Development of Physics E-Comic Momentum And Impulse Material Using Flipped Classroom Learning Method to Improve Student's Mathematical Representation and Critical Thinking

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Abstract. Rapid technological advances have made it easier for students to study flexibly. E-comic has been proven as an effective learning medium at various levels of education. The purpose of this research is to produce appropriate learning media for momentum and impulse material. In addition, this study also measures the effectiveness of using e-comics in physics learning, and analyzes students' abilities in mathematical representation and critical thinking. This development research uses the ADDIE model with five stages. The research instruments included product feasibility assessments by the validator, student response questionnaires on the use of e-comics using the flipped classroom method, as well as tests of mathematical representation abilities and critical thinking. The research design involved a pretest-posttest control group with three comparison classes using teaching media. The research was conducted in X class Senior High School. The research subjects included X class students who were randomly selected using the cluster sampling technique. Data analysis begins by examining the feasibility of media, lesson plans, and test and non-test instruments such as questionnaires, observation sheets, and interviews. Instrument validation was carried out with V Aiken and quest software. The media hypothesis and effectiveness were analyzed using SPSS, while the student's ability profile was analyzed using the output quest. The results of the study show that the physics e-comic developed is feasible for use in learning momentum and impulse. The Manova test shows that the use of e-comics significantly improves students' mathematical representation abilities and critical thinking, with an effectiveness of 84%. Student ability profiles ranged between moderate and low on the topic of momentum and impulse.

Keywords: Critical Thinking, E-Comic, Flipped Classroom, Instagram, Mathematical Representation

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1 Introduction

The 21st century is a period of time where all aspects of life must adapt to technological advances that are so sophisticated. One of these aspects is the field of education. The current educational curriculum helps students and educators to carry out learning processes that utilize technology in learning activities such as smartphones [1]. Learning activities that utilize technology can be carried out flexibly and are not fixated on teaching that is teacher-oriented, but learning can be carried out individually by students [2]. One of the advantages of using technology in learning is that teachers and students can have various teaching materials such as e-book, e-module, e-LKPD, e-comic, and so on.

Physics is one of the subjects that uses technology a lot in its learning activities, to help understand and master concepts. Physics material for high school students consists of various KD and KI, one of which is the KD material on momentum and impulse. The results of research on understanding the concept of momentum and impulse materials are still not optimal [3]. Students still lack conceptual understanding due to misconceptions about the law of conservation of momentum in students when learning [4]. Problems understanding students' concepts lead to a lack of student interest in learning about momentum and impulses, of course this has an impact on solving students' problems.

The low ability of students' mathematical representation and critical thinking can be seen through the learning outcomes and student behavior when participating in the learning process in class. Students' interest is still minimal in calculating mathematical operations and students' way of reasoning or thinking is still less than optimal regarding physics concepts. Responses from teachers and students were obtained to create alternative learning media to improve mathematical representation and critical thinking skills. Comic media can be said to be a learning medium that is simple, clear, easy to understand, and more personal so that it can be used as informative and educative teaching material. Student responses show that comics are an attractive medium because they are easy to understand. Comic plots are more interesting to prevent student boredom [5]. It is hoped that comics can foster students' curiosity to deepen their understanding of the material they are studying [6]. This makes comics an attractive choice for students to improve their mathematical representation and critical thinking.

Physics learning contains various abilities that students need in order to be able to solve problems that exist in the concept of physics. The ability of mathematical representation is an example of a basic ability that must be occupied by students [7]. Mathematical representation abilities are still lacking in students, there are problems such as students still having difficulty placing positive and negative number symbols resulting in wrong calculations [8]. Another error is when using arithmetic symbols in solving problems, and determining variables to make equations [6]. Students are more likely to memorize formulas in the learning process, without understanding complete and clear stages of completion [9], [10]. The concept of momentum and impulse also emphasizes its nature or application, but students pay more attention to the formula [11]. Some students are also fixated on formulas without knowing the proof or origins of how these formulas can be used in physics concepts [12]. The results of studies regarding students'

mathematical representation abilities indicate the need for learning that can help students improve their mathematical representation abilities.

