Physics Formative Feedback Game: Utilization of Isomorphic Multiple-choice Items to Help Students Learn Kinematics

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Abstract **– In a physics classroom, kinematics is an essential concept that must be mastered before learning others. The students need ongoing practice and assistance in understanding it. Formative assessment is one of the alternatives to help students reshape their conceptual understanding, but its implementation is often constrained. The implementation of isomorphic multiple choice items as part of computer games is expected to help them overcome the problems. Physics Formative Feedback Game (PF2G) has been developed by utilizing isomorphic multiple choice items. Based on the results of the initial trial, PF2G got a good response, from the physics teacher and also from the students.**

Keywords **– formative feedback game, isomorphic items, kinematics graphs**

1. Introduction

Kinematics graphs are critically important and must be mastered by the students in learning physics. The students' mastery in graphics interpretation is often related to the understanding of science concepts [1]. According to Petrova [2], various physics problems required the ability to interpret graphics in its solution. Furthermore, if the students have a good interpretation of physics graphs, they will also tend to interpret graphs in other disciplines well [3].

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Specifically, in kinematics graphs can deepen students' knowledge [4]. This is important because the concept of kinematics is the basic needed for students in solving other problems of physics.

The students' difficulties about kinematics graphs were identified by several researchers. They consider the graph to be a real situation of object motion, difficulty in determining the slope of the graph if the line does not cross the origin and confusion about the area under the curve [5]. This was also revealed in a study conducted by Planinic et al. [6]. This study found other difficulties for students in understanding the shape of the curve and describing a graph into a statement. Other researchers also found students' difficulties in distinguishing various types of motion graphs (x-t, v-t, a-t) [7].

Various attempts have been made to overcome the students' difficulties related to the kinematics graph problems. The information related to students' difficulties in interpreting kinematics charts can be used in improving their kinematics learning outcomes [8]. By using microcomputer based laboratory tools, Antwi et al. [9] succeeded in increasing students' understanding of kinematics graph. Moreover, as Çelik & Pektaş [10] noted, the use of information technology in learning had a significant influence on improving students' ability to interpret graphs. In addition, Cagande [11] succeeded in increasing the ability of students to interpret graphics using a flipped classroom. These studies showed that students' ability to interpret kinematics charts can be improved in a planned learning process through the help of technology.

One attempt that needs attention in the learning process is formative feedback. As pointed out by Evans et al. [12], immediate formative feedback for each question was useful for the development of students' learning. Feedback is also useful to know the development of their learning, their shortages in learning, and improve the teaching and learning processes [13]. Providing repeated formative feedback on an ongoing basis can lead to the success of the learning process [14]. Moreover, formative feedback plays an important role in a students' learning experience [15]. The application of formative feedback also significantly increases academic achievement and students' attitudes towards class and influences their self-regulation skills [16]. In line with those results, the research conducted by Ozan & Kıncal [17] also showed that the use of formative feedback and assessment can overcome the problems experienced by students generally.

Although formative feedback is needed to support students' learning, providing repeated and ongoing feedback is not easy to implement. In this case, the teacher needs to know the various types of difficulties experienced by them and provide appropriate assistance [8]. The factors of limited time, number of students, and the variety of problems experienced by students are some of the obstacles for providing this feedback. From the student side, several studies have shown that students' interpretation of graphs is highly dependent on the context of the problem [4], [18]. Therefore, they need a system that can support them to identify and realize the difficulties and try to get learning assistance. However, this kind of effort has not been much developed, especially with regard to learning basic concepts of physics such as kinematics graph problems.

One solution that can be developed to overcome the formative feedback problems above is utilizing computer games. At this time, computer games have developed rapidly and provided benefits in the area of education. The use of game-based applications can be effectively used in learning in order to improve students' achievement [19]. The use of games in assessment can also be used to determine the students' skills and knowledge [20], [21]. According to Dempsey et al. [22], computer games do not only have the potential to be applied in learning but also in the assessment. The assessment should not only assess the students' learning outcomes but can also facilitate their learning processes. Formative assessments can help them identify difficulties and provide feedback in accordance with the difficulties faced by them [23].

At this time, many computer games and kinematics learning media have been developed. A fairly modern media is a motion tracker tool that is integrated with a computer to visualize movement into a computer [24] and augmented reality to visualize graphics in a three-dimensional form [25]. Broadly, the variety of learning media kinematics graphs is explained in a systematic review by Duijzer et al. [26]. Computer-based media are usually accompanied by multiple choice test items. This happens because the computer is suitable for use with this kind of test [27]. However, the use of multiple choice test forms has the possibility of student users not really thinking, but only guessing the answers [28]. To overcome this, an isomorphic multiple choice item model consisting of three multiple choice items with the same learning indicators can be utilized. Thus the use of isomorphic items will examine the consistency of student responses and detect students who only guess the answers... In isomorphic question types, the level of students' confidence in answering is considered [29]. Furthermore, isomorphic items can identify their difficulties, so specific feedback can be given [30]. However, this kind of computer game has not been developed.

