present solutions in solving complex problems [5]. Determining the indicators of the quality of an education is reflected in the high level of critical thinking skills of students [6]. However, most students still have critical thinking skills in the low category, both from the aspects of the ability to ask questions and argue [7,8]. Additionally, school learning often focuses on memorization and understanding, making it hard for students to develop critical thinking skills and apply the material [3]. This finding is supported in Putranta and Kuswanto's research (2018) that the critical thinking skills of current students are still low [9]. Therefore, the critical thinking skills of students in learning physics need to be improved by efforts to present learning that is more innovative and attracts the interest of students.

In physics learning, in addition to critical thinking skills, students are inseparable from abstraction and analysis of an image case to understand the concepts and principles of physics. Visual representation is one of the representation abilities used to understand physics learning through an image, diagram, or graph presented in the case of physics problems. Visual representation is an ability to understand a picture, diagram, table and graph [10]. Visual representations are categorised into non-notational representations (*e.g.*, photographs, paintings and drawings) and notational representations (*e.g.*, diagrams, maps, graphs and charts) [11]. Non-notational representations provide a view of multiple complex meanings of abstraction reality that can visually present physical phenomena in life and increase students' interest in learning [12]. In contrast, notational representations seek to reduce reality in some way in order to produce a one-to-one correspondence between components and their referents [12,13]. Visual representation for students plays an important role in understanding the retention of abstract text and communicating scientific phenomenon data for problem-solving in the learning process [14]. In physics learning, the importance of developing visual representations can foster science process skills in the scientific method process in students [15,16]. Visual representation skills in learners can play a role in communicating a concept through graphs, images, and demonstration models in solving problems [17,18]. However, visual representation is a complex ability that consists of

many components with different levels, so there are difficulties faced by students in replicating the visuals in their minds [19]. Therefore, visual representation needs to be trained in students so that it is easy to abstract cases of phenomena and illustrations of physics concepts in the form of pictures, graphs or diagrams so that they can solve problems through innovative and interactive learning media.

E-books in the digital era 4.0 are a future learning innovation that can replace printed books. E-books have characters in the form of colour images, animations, simulations, audio, and video images that can support concepts and improve learning outcomes [20,21]. E-books make learning more flexible and practical by allowing activities to be organized for both classroom and independent use [22]. Technology-based books can improve the quality of learning and the ability of students in the form of motivation, and understanding of concepts can also increase [23,24]. E-books that are interactive in use can interact and communicate reciprocally so as to enhance the learning experience of learners [25,26]. Thus, developing interactive e-books can enhance learning by stimulating students' senses with simulations and multimedia features, making them more effective than textbooks.

In the world of education, the application of Augmented Reality (AR) provides a technology-based learning orientation. Augmented Reality can support learners in performing abstractions in three dimensions, making it look real through electronic devices in real-time [27-29]. AR technology merges physical and virtual worlds to enhance the user's environment with supplementary information from camera images, videos, and audio, using computer and mobile technology [30,31]. AR helps students to perform spatial visualisation tasks, such as mentally manipulating, rotating and flipping objects [32]. In addition, AR can provide dynamic images of 3D shapes and facilitate intuitive, natural interactions with users, allowing them to manipulate these shapes through hand gestures, which enhances their understanding and makes the knowledge more memorable and enduring [33].

Some of the advantages of Augmented Reality technology are (1) Interactive and effective to use, (2) can be widely used in various media, (3) Imaging objects that are simple but easy to understand, (4) affordable manufacturing costs [34,35]. This is also in line with the opinion of Ismail *et al.* (2019) that the advantages of using Augmented Reality for learning are in attracting the interest of learner activities, affordability and practicality in its use [36]. AR-based learning improves spatial skills, practical application, and provides learners with conceptual and inquiry-based understanding [37,38]. Therefore, the use of Augmented Reality in learning supports students to improve cognitive (concept understanding, investigation, spatial visualisation), affective (motivation, attitude, interest), and psychomotor (sensory movement, sound and three-dimensional touch) abilities of students so that the achievement of competence and the cultivation of potential are achieved, especially in physics learning.