Student learning activities cannot be separated from thinking skills such as logical thinking, analysis, critical, systematic, critical, and the ability to collaborate. Physics learning also primarily requires students to have critical thinking skills because critical thinking is considered an important component in activities to solve physics problems [13], [14]. The results of previous studies showed that students were not well trained with HOTS questions, resulting in low critical thinking skills [15]. The results of the research through assignment reports as many as 23.53% of students still have weak critical thinking skills [16]. The low level of critical thinking is also influenced by students' habit of memorizing material and formulas rather than analyzing concepts [17]. In addition, monotonous and boring learning activities can hinder the process of transferring knowledge from teachers to students [18]. Therefore, follow-up research is needed to improve the critical thinking skills of high school students.

Momentum and impulse is one of the materials taught in X class at senior high school in even semester. In studying this material, students also often make mistakes in working on questions related to the material [19]. The most common error that also occurs in students is looking for a solution strategy such as errors in symbolic use or mathematical calculations that often occur [20]. Therefore, students' mathematical representation and critical thinking abilities need to be improved in order to achieve the learning objectives of momentum and impulse that are successful and good for students.

The impact of technological developments and even the use of computers smartphone very rapidly for the world of Education. In this regard, one of the interesting teaching materials is comics [21]. Until now, comics have a high interest for readers to read because they feature humor, narrative and visual imagery [22], [23]. The use of words and conversations in comics can be made into simpler sentences so that students can more easily understand in studying science [24]. Usually comics are made on paper, but nowadays comics can also be made using digital technology [23], [25], [26]. Comics can be displayed using a smartphone so that the current trend of learning styles can make learning more real, efficient and easy to do [27]–[29]. Comic media can be said to be a learning medium that is simple, clear, easy to understand, and more personal in nature so that it is informative and educative.

The learning method is one of the major impacts of the success of students in the teaching and learning process. Flipped classroom is a method where students learn material outside the classroom and practice in the classroom with the guidance of the teacher [30]. This method provides opportunities for students to learn material at their own pace and time in class is used to solve problems in their learning [31]. Learning activities before entering class focus on students' LOTS abilities, so that in class students can focus on HOTS abilities.

The description above explains that the ability to represent mathematically and think critically as well as the development of physics comics is very good to continue in the learning process to create a sense of independent learning for students. This research aims to develop e-comic physics products on momentum and impulse material that are appropriate for use to improve their mathematical representations and critical thinking, as well as to determine the effectiveness of using e-comic products and to determine

the profile of students' abilities on momentum and impulse material, especially in the ability of mathematical representation and critical thinking.

2 Method

This study uses the ADDIE model with five stages consisting of analysis, design, development, implementation, and evaluation [32]. Figure 1 shows the stages at each stage of development,