Based on the background above, this study aims to develop PF2G with isomorphic multiple choice items on kinematics graphic material and determine the feasibility of the product at the trial classroom.

2. Methods

This development research involved 100 high school students and several physics teachers. The stages of research include: (1) preliminary studies, (2) product development, and (3) try out. In the preliminary study, a literature study was conducted to examine the results of research on kinematics graphic difficulties, approaches to overcome difficulties and the recent development of media and games related to the formative assessment. Based on various learning difficulties of kinematics graphs found, the researchers determine and develop learning indicators as a reference to develop isomorphic multiple choice items and other learning materials. Furthermore, for each learning indicator, 3 isomorphic multiple choices of multiple points were developed so that a total of 18 points were produced. The set of learning indicators and items were reviewed by the material experts and teacher to get suggestions for improvement. After the revision, the test items were tested on conventional high school students. This set of multiple choice items became material for developing formative feedback games.

In the product of the development stage, designing a formative feedback game, developing product prototype, and validation were carried out. The main components of this formative feedback game are isomorphic items and related learning material, especially in videos. In the design of this game, students faced 3 isomorphic multiple choice items. If they feel confident about their answer, they could proceed to the next problem without any feedback and so on until they answer the three points isomorphic multiple choice. Based on their response, the system will analyze with the decision not to master if there is one wrong answer. Those who are in the category not master this will get an explanation of the video explanation in accordance with the difficulties they experience. They are also expected to be able to repeat in answering isomorphic multiple choice questions. Meanwhile, if they master, they can continue to the next isomorphic problem. The PF2G design can be described in Figure 1. The validation was carried out by three high school teacher validators and a physics lecturer. The revised question and prototype items were then tested on 100 high school grade X students.

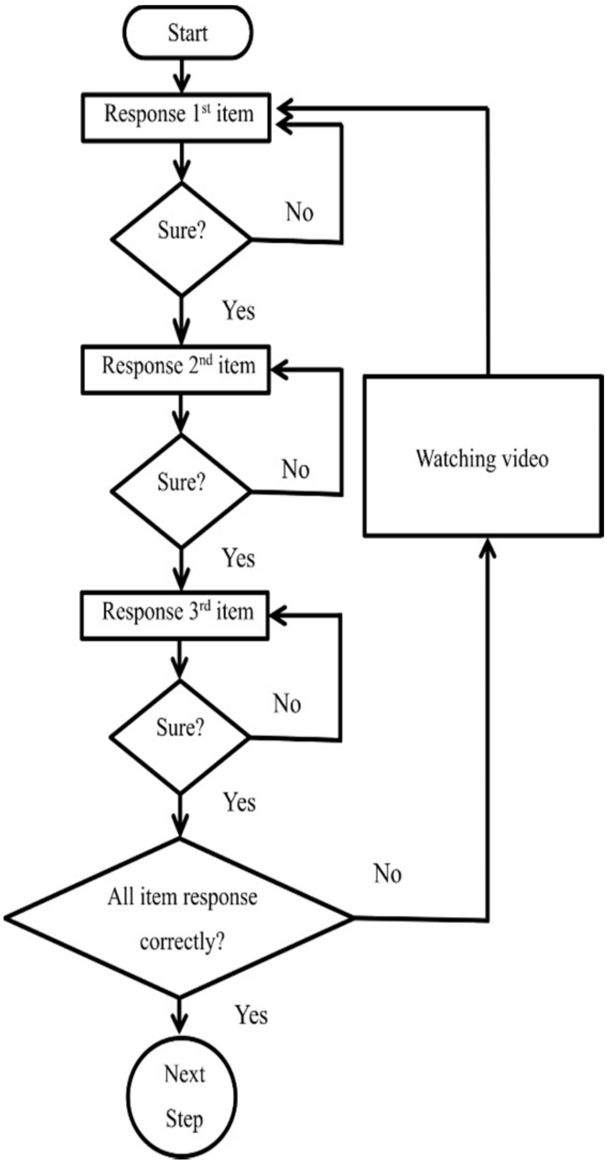


Figure 1. Physics Formative Feedback game design

The type of data collected was based on the design of trials in the development research. The data were gathered in quantitative and qualitative data. Quantitative data were obtained from scores on the question and product validation assessment questionnaire by the validator and assessment questionnaire from the product readability questionnaire by students. Qualitative data were obtained from comments and suggestions by validators and students. A descriptive analysis was carried out in this study.