Physics learning on rotational dynamics material cannot be separated from physics cases in everyday life. One of the cases of rotational dynamics that is close to the experience of students and local cultural wisdom is the Traditional Game of Top. In the case of playing tops, it can provide illustrations or demonstrations of physics concepts such as the balance of rigid bodies, rotational dynamics, and the concept of pressure [39]. The research of Sintauri *et al*., (2020) suggested that there are physics concepts that can be reviewed in the spinning top game, namely the mass of the spinning top related to the moment of inertia, the stability of the spinning top related to the balance of a rigid body [40]. A spinning top rotates on its axis to maintain its balance at one point [41]. In the spinning top game as time increases, the angular momentum and rotational speed will decrease so that if the rotation of the spinning top stops the fastest, the player loses [42]. In the spinning top game as time increases, the angular momentum and rotational speed will decrease so that if the rotation of the spinning top stops the fastest, the player loses [43].

Learning physics through games is an effective way for children to develop their abilities, acquire and process information, and enhance their skills through play [44]. The application of ethnophysical culture-based learning has the potential to develop learning methods into active student-centred learning [43,45]. Additionally, using traditional top games as learning content helps students preserve cultural heritage, fostering a sense of cultural appreciation and reinforcing character values [46]. This is because today has entered the era of technology, so that most students rarely play the traditional top game because it is shifted by modern technology-based games [40]. Previous research by F. Permata Sari *et al*. (2020) showed that developing a physics comic based on the traditional game "engklek" and an Android platform effectively improves cognitive skills such as mathematical representation and creative thinking in students [47]. Therefore, using the Traditional Top Game in physics education facilitates students' cognitive development (both representational and cognitive skills) while also imparting cultural values and character development, making learning more student-centered.

In solving physics problems, most students still have difficulty. One of the physics materials that often becomes an obstacle for students is rotational dynamics. In the subject of rotational dynamics, most students still have difficulty visualizing problems related to the concept, which leads to errors in drawing sketches and force diagrams [48]. Oktavia and Admoko's research states that there are misconceptions in rotational dynamics material with the lowest misconception of 19.84% on the concept of the moment of force and the highest of 46.31% on the concept of kinetic energy in rotational motion objects [49]. Based on previous research, it is stated that the ability of students to solve physics problems in rotational dynamics material is unsatisfactory [50]. Therefore, it is necessary to improve the quality of physics learning in rotational dynamics material so that students are easy to solve problems and avoid misconceptions.

Therefore, this research describes the development and implementation of learning media E-Book Physics Rotational Dynamics on Traditional Top Games Assisted Augmented Reality so that learning is more interactive, and provides ease of visualisation to students on the concept of rotational dynamics based on local wisdom. In addition, this study was conducted to have a positive impact on students' critical thinking and visual representation skills. This study aims to determine the effectiveness of E-Book Physics Rotational Dynamics on Traditional Top Games Assisted Augmented Reality in improving critical thinking skills and visual representation of students.

2. Method

In this study, e-book product development is carried out with the ADDIE research and development (R&D) model, whose stages include analyze, design, develop, implement and evaluate [51]. The ADDIE development concept is used to facilitate the complexity of the learning environment by intentionally designing responses to various conditions, reviewing contextual interactions, and considering the relationships between different situations [52]. Based on research by Aini *et al*. (2022), product development through the stages of the ADDIE development model can produce modules on the dynamics of rotation and balance of rigid bodies that are feasible and effective in increasing student motivation [53]. Thus, the purpose of using the ADDIE model in this study is to create instructional media as a product, an e-book on rotational dynamics in the traditional spinning top game assisted by augmented reality, which effectively enhances students' critical thinking and visual representation skills during the physics learning process.

2.1. Research design

This research design uses a quasi-experimental design with the treatment of three different classes through a pretest and posttest. In experimental class 1 learning using physics e-book rotational dynamics on AR-assisted top game, experimental class 2 using PBL-based flip-book teaching materials with Ophysics simulations assistance, and control class using teaching materials through `PowerPoints` presentation media used by teachers. This research design can be shown in Table I.

Description: O_1: Pretest; O_2: Posttest; X_1: Physics learning with the help of physics E-book media rotational dynamics in traditional top games assisted augmented reality; X_2: Physics learning with the help of PBL-based flip-book teaching materials with the help of Ophysics; X_3: Physics learning with the help of teaching materials through `PowerPoint` used by the teacher.

TABLE I. Design of field trial.