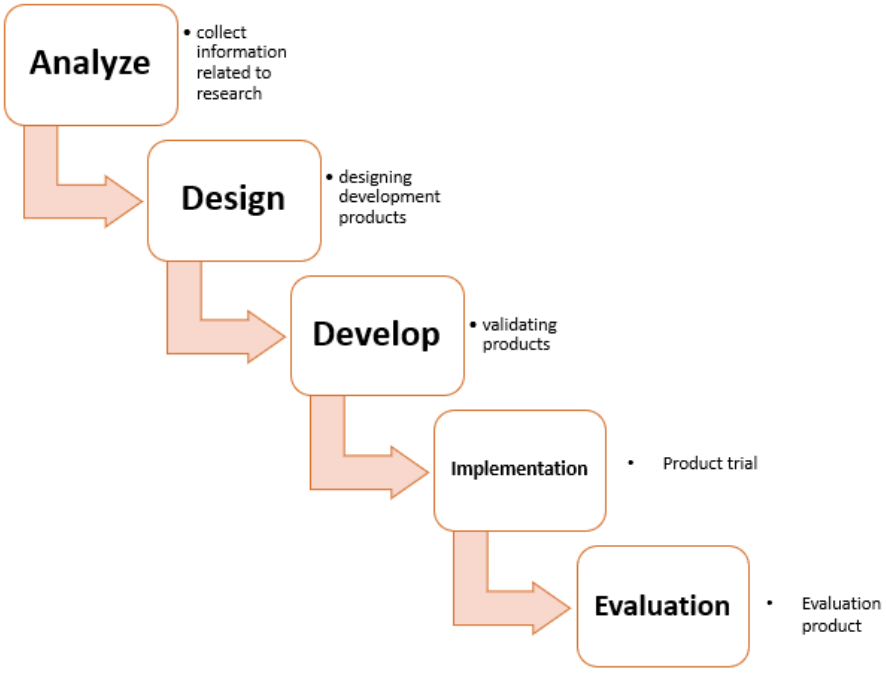


Fig. 1. ADDIE Model Research

The research design in this study is a research design pretest-posttest control group desain. Pretest-posttest control group design This design consists of an experimental group and a control group which have the same characteristics, because they were taken randomly from a homogeneous population [33]. Table 1 shows the design of this study

Table 1. Research Design

Class	Test	Treatment		Test
		Media	Method	
Experiment 1	Pre Test	E-comic	Flipped	Post Test
Experiment 2		LKS		
Control		PPT		

This research uses three classes or groups, namely experimental class 1, experimental class 2, and control class. The three classes were given a pretest, then continued with the administration treatment teaching materials used. The teaching material for the experimental class 1 was physics e-comics, for the experimental class 2 was worksheets and the control class used conventional, namely teacher PPT. The learning method for the three classes is the same, namely the method flipped classroom

The population in this study were all students of class X at senior high school. The subjects of this study were students in class X_1, X_2 and X_3 in the academic year 2022/2023 totaling 108 students who were randomly selected using thecluster sampling. The data collection instruments in this study are arranged as Table 2,

Table 2. Data Collection Instruments

Data Collection Techniques	Instrument Type	Instrument	Data
Test	Pretest and posttest	Test the ability of mathematical representation and critical thinking	Student
Non test	Observation	Analyze the concepts, assignments and learning activities of students	Students and teachers
	Interview		
	Photo documentation		
	Student Response Questionnaire	Knowing the response to the use of e-comics	

Product feasibility assessment is carried out by calculating the score on the assessment sheet. Each item of the assessment sheet statement uses a score of 1 to 4 [34]. The score calculation goes through several stages: first, transforming the ordinal scale into intervals. Second, calculating the average product rating [35],

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

third, categorizing product feasibility based on criteria.

This development research wanted to use the SPSS-assisted MANOVA test in processing data. The data that is processed must first go through prerequisite test analysis (Stevens, 2002) such as the normality test and homogeneity test. If the significance value is less than 0.05, the data is normally distributed and homogeneous. The value of effectiveness can be known through GLM analysis (General Linear Model) with multivariate analysis and categorized the value of its effectiveness.

The results of students' mathematical representation and critical thinking ability profiles on momentum and impulse material were analyzed with the help of QUEST software on the output .ca. The .ca output will display the output value T (Z), then analyzed using the formula,

$$T = 10(Z) + 50 \quad (2)$$

Equation 2 will be processed so that the T output value becomes positive so that it can be categorized as students' mathematical representation abilities and critical thinking in the high, medium, and low categories.

3 Result and Discussion

This development research refers to the ADDIE model which starts from analysis, design, development, implementation, and evaluation to produce e-comic physics teaching material products on momentum and impulse material for high school students in improving their mathematical representation skills and critical thinking.

3.1 Analyze Stage

This first stage was carried out with the aim of collecting and obtaining information related to physics learning activities in X class at senior high school. The results of the study found that the school still uses the 2013 curriculum with the material being discussed in accordance with Permendiknas no 69 of 2013. The physics learning process still uses books provided by the school. The most frequently used learning methods are discussions and questions and answers. Learning activities are emphasized on affective, cognitive, and psychomotor aspects. But in fact the curiosity and desire of students in learning has increased and decreased as in previous years, especially in cognitive aspects such as how to count and how students reason in such as mathematical representation and critical thinking.