3. Results and Discussion

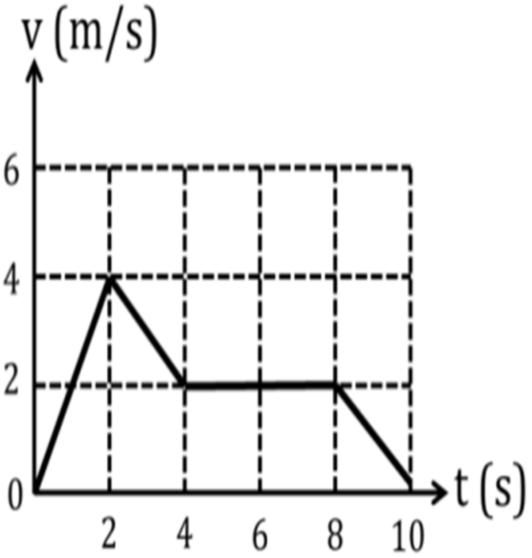
Based on the results of a literature review on various difficulties related to kinematics charts, six learning indicators were developed. For each indicator, then 3 isomorphic multiple choice items were developed so that a total of 18 items are obtained with (r=0,58). These test items were then reviewed by subject matter experts and physics teachers and improvements were made based on expert input. From the results of the tests on students, the internal consistency data of the test items are obtained as in Table 1.

Table 1. Internal consistency of test item

Learning indicator	Item No.	Discrim-ination index	Difficulty index	Point-biserial
Analyzing the speed of an object based on a position-time graph	1	0,37	0,24	0,40
	2	0,57	0,40	0,55
	3	0,50	0,50	0,44
Analyzing the motion of an object based on a position-time graph	4	0,30	0,32	0,48
	5	0,30	0,65	0,45
	6	0,30	0,55	0,30
Determining the quantity of speed of an object based on a position-time graph	7	0,40	0,69	0,48
	8	0,40	0,31	0,36
	9	0,20	0,20	0,27
Determining the quantity of distance of an object based on a position-time graph	10	0,20	0,20	0,27
	11	0,03	0,07	0,29
	12	0,00	0,11	0,33
Determining the quantity of acceleration of an object based on a velocity-time graph	13	0,10	0,04	0,38
	14	0,03	0,02	0,32
	15	0,17	0,10	0,24
Determining the velocity-time graph based on the information of acceleration-time graph	16	0,23	0,09	0,41
	17	0,20	0,71	0,42
	18	0,03	0,11	0,21

One of the questions developed in the formative game can be seen in Figure 2.

A moving object with a velocity graph (v) with respect to time (t) can be described as in the graph below.



The acceleration of the object during the first two seconds is ...

A. $-2{,}0$ m/s^2 C. 4,0 m/s^2 E. 9,8 m/s^2

B. 2,0 m/s^2 D. 8 m/s^2

Figure 2. An example of a question item

The data on the results of students' responses were also analyzed to identify mastery of concepts and students' difficulties on kinematics charts. The results of the analysis of students' answers as a whole can be seen in Table 2.

Table 2. Students' Conceptual Understanding (max score 18)

Statistics	Value
Mean	5,56
SD	2,67
Min	1
Max	17

The average score of the students is 5.56 from the maximum score of 18. This shows that the students' mastery of the concept of kinematics charts is still low. Many students have difficulty in understanding and interpreting kinematics charts. The difficulty of students in understanding kinematics graphs in more detail can be determined by analyzing the percentage of students' correct answers per learning indicator. The results of the analysis of students' responses to 18 test items and 6 learning indicators can be seen in Table 3.

Table 3. Percentage of the correct answer

No.	Learning Indicator	Correct Percentage (%)
1	Analyzing the speed of an object based on a position-time graph	30
2	Analyzing the motion of an object based on a position-time graph	50.7
3	Determining the quantity of speed of object based on a position-time graph	40
4	Determining the quantity of distance of object based on a position-time graph	12.7
5	Determining the quantity of acceleration of object based on a velocity-time graph	5.3
6	Determining the velocity-time graph based on the information of an acceleration-time graph	30.3

The mean percentage of correct answers is 29.5% giving a hint that only a small proportion of students can interpret the kinematics graph well. It can also be said that most students have difficulty in interpreting graphs, especially in indicators 5 and 4. They have difficulty in determining the amount of acceleration if they are confronted with a time-speed graph. The highest percentage of correct answers was related to analyzing motion based on a position-time graph.