No	Class	Pretest	Treatment	Posttest
1	Experiment 1	O_1	X_1	O_2
2	Experiment 2	O_1	X_2	O_2
3	Control	O_1	X_3	O_2

2.2. Research sample

2.2.1. Validity test

Validation in this development aims to provide assessment and input from e-book products and instruments of critical thinking skills and visual representation developed before being tested in the field. Product validation was carried out by three expert lecturers consisting of material experts and media experts and two physics teachers. While the validation of question instruments was carried out by five expert lecturers and two physics teachers.

2.2.2. Empirical test

The empirical test of this research was conducted to determine the validity and reliability of the instrument questions measuring the variables of critical thinking ability and visual representation of rotational dynamics material in the traditional game of spinning top. Empirical tests were carried out on students of class XI science at senior high school of 2 Yogyakarta and senior high school of 11 Yogyakarta and class XII science at senior high school of 7 Yogyakarta. The empirical test sample consisted of 254 students. The empirical test sample selection used the purposive sampling technique, which was aimed at students who had high, medium and low abilities. The empirical test instrument consists of two packages of questions, namely package A and B, each of which amounts to 7 questions.

2.2.3. Effectiveness test

The effectiveness test was conducted to determine how effective the Rotational Dynamics Physics E-book media on Traditional Top Games Assisted Augmented Reality in physics learning. The sample of this research was conducted at the senior high school of 4 Yogyakarta class XI science in the independent curriculum consisting of 81 students. In selecting the sample using cluster sampling technique so that the ability of students is diverse.

2.3. Research instruments

The research instruments used are the physics teaching module for rotational dynamics in the traditional game of AR-assisted tops that has been developed based on the Merdeka Curriculum [54] and test questions in the form of descriptions that include indicators of critical thinking ability and visual representation. Indicators of critical thinking ability and visual representation in the description test instrument can be shown in Table II.

TABLE II. Indicator of test instrument.

Variables	Variable indicator	Item number	Question indicator
Critical thinking	Identify problems, facts and hypotheses	1A, 1B	Identify problems, facts and hypotheses from the case of moment of force and inertia of a top.
	Provide arguments based on the problem	2A, 2B	Evaluate a spinning top based on the moment of inertia value to solve the case of spinning top time.
	Testing the accuracy of arguments and hypotheses.	3A, 3B	Proving the spinning top case statement through the concept of spinning top moment of force.
	Provide conclusions	4A, 4B	Conclude the case of the length of time a spinning top rotates through the concept of moment of inertia.
Visual representation	Identify information (pictures, diagrams, tables, or graphs) to solve problems.	5A, 5B	Stating the value of moment of inertia of a top to solve problems.
	Draw diagrams, graphs, or tables solving problems in a text through visual representations.	6A, 6B	Draw diagrams and graphs of the top case through the narrative presented.
	Analyse figures, diagrams, tables or graphs to make inferences.	7A, 7B	Comparing moments of inertia and moments of force between tops to draw conclusions.

2.4. Data analysis

2.4.1. Analysis of E-Book validation results

Data analysis techniques for the feasibility of e-book products, the validity of learning devices (teaching modules and worksheet), and the readability of e-book products through questionnaire assessment sheets are carried out with the following steps:

1. Recapitulate all statement items in the feasibility assessment sheet.
2. The average score of each item is calculated using Eq. (1) as follows:

$$\bar{X} = \frac{\sum X}{n}. \quad (1)$$

Description: $\bar{X}$: Average score per aspect; $\sum X$: Number of scores per aspect; n : Total score.

3. Converting the average score into category value.

As for knowing the quality of e-books, learning devices and readability of e-books, the results of the development and assessment of material experts, media experts, teachers, and students then use a 4-point Likert scale where the data that was originally in the form of scores was converted into qualitative data with a scale of four on content validation, and readability of students. On a Likert scale, the highest score is 4 and the lowest is 1. The formula used refers to Widoyoko, (2012) shown in Table III.

Description: X_i: Average ideal score; $\bar{X}$: Average score; Sb_i: Ideal standard deviation.

Which is

$X_i = \frac{1}{2}\times$ (highest score+lowest score)

$$X_i = \tfrac{1}{2} \times (4.00 + 1.00) = 2.50$$

$Sb_i = \frac{1}{6}\times$(highest score-lowest score)

TABLE III. Ideal score conversion guide [55].

