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Computer-assisted recitation program: A focused study on students' conceptual understanding on force and motion

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Abstract: Recitation programs have been developed and tested on the topic of force and motion. The program consists of 63 multiple choice questions with feedback made in 3 packages (one package each week). This study aims to analyze the effectiveness of the program. This research is a quantitative research with a quasi-experimental design. The applied experimental design is a one group pretest-posttest design. The program was given for 3 weeks by giving 1 recitation package at each meeting (there are 21 questions for every package). The study was conducted on 38 Physics Education students' who enrolled the Material and Learning Physics I course. The pretest-posttest questions consisted of 15 reasoned multiple-choice questions. Data analysis was performed by determining descriptive statistics, paired sample t-test, N-gain, and d-effect size. The research found that the program significantly improved students' conceptual understanding with N-gain of 0.498 and d-effect size of 1.559. These results indicate that the provision of recitation programs can improve students' conceptual understanding on force and motion, especially in determining the F(t) graph from the v(t) graph, where initially the ability to solve problems in the form of graphical representations is one of the difficult matters for students
Keywords: recitation program; conceptual understanding; force and motion

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Introduction

One of the significant goals of physics learning is to help students understand the concepts and principles of physics in depth so that they can use them to solve problems (Docktor & Mestre, 2014a; Hegde & Meera, 2012; Ryan et al., 2016; Sutopo et al., 2016; Taqwa et al., 2017). However, efforts to achieve these goals are often constrained by students' initial knowledge that is not in line with the scientific knowledge and tends to distract students in constructing and storing new knowledge. Students' knowledge structure is in pieces and not coherent into complete knowledge yet. It is a serious problem, an inhibiting factor in achieving learning goals. It takes a considerable amount of time to help students store strong new knowledge so that it can reactivate quickly when needed (Docktor & Mestre, 2014a). Students need to be triggered using every new knowledge they have to solve the physical problems presented in various contexts and representations.

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There are many ways to help students understand the concept of physics. One way is to provide practice the problem-solving questions with feedback (Hassouny et al., 2014; Heron, 2015; Sornkhatha & Srisawasdi, 2013). The questions related to a concept/principle should be presented in various contexts and representations. This varied context is important so that students have broad insight into the context in which the concept can be used and are able to easily recall the concept from long-term memory when needed. Questions also need to be presented in different formats of representation, because based on the findings of previous studies about the use of multi-representation in physics learning and the influence of the format of representation questions on the success of students solving these problems (De Cock, 2012; Sutopo et al., 2012; Waldrip et al., 2010). Implementation of these strategies will certainly take a lot of time. Therefore, the practice of the questions and their feedback needs to be packaged with computer aids so that students can be used outside the lecture.

This study has developed a learning assistance program that contains recitations in conceptual questions. The questions given are accompanied by feedback and packaged in a computer program. The questions are presented in a multiple-choices format, where all the options raised 'student thoughts' that might occur. It was found through literature review and team experience in interacting with students and teachers. All answer options, both true and false options, are given feedback. The feedback accompanying the incorrect options in such a way can help students recognize their mistakes; while the feedback that accompanies the correct answer is intended to provide reinforcement. All of feedback for correct answer option is presented in video format. Given the function of this program, similar recitation programs were conducted in many universities in America, namely the deepening program of material given to a small group of students after attending classes in large ones (Docktor & Mestre, 2014b). We named the program with a computer-assisted recitation program. The development of this recitation program also has been carried out on several different topics, such as rotational (Rahmawati & Sutopo, 2019) and dynamics fluid (Pebriana et al., 2018). However, the feedback is provided in writing, not in video form. The development of feedback in the form of videos is important for visualizing moving objects (Rosdiana & Ulya, 2021). With video feedback, students are expected to understand the concept better.

This study focused on the topic of force and motion. This is based on several things, including the concept of force and motion which is the core of Newtonian mechanics and is needed in understanding most everyday phenomena (Sornkhatha & Srisawasdi, 2013). Over the past few decades, many researchers have revealed the difficulties faced by students in conceptual understanding of force and motion (Hassouny et al., 2014; Sutopo et al., 2016; Taqwa et al., 2017). Some studies that apply computer assisted recitation programs have been carried out in several different topics. Some of them focus on the topics of rotational dynamics (Rahmawati & Sutopo, 2019), static fluids (T. N. Diyana et al., 2020; Tsania Nur Diyana et al., 2020), and dynamic fluids (Pebriana et al., 2018). Recitation needs to be developed on the topic of force and motion, since students have many difficulties on this particular topic. This article aims to determine the effectiveness of the recitation program to improve the students' conceptual understanding.