3.2 Design Stage

This second stage is divided into several stages, namely: analyzing the physical aspects contained in the physics e-comics of the momentum and impulse material, designing a physics e-comic product and creating a validation sheet to be validated by experts. The media design stage is carried out by making the characters in the e-comic, then proceed with making a storyline (including determining the conversation, text balloons, and the background behind the conversation in the story).storyboard e-comic development design, then combining all of these design stages to become a comic through the Canva application. The storyline is made in advance using the help of software Microsoft word to determine the parts of each character's conversation. The images include the characters and background specified and do the sorting on the sub menu element on Canva. The final stage of the design was to incorporate comic physics into the mix feeds instagram account. Students and readers will access comics through smartphone each through the Instagram application with the search username for the Instagram account @physicscomic.

The e-comic development format includes content opening, developer identity, e-comic reading guide, concept map, introductory story, character introduction, and comic content (episode 1, sample question video 1, practice questions, episode 2, video sample questions 2, practice questions, episode 3, video sample questions 3, practice

questions, and episode 4, video sample questions 4, practice questions). Moment and impulse physics e-comic media is equipped with additional photos to complement the material. The photo contains interesting facts about the application of momentum and impulse in everyday life. The final product form of e-comics before being uploaded to Instagram is .JPG and all of these photos will be posted on Instagram using a laptop in the final stage. Moment and impulse physics e-comics can be accessed using computers or smartphone with various brands such as Android or IOS.

The following are some examples of material physics e-comic media display of momentum and impulse using the method flipped classroom learning can be seen in Figure 2 for the overall view, and Figure 3 Comic cover,

Fig. 2. Display of Momentum and Impulse Physics E-comics on Smartphone

Fig. 3. Samples of Physics E-Comic Design

3.3 Development stage

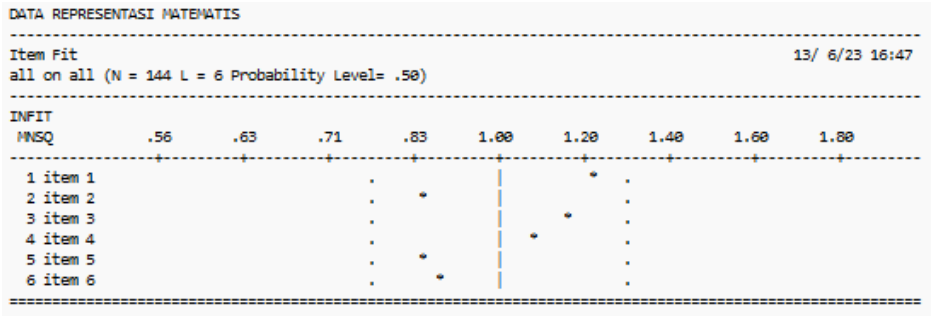
The development stage is carried out by validating research products and instruments to experts. The development media that have been developed are validated by expert lecturers (media and material), 2 physics teachers, 3 peer reviewer. The task of these validators is to provide an assessment of product development based on the feasibility of the material and media presentation.

The development stage is divided into two parts, namely, the validation stage and the limited test, where the limited test consists of two stages, namely the empirical test and the small-scale test or what is known as the initial field test.

Fig. 4. Empirical Test

Product feasibility assessment is divided into two parts, namely media feasibility and material feasibility. Means that have been categorized in the assessment of media and material products of e-comic physics material momentum and impulse with the method flipped classroom learning have categories that are eligible to be used as learning media.

Item analysis was done using software Quest. Empirical tests were conducted to determine the reliability of the items to be used in large-scale experiments.



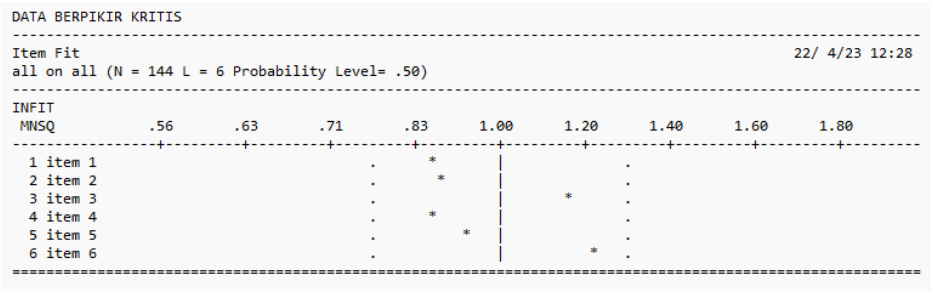


Fig. 5. The results of the analysis of the mathematical representation and critical thinking of fit items