Score Range	Category
$\bar{X} > X_i$+1.8 Sb_i	Very good
X_i+0.6 $Sb_i < \bar{X} \leq X_i$+1.8 Sb_i	Good
X_i-0.6 $Sb_i < \bar{X} \leq X_i$+0.6 Sb_i	Fair
X_i-1.8 $Sb_i < \bar{X} \leq X_i$-0.6 Sb_i	Poor
$\bar{X} \leq X_i$-1.8 Sb_i	Very poor

TABLE IV. Category of product feasibility assessment.

Score Range	Category
$\bar{X} > 3.40$	Very good
$2.80 < \bar{X} \leq 3.40$	Good
$2.20 < \bar{X} \leq 2.80$	Fair
$1.60 < \bar{X} \leq 2.20$	Poor
$\bar{X} \leq 1.60$	Very poor

$Sb_i = \frac{1}{6} \times (4.00 - 1.00) = 0.50$

Based on the category assessment in this study using a Likert scale from 1 to 4, it can be found that the average value of the ideal score is 2.50 and the ideal standard deviation is 0.50, so that the feasibility categorisation can be shown in Table VI.

2.4.2. *Analysis of research instrument*

Data analysis obtained through the assessment validation sheet by several experts was carried out using the Aiken's V test [56]. The following are the stages of analysing the validation of the assessment instrument according to Aiken's V. Calculating the Aikens' V index on each item based on the validator's assessment with Eq. (2).

$$V = \frac{\sum s}{n(c-1)}. \tag{2}$$

Description: V: Content validity coefficient; s: $r - l_0$; l_0: Lowest validity score; c: Highest validity score; r: The number given by the validator; n: Number of validators.

Comparing the Aiken's V index with the predetermined eligibility category. In this study, the number of item categories was 4 and raters were 7, then the items were said to be valid if the V value was $\geq$ 0.76 [56]. The scores obtained were then converted into four categories by comparing Aiken's V scores with quality categories shown in Table V.

2.4.3. *Analysis of empirical test results*

Analysis of the results of the validity and reliability test of the question instrument in this study using the item review application programme. The item is said to be valid based on classical analysis if the INFIT MNSQ value is 0.77 $\leq$ X $\leq$ 1.33, and further analysis to determine the fixity of the item with the fit model can be done by looking at OUTPUT MNSQ $0.5 <$ MNSQ < 1.5 [58,59]. While the reliability of question instrument uses Cronbach's Alpha analysis with criteria shown in Table VI.

TABLE V. Criteria of instrument validity [57].

Score Range	Category
$0.2 < V \leq 0.4$	Less
$0.4 < V \leq 0.6$	Fair
$0.6 < V \leq 0.8$	Good
$0.8 < V \leq 1.0$	Very good

TABLE VI. Reliability category [60].

Cronbach's Alpha Score	Level of Reliability
$0.0 - 0.2$	Very low
$0.2 - 0.4$	Low
$0.4 - 0.6$	Moderate
$0.6 - 0.8$	High
$0.8 - 1.0$	Very high

2.4.4. *Analysis of effectiveness test results*

Effect size is used to determine how much the effectiveness of the Physics E-book Rotational Dynamics in Traditional Top Games Assisted Augmented Reality to improve critical thinking skills and visual representation of students. However, before the data is tested using GLM, the data is carried out prerequisite tests, namely normality test (Kolmogorov-Smirnov) and homogeneity (Levene Statistics). After the data has been tested normal and homogeneous, then, it can be tested GLM (General Linear Model) using a data processing programme. Effect size is done by multivariate analysis using GLM (General Linear Model) [61]. Effect size is obtained through the results of the eta square value of GLM analysis output [62]. Partial Eta Squared values are expressed in the categories shown in Table VII.

3. Finding and discussion

3.1. Product and instrument feasibility validation test

3.1.1. *E-book product feasibility test*

The results of the feasibility assessment of e-book products by material experts from expert lecturers and teachers can be shown in Table VIII.

TABLE VII. Interpretation of effect size categories [62].

Partial eta squared value	Interpretation
0.01	Small effect size
0.06	Medium effect size
0.14	Large effect size

TABLE VIII. E-Book feasibility assessment results material aspects.

Aspect	Average score	Category
Learning	3.65	Very good
Material	3.60	very good
Language	3.53	Very good
Average	3.59	Very good

TABLE IX. Media aspect E-book feasibility assessment results.