By using an isomorphic concept, the students' answers to a specific indicator are categorized as "understand" if 3 items are answered correctly, "partly understand" if 2 items are correct, and "misunderstand" if only 1 is true or all wrong. The recapitulation of students' answers can be seen in Table 4.

Table 4. The result of analyzing students' conceptual understanding category

Learning Indicator	Percentage (%)		
	Understand	Partly Understand	Misunderstand
1	10	26	64
2	20	35	45
3	3	26	71
4	1	5	94
5	1	1	98
6	3	11	86

In the next stage, a formative game feedback system is designed. Broadly speaking, the formative game feedback system design is as shown in Figure 3.

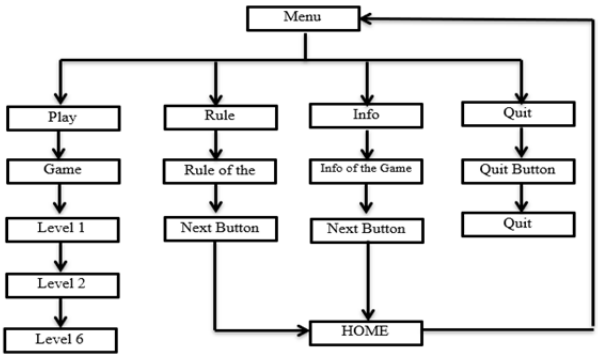


Figure 3. Navigation of game

The menu in this game consists of 4 parts with the main part is the game itself as shown in Figure 4. The rules menu is the menu that the users are expected to read before using the game. In the rules section, it is emphasized that this game is designed to help students learn. The game will identify students' conceptual understanding and provide assistance in the form of video explanations if they experience concept errors or difficulties. If they succeed in working on 3 isomorphic items, they will be challenged to work on other isomorphic items until finally, they complete all indicators related to the kinematics graph. The information page explains about the game in general, the developer, and the purpose of its development. The quit button is navigation to exit the game.

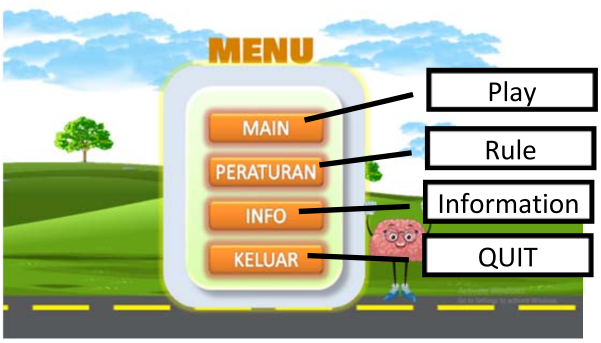


Figure 4. Menus of the game

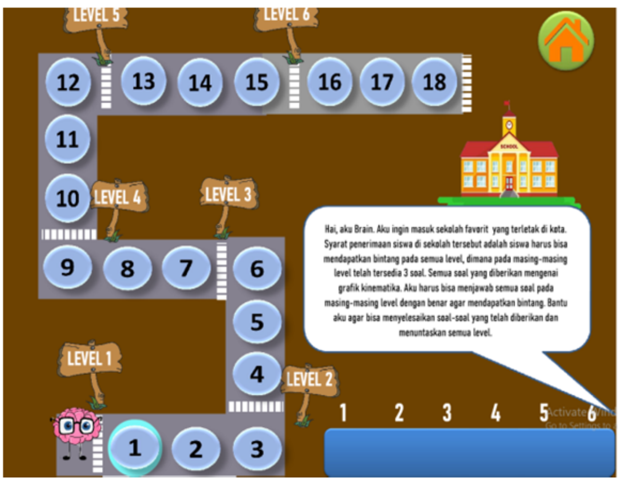


Figure 5. PF2G Appearance

If users enter the game, they will see PF2G appearance and challenge to work on a multiple choice problem as in Figure 5. If the user has chosen an option, they will be asked by the system whether they are sure of the answer. If the user presses the sure button, they will be challenged with the second question. After the user has answered the three problems at this level, the software will analyze the answers. If there is one or more wrong answers, the user is considered not to have mastered the learning indicators. The users can only continue to the next level if they have perfectly answered the three questions presented. If the user has completed the game stage up to level 6, it is expected that the user can master the kinematics graph concept.