Figure 5 shows the item item ability of mathematical representation is in a state of fit or feasible to use. Infit value meansquare are in the range of values from 0.83 to 1.20 for the ability of mathematical representation items. While value the mean square is fitted critical thinking is in the range of 0.84 to 1.22. So it can be concluded that the items of mathematical representation ability and critical thinking are included in the good category. Testing the reliability of questions on the ability to test mathematical representation and critical thinking summary of case estimates each ability is 0.72 and 0.80. Both values are included in the reliable category. Reliable means that the items in the items are good for use as a research test instrument to measure the ability of mathematical representation and critical thinking.

Profile measurement of students' mathematical representation and critical thinking abilities on momentum and impulse material. The category of students' abilities in this mathematical representation item can be seen in two categories, namely medium and low. Students' Z scores still show below average but there are still high scores, this is because the research subjects for empirical tests were conducted on grade 11 students who had studied momentum and impulses in grade 10.

Small-scale tests or initial field trials were carried out for small class. The assessment was carried out by students using a questionnaire in response to the use of e-comic media physics material on momentum and impulse with learning methods flipped classroom which has been validated by expert lecturers. The results obtained in the small-scale test are feasible products with a percentage of 100% for use in the learning process of momentum and impulse material.

3.4 Implementation Stage

The implementation phase was carried out with the aim of knowing the effectiveness of using e-comics in improving the ability of mathematical representation and critical thinking of high school students in the subject of momentum and impulse by using the method flipped classroom learning. The process of implementation stages produces results of field trial data consisting of several things, namely: implementation of lesson plans and student response questionnaires to the use of momentum and impulse physics e-comic media. The result of the implementation of the lesson plan is the reliability of the results of observations of the implementation of learning included in the reliable category, which means that overall all stages of the lesson plan are carried out in the learning activities in class.

Experimental class students who use e-comic media physics material on momentum and impulse by applying the method flipped classroom gives 100% decent results, which means students agree in using the e-comic media physics of momentum and impulse material by applying the method flipped classroom learning in learning.

Fig. 6. Use of Momentum and Impulse Physics E-comic in Class

3.5 Evaluation Stage

The evaluation stage wants to see the effectiveness of using e-comics in classroom learning. Testing the effectiveness starts from the prerequisite test for normality and homogeneity. Normality testing data on the test Kolmogorov-Smirnov because the test subjects are more than 100 (> 100). Table 3 shows earned value them selve.more than

0.05 for score pretest and posttest ability mathematical representation of the experimental class 1, experimental class 2, and control class. So that it can be stated that it is accepted, because according to statistical theory the data can be said to be normal if the value them selves greater than 0.05. This also proves that the data for the three classes, both experimental class 1, experimental class 2, and class contrast, are normally distributed.

Table 3. Normality Test

Test	Class	Sig	Decision
Pre Test Math Representation	Experiment 1	.200	Normal
	Experiment 2	.179	Normal
	Control	.055	Normal
Post Test Math Representation	Experiment 1	.090	Normal
	Experiment 2	.200	Normal
	Control	.200	Normal
Pre Test Critical Thinking	Experiment 1	.078	Normal
	Experiment 2	.200	Normal
	Control	.200	Normal
Post Test Critical Thinking	Experiment 1	.090	Normal
	Experiment 2	.200	Normal
	Control	.157	Normal

Table 4. Homgenity Test

Box'M	F	Sig	Decision
5.534	0.519	.878	Homogen

Based on the homogeneity test, the significance value of the Box's Test is 0.593, which means more than the significance level used (0.05), then it is accepted. This means that the sample is homogeneous and comes from a normally distributed population. So by using the significance level it can be concluded that both the experimental class 1, the experimental class 2, and the contrast class have the same matrix of variance covariance of the dependent variable.

The increase in the ability of mathematical representation and critical thinking is seen through the hypotheses in the MANOVA test using SPSS 24 software.