Aspect	Average score	Category
Visual display	3.73	Very good
Software engineering	3.60	very good
Average	3.67	Very good

Based on Table VIII, of the three aspects of assessment by material experts, the language aspect has the lowest average score compared to other aspects. This is because there are errors in writing equations, using punctuation marks, and sentence structure that need to be corrected so that the presentation of e-book material is easier to understand and there are no errors. So it can be stated that the assessment by material experts on e-book products developed is feasible to use in learning with improvements. While the results of the feasibility assessment of e-book products by media experts can be shown in Table IX.

Based on Table IX, of the two media aspects, the one with the lowest score is the software engineering aspect. This is because the use of e-book applications seems boring, there is an ineffective answer submission feature, and the video is still not available with a start/stop button, so that there needs to be improvements in the media aspect to make it easier to accept and have practicality and efficiency in physics learning. So it can be stated that the assessment of e-book products by media experts is declared feasible for use in learning but with improvements.

3.1.2. Content validity test of problem instruments

The results of content validity were analysed using Aiken's V with the number of item categories 4 and 7 raters, based on the eligibility criteria for the V value, the items can be said to be valid if the V value is ≥ 0.76 [56]. The results of Aiken's V analysis can be shown in Table X.

Based on Table X, it can be shown that the Aiken's V coefficient value on each item is in the value range of $0.76 - 0.86$. Which can be stated that all items are valid to be used to measure students' critical thinking and visual representation skills. However, each item still has some suggestions and input from validators to make improvements including: the existence of several ineffective sentences, the use of improper punctuation, the incompatibility of the question indicators with the selection of Bloom's Taxonomy Verb Chart, the question is not in accordance with the indicators of critical thinking ability or visual representation and the Bloom's Taxonomy Verb Chart has not appeared according to the indicators in the questions presented.

3.1.3. Empirical validity and reliability test of problem instruments

The suitability of items with the Partial Credit Model (PCM) [63] can be shown based on the INFIT MNSQ value in the Quest programme analysis of the output file section ending in "sh". Question items can be said to be valid and in accordance with PCM if the INFIT MNSQ value has a range of 0.77 to 1.33. Based on the results of the Quest programme analysis, the results of the analysis of the suitability of critical thinking and visual representation items with the Partial Credit Model (PCM) were obtained. The results of the analysis of the suitability of critical thinking ability items can be shown in Fig. 1.

Based on Fig. 1, it can be seen that 8 items of critical thinking ability show INFIT MNSQ values in the range of 0.77 to 1.33, so it can be stated that all items are valid and in accordance with the Partial Credit Model (PCM). Meanwhile

TABLE X. Item content validity analysis results.

Package	Ability	Item	Aiken'V	Description	Category
A	Critical thinking	1	0.86	Valid	Very good
		2	0.76	Valid	Good
		3	0.86	Valid	Very good
		4	0.76	Valid	Good
	Visual representation	1	0.86	Valid	Very good
		2	0.81	Valid	Very good
		3	0.76	Valid	Good
B	Critical thinking	1	0.76	Valid	Good
		2	0.76	Valid	Good
		3	0.86	Valid	Very good
		4	0.76	Valid	Good
	Visual representation	1	0.76	Valid	Good
		2	0.81	Valid	Very good
		3	0.81	Valid	Very good

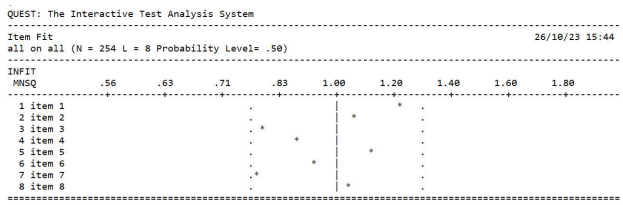

FIGURE 1. Results of analysis of question item conformity with PCM on critical thinking ability questions.

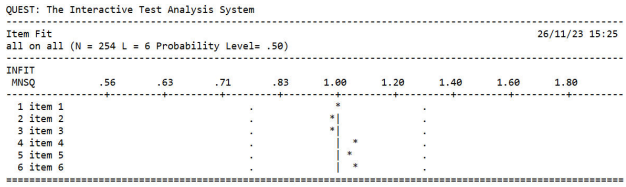

FIGURE 2. Results of analysis of question item conformity with PCM on visual representation ability questions.