Figure 6. Item test and justification

In the next stage, the prototype of the product developed was reviewed by the subject matter experts and teachers. The review includes content validation of multiple choice items used and a review of the entire prototype. There were six aspects assessed in the validation of formative feedback game products with isomorphic items. The average value of the three reviewers is 3.84 from the maximum score of 4. This result showed that the product formative feedback game with isomorphic items was believed valid or feasible to be tested on the students with several revisions. The reviewers also provide input to improve the prototype that had been developed.

After a revision based on expert's and teacher's input, the formative feedback game products were given to 100 high school students. They were given an assignment by the teacher to utilize the game in addition to face-to-face learning. Two weeks after they received the game file, they were asked to fill out a questionnaire regarding their perception of the game. A summary of the results of perception is as in Table 5.

Table 5. Summary table of students' perceptions about PF2G

No	Question	Percentage (%)	
		Yes	No
1	Is the game easy to run?	89	11
2	Are the images and colours in this game interesting?	89	11
3	Is the type and size of letters in the game suitable and comfortable to read?	91	9
4	Is the language used in games easy to understand?	87	13
5	Is the menu easily accessed?	93	7
6	Can the navigation buttons on the game be found and used easily?	93	7
7	Are the questions presented clearly and easily understood?	80	20
8	Did the video presented in the game help you solve the kinematics problem?	85	15
9	Are you interested in each game level using three questions?	82	18
10	Does this game provide information about your shortcomings in understanding the material?	94	6
11	After playing the game, do you understand the kinematics concept better?	94	6
12	Are you interested in learning the kinematics graph concept after playing the game?	81	19
13	Does this game make you motivated to learn physics?	84	16

The analysis shows that the percentage of students' perceptions ranging from PF2G is between 80% to 95% both with an average value of 87.8%. That is, they have a good perception of PF2G. Some of the relatively low responses include questions about whether they are clear and easy to understand. Only 80% of them answer easily. This may be related to their difficulties regarding the concept of kinematics graphs. Likewise, with the use of isomorphic problems, only 80 percent of students are interested in this kind of model. This can happen considering that in general the game only uses one item, so they can play only by guessing the answers. Such a thing cannot be done in PF2G, because if they are guessing, it is most likely to be justified not mastering.

In addition to answering the questionnaire items that have been provided, the students are also asked to provide comments freely on PF2G. Most of their comments were positive for PF2G. Some of their comments are as follows.

"*The brain-sharpening game teaches students to keep thinking until all the answers are correct. Suggestion, if repeatedly fail, it should be given the answer key*"
"*This game is very interesting. We can play while learning with this game. The questions are also given a detailed explanation in the video provided*"
"*Very good, this game motivates and helps us learn physics. But in my opinion, the problems are difficult*"
"*This game really helped me to study physics*"
"*The game is interesting and can motivate students to learn physics.*"

In this research, PF2G has been doped, a physics learning game using isomorphic problems. Besides getting reviews from experts, the students also have a good perception of this game. This result is consistent with Nadhiif & Diantoro [31] research that isomorphic questions could be used to identify students' thinking. After students answer the questions, the results of their understanding will be known on the understanding check page. Those who have not answered the questions correctly will be given feedback in the form of videos that contain a little material and examples relating to the questions given and help them understand the material better. Based on the research conducted by Nahadi et al. [32], this kind of feedback on formative assessment makes students more enthusiastic about participating in learning and motivated to better understand the material being studied and complete the quiz. This was also expressed by Noemí & Máximo [33], educational games aimed to strengthen learning in a dynamic, interactive, motivating, and entertaining way. The results of the formative assessment indicate the level of understanding of the material students have learned so that the teacher can take what steps must be taken for effective action [34].

PF2G with isomorphic items that had been developed has advantages and disadvantages. The advantages of formative feedback game products with isomorphic items are (1) being able to identify student errors related to the concept of kinematics graphs, (2) providing feedback in the form of information about students' understanding as well as material and ways of working on the questions which are packaged in video form. The shortcomings of formative feedback game products with isomorphic items are (1) limited to kinematics graphic material, (2) this product can only be accessed using a PC, and (3) this product can only be used for independent training, (4) there are no extensive trials on the effectiveness of this game.

4. Conclusion

In this study, PF2G has been developed, an assessment-based formative game that uses isomorphic multiple choice items. The game can identify students' mastery of concepts through the analysis of isomorphic multiple choice items. If the students have not answered completely correct, they will be directed to look at the help in the form of explanatory videos. Based on expert's and teacher's reviews, PF2G is justified for use. It has also been proven to be used by them and is perceived well by most of them. Formative game models are recommended to be implemented in other concepts. The research to investigate the effectiveness of this formative feedback game is also suggested.

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