Table 5. MANOVA test

Effect	Sig.	Result
Hotteling's Trace	0,000	$\boldsymbol{H_0}$ rejected

Table 5 show the results of the analysis obtained with a significance value of 0.000 <0.05 were rejected. In conclusion, there are differences in the ability of mathematical representation and critical thinking of students who use physics e-comic media with learning using worksheets provided by schools, and also PPT provided by teachers using the flipped classroom during learning.

Table 6. Test of Within-Subject Contrass

Source	Measure	df	F	Sig
Time*kelas	Measure_1	2	11.358	.000
	Measure_2	2	9.013	.000

Table 6 show the significance value of the time*class section shows a result of 0.000 <0.05, this indicates that there is a significantly different interaction between pretest and posttest for mathematical representation abilities and critical thinking in each class.

Table 7. Pairwise comparison

Variabel	Class	Sig
Math Representation	Experiment 1	.000
	Experiment 2	.000
	Control	.000
	Experiment 1	.000
	Experiment 2	.000
	Control	.000
Critical Thinking	Experiment 1	.000
	Experiment 2	.000
	Control	.000
	Experiment 1	.000
	Experiment 2	.000
	Control	.000

Table 7 show the significance value of the variables of mathematical representation and critical thinking shows a result of 0.000. This indicates that there is an increase from the pretest score to the posttest score in each class because the sig value <0.05.

The results of the effectiveness contribution were analyzed based on the SPSS output in the multivariate table. The different effectiveness between classes means that there are differences in effectiveness, as follows, fisrt; The effective contribution of the experimental class 1, experimental class 2, and control class to increasing the ability of mathematical representation and critical thinking were 84%, 74%, and 80%, respectively. Second; The effective contribution of the experimental class 1, experimental class 2, and control class to increasing the ability of mathematical representation is 17.8%. Third; The effective contribution of the experimental class 1, experimental class 2, and control class to critical thinking skills was 14.7%.

Summary of student responses on the use of momentum and impulse physics e-comics during learning takes place including: first; Learning using physics e-comics material on momentum and impulse contains fun stories so that there are new experiences in learning physics. Second; E-comic physics of momentum and impulse material is very interesting to use in learning because it contains easy-to-understand explanations. Third; Strengthening the concept of physics in physics e-comic material is also interesting because it uses the application of physics concepts in everyday life so that it makes it easier for students to learn. Fourth; Stories in physics e-comics display the

estimated errors in solving physics problems. This really helps students in learning so as to minimize the inaccuracy of students.Method flipped classroom It is also interesting because students are required to read the material first so that learning becomes more meaningful. Fifth; Overall, the material for physics e-comics, which includes examples of questions in the form of videos, e-comic storylines, and practice questions, are all good and interesting.

4 Conclusion

The research that has been going on has three conclusions according to the research objectives, namely, firstly, a physics e-comic product has been produced that is feasible for use in high school physics learning activities on momentum and impulse material using the flipped classroom learning method. Second, the effectiveness value of using e-comic physics teaching materials on momentum and impulse material using the flipped classroom method is 84% which is in the high category. Third, the profiles of students' mathematical representation abilities and critical thinking on momentum and impulse material fall into the high, medium and low categories.

There are three limitations to this research, namely, first; the second meeting was hampered by the presence of PPG students who taught over time, resulting in reduced research time. Second, the implementation of the pretest was not optimal for some students because they attended seminars held at school. Third, there were only 144 empircal test subjects using quest due to limited research time with the eid holiday.

Suggestions for utilizing media that has been developed as, first; development of physics e-comic media on momentum and impulse material using the flipped classroom method which can be created for physics material and other learning methods. Second; media capacity must be considered, this is intended for all students can access well the product using PC or smartphone. Third; use of e-comic in the class need control from the teacher so that students can't open other smartphone applications causes students can lose focus in learning.

5 Authors' Contributions

Angela designed and conceptualized the research to be carried out, such as drafting concepts and drafting learning product designs, designing learning activities, analyzing the data obtained, finding and selecting schools for research, and taking care of all research administration and saving funds. Mundilarto oversees product development to research to research supervision, validates media products, and review draft articles. All authors have read and agreed to the published version of the manuscript.

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