TABLE XI. Results of problem reliability analysis.

Ability	Reliability value	Category
Critical thinking	0.55	Moderate
Visual representation	0.73	High

the results of the analysis of the suitability of visual representation ability items with the Partial Credit Model are shown in Fig. 2.

Based on Fig. 2, it can be seen that 6 items of visual representation ability show INFIT MNSQ values in the range of 0.77 to 1.33 so that it can be stated that all items are valid and in accordance with the Partial Credit Model (PCM). The results of the reliability value of the question instrument can be obtained through the Quest programme analysis on the output data ending in "sh" based on the reliability value of the summary of the case estimate. The summary of the case estimate reliability value can be categorised based on Table VI. Clearly, the results of the reliability analysis of critical thinking and visual representation instruments can be shown in Table XI.

Based on Table XI, the moderate category in the reliability of critical thinking skills questions is due to several factors that affect students in empirical tests which include fatigue, varying class schedules, and student motivation in working. This is supported by research by Setyaningsih *et al*. (2020) which states that students will lose concentration during the day due to reduced motivation and fatigue [64]. In addition, the placement of items affects item analysis where students tend to work in order, causing the reliability of critical thinking skills questions to be categorised as moderate. This is supported by the source of Clauser & Bunch, (2021) which states that reliability is influenced by various problem-solving strategies [65].

3.2. Effectiveness of using physics E-book of rotational dynamics in traditional top game with AR technology assisted

3.2.1. MANOVA statistical prerequisite test

Data on the value of critical thinking skills and visual representation can be said to be tested normally if it has a significance value (sig.)> 0.05 (greater than 0.05). The results of the data normality test can be shown in Table XII.

Based on Table XII, it can be seen that the Kolmogorov-Smirnov significance value on the value of the critical thinking ability variable and visual representation of students in each research class is greater than 0.05, which indicates that the data is normally distributed. While in the Shapiro-Wilk analysis, it can be seen that there is abnormal data on the control class critical thinking ability variable. This is because there are several factors that affect the normality of the data during the implementation test such as variations in the subject schedule and constrained external activities of students so that the number of students is not evenly distributed between classes. This is supported in the research of Realyvasquez-Vargas *et al*., (2020) which states that if one of the research classes has a small sample, there is a possibility that the data is not normal [66]. The results of the data homogeneity test using the Levene test analysis are shown in Table XIII.

Description: df 1: between-group degrees of freedom; df 2: within-group degrees of freedom; Sig.: Significance.

Based on Table XIII, it can be seen that the critical thinking and visual representation variables have a significance

TABLE XII. Results of data normality test.

Variables	Class	Shapiro Wilk					
		Statistic	df	Sig.	Statistic	df	Sig.
Critical thinking	Experiment 1	0.095	27	0.200	0.989	27	0.987
	Experiment 2	0.143	27	0.166	0.932	27	0.080
	Control	0.143	27	0.165	0.921	27	0.042
Visual representation	Experiment 1	0.129	27	0.200	0.963	27	0.440
	Experiment 2	0.150	27	0.123	0.936	27	0.099
	Control	0.117	27	0.200	0.961	27	0.394

TABLE XIII. Homogeneity test result using levene test analysis.

Variables		Levene statistic	df 1	df 2	Sig.
Critical thinking	Pretest	0.653	2	78	0.524
	Posttest	1.175	2	78	0.314
Visual representation	Pretest	3.025	2	78	0.054
	Posttest	0.278	2	78	0.758

TABLE XIV. Partial eta squared value results.

Class	Sig.	Partial eta squared	Category
Experiment 1	0.000	0.880	Large effect size
Experiment 2	0.000	0.895	Large effect size
Control	0.000	0.547	Large effect size

value greater than 0.05 (Sig.> 0.05) which indicates that the pretest and posttest data of critical thinking and visual representation variables come from samples with the same population or are homogeneous. So it can be concluded that the data on the value of critical thinking ability and visual representation at the implementation test stage comes from sample data taken from the same population and is homogeneous.

3.2.2. Product Effectiveness Test Through Partial Eta Squared Value

The results of the product effectiveness test can be seen through the partial eta squared value generated by the multivariate statistical test with Hotteling's Trace test. The categorisation of product effect size through the partial eta square value can be interpreted based on Table VII. The results of the partial eta squared value in the Hotteling's Trace test in the experimental 1, experimental 2 and control classes can be shown in Table XIV.

Based on Table XIV, of the three research classes that have the largest partial eta squared value in experimental research class 2, which is worth 0.895, which is then the next largest in experimental research class 1 worth 0.880, while the control class has the smallest partial eta squared value of 0.547. This shows that the use of flip-book products based on problem-based learning with the help of Ophysics is the most effective for improving students' critical thinking skills and visual representation compared to using physics e-book products on rotational dynamics on a top game with AR technology and products commonly used by teachers (`PowerPoints` teaching modules and practice questions). However, this needs to consider several influencing factors such as pretest-posttest data collection factors for each research class and smartphone devices used by students.

The factor of taking pretest and posttest data for each research class has different variations, research classes that conduct pretest-posttest in the last lesson hours tend to be less motivated and concentrated in working well and optimally compared to research classes that conduct pretest and posttest in the first lesson hours. This is in line with research by Mthimunye & Daniels (2020), which states that learning at the morning is better in concentrating and the emergence of motivation compared to daytime learning [67]. In the constraints of the devices used by students, some are not compatible because they use IOS smartphones and most of the students' smartphones have a small memory capacity, which inhibits students in installing physics e-book products on rotational dynamics in traditional top games with AR technology. This is in line with the research of Saha *et al.* (2021), which states that device incompatibility is a major obstacle for students in learning [68].

In addition, some learners' devices are difficult and not supported to access the AR presented in the e-book product in the research class, so that the use in learning is still not optimal and running well. This is supported in the research of Oliveira Da Silva *et al*. (2019), which states that a major inhibiting factor for students to access augmented reality is the type of device that varies in students so that some devices are not supported [69]. Therefore, the acquisition of partial eta squared values in experiment 1 did not get the optimal value compared to experimental class 2. But even so, the partial et squared value in experimental class 1 and experiment 2 is not far adrift so that if it is decided with consideration of the factors and constraints found, the use of rotational dynamics physics e-book products on traditional games of AR-assisted tops has good effectiveness with the level of "Large Effect Size" to improve students' critical thinking and visual representation skills compared to using problem-based learning-based flip-book products with the help of physics simulations and products commonly used by teachers (teaching modules, Power-Point, and worksheet).

3.3. E-book product of rotational dynamics physics on augmented reality-assisted traditional top game

An e-book product of rotational dynamics physics on the traditional game of tops assisted by augmented reality in this study can be shown in Fig. 3. The e-book is designed in the form of an `android` application using `Smart Apps Creator 3.0`. The e-book can be run using an `android` smartphone with a minimum operating system of 4.4 (kitkat). The e-book product is embedded with a practical simulation using augmented reality technology which is presented in the form of a hyperlink on the image so that it can be accessed when clicking the AR logo on the inquiry step. The type of AR used in this research is Marker Based Tracking so that it requires a marker to access the augmented reality practical simulation. The AR technology practicum simulation is designed using the Unity application to design a three-dimensional visualisation where several variables in the practical can be changed as an interactive practice medium for students as shown in Fig. 4.

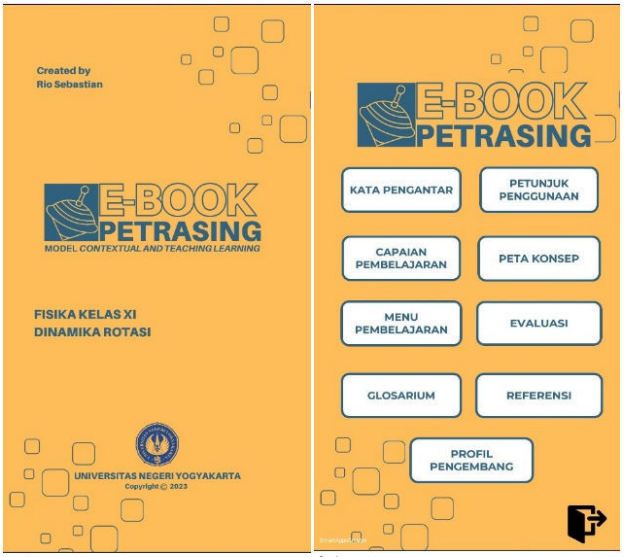

FIGURE 3. Cover a) and Main Menu, b) of the E-book.

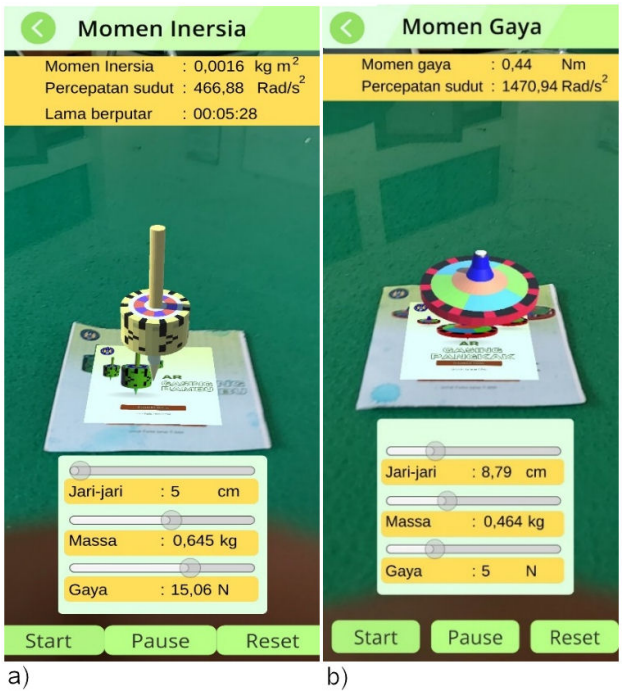

FIGURE 4. Simulation moment of inertia a) and force b) of AR Practicum in the developed E-Book.

While, the AR markers used are designed through Canva and then connected to the Vuforia Engine so that they can be embedded in the Unity programme. The construct parts of the physics E-book of rotational dynamics in the traditional AR-assisted spinning top game include the application icon, initial appearance, main menu, preface, instructions for using the e-book, learning outcomes, learning menu, learning activities 1-2, summative evaluation, glossary, bibliography, developer profile, final view, AR marker, and AR simulation display of learning activities 1-2 as shown in Fig. 3. The curriculum used to design learning in e-books is the Merdeka Curriculum. The learning objectives and indicators of learning achievement in the e-book are synthesised from the learning outcomes of the Merdeka Curriculum phase F which is oriented towards improving students' critical thinking and visual representation skills. The learning arrangement in the e-book uses the syntax of the Contextual Teaching and Learning (CTL) learning model which includes constructive, inquiry, questioning, learning community, modelling, reflection, and authentic assessment. E-book learning raises the material of rotational dynamics in the traditional game of spinning tops, which consists of two learning activities, namely learning activity 1 about the moment of force and learning activity 2 about the moment of inertia.

4. Conclusion

Based on the results of research and discussion, it can be stated that the physics e-book product of rotational dynamics in the traditional top game assisted by AR is effective in improving critical thinking skills and visual representation of students. This is shown through the Hotteling's Trace test, which produces a partial eta squared value to categorise the level of contribution to the effectiveness of e-book products. Hotteling's Trace test results on e-book products have a partial eta squared value of 0.880 which is included in the Large Effect Size category. In addition, this research plays a role in the advancement of science learning technology and preserving the traditional game of spinning top, which is increasingly eroded by modern games, so that the product can be used as a reference or material for learning physics at school.

5. Scopes and future works

The physics e-book developed in this study is still constrained by the presentation of AR to the e-book in the form of a web that can only be accessed for one month, so that in future research it is necessary to integrate AR simulations into the e-book application systemically and permanently so that it is inseparable from AR simulations. The physics e-book product developed in this study is still limited to the rotational dynamics material of the traditional top game case, so that future research e-books need to expand the scope of physics material by integrating other local content based on the character of the students at hand. The form of physics e-book application developed by this research is still limited to `Android` smartphone devices so that future research e-books need to be presented in web form or a more flexible form used by all devices so that they can be accessed easily by students.

Acknowledgements

The author would like to thank Yogyakarta State University for facilitating and guiding, this my research thesis, so that the article can be completed. In addition, the authors are also

grateful to LPDP (The Indonesia Endowment Funds for Education) for their support in conducting research and preparing articles.

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