Method

This research is a quantitative research with a quasi-experimental design. The experimental design used is a one group pretest-posttest design. The effectiveness of the program is measured by paired sample t tes and N-gain score from the pretest to posttest. The subject of the study consisted of 38 students in the Material and Learning Physics I course at Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang. This research was carried out in the 2020/2021 academic year. The pretest was given after the Kinematics and particle dynamic had been discussed through lectures. Three weeks after the pretest, students were given the opportunity to use the program for three weeks and then worked the posttest.

Pretest and posttest use the same test instrument which consist of 15 multiple choice questions. Questions were developed from conceptual questions found in several physics textbooks (R. A. Serway et al., 2013; R. Serway & Jewett, 2015) and several instruments that have been developed by previous researchers such as Force Concept Inventory, Mechanical Baseline Test, standard instrument for testing our basic physics course, and questions of force and motion developed by Keeley (Keeley, 2011). The instrument has been reviewed by two lecturers of the Department of Physics at Universitas Negeri Malang and stated that all items have high validity in the sense of measuring competency indicators that are formulated, conceptually correct, and do not lead to ambiguity. All items have been empirically tested and based on the analysis of validity, reliability, discriminant index, and difficulty level index of all items are feasible to be used in research based on Suruchi & Rana criteria (Suruchi & Rana, 2014). The abilities tested are as shown in Table 1.

Table 1. Abilities Tested

Abilities Tested	Number of Question(s)
Newton's First Law and Inertial Framework	1, and 2
Determine the graph $F(x)$ based on the information from the graph $v(t)$.	2, and 3
Determine the graph $v(x)$ based on the information from the graph $F(t)$.	5
Drawing Free-Body Diagrams (FBDs)	6
Determine the direction of a, v, and/(or) F in the case of uniform circular motion	7, and 8
On two boxes being pushed by a force F, compare the force acting on one of the boxes with F	9
Comparing the pull and frictional forces in the case of tug of war	10
Comparing the two forces in the case of the collision of two identical objects with different speed	11
Comparing the two forces in the case of the collision of two objects with same speed	12
Determine the normal force changes in the case of elevator motion	13
Determine the direction of the resultant force	14 and 15

The practice questions outlined in the recitation program are different from the questions used in pretest-postest. However, the physical principles used are the same. As much as possible the questions in the recitation program are presented in a different context from the pretest-posttest question. Thus, the success of students in solving the posttest is believed not to have been discussed in the recitation program.

Results and Discussion

Implementation of Recitation Program

The recitation program contains practice questions to strengthen the student conceptual understanding on force and motion. The recitation program was designed to contain as many as 63 questions and feedback. The practice questions were designed in various representations and contexts to develop students' abilities. Conceptual practice questions and feedback were designed in multiple-choices forms. Each answer option provided as far as possible represents the most likely thinking by students. The feedback given is distinguished for each option according to the 'possible thinking' that students have in choosing options based on the difficulties experienced by students from the studies that have been conducted (Ambrosis et al., 2015; Mashood & Singh, 2012), student difficulties during lectures, as well as from the experience of researchers. For the incorrect options, the feedback was designed with the aim that students recognize the errors of thought they have. For the correct options, the feedback was designed to provide reinforcement because the students have successfully answered the question correctly. In addition, after students successfully answer questions, problem-solving will be discussed in the form of a video tutorial to strengthen students' understanding. The discussion of each question also aims to avoid the possibility of students answering correctly due to guessing. For students who chose the wrong options, they were required to redo on the problems to find the right answer. The following is an example of the appearance of the question (Figure 1) and the feedback given (Figure 2).

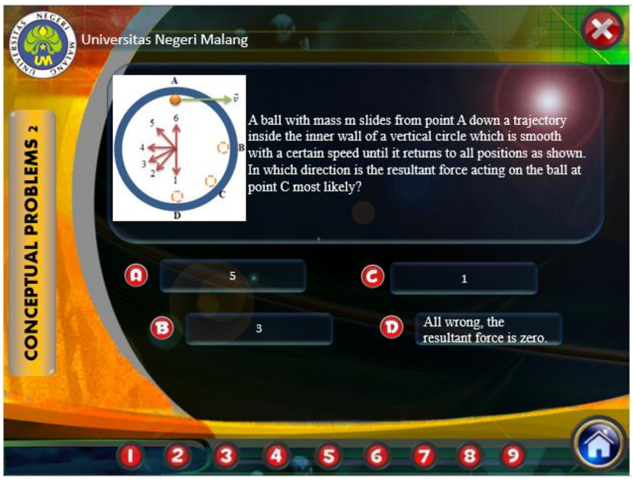


Figure 1. Display Example of Particle Dynamics Problem Number 3

Figure 2. Display Example of Feedback of Option B (False Option)

The Increase of Conceptual Understanding Score

The results of data changes in the students conceptual understanding are indicated by an increase in the conceptual understanding score. The description of pretest and posttest score statistics is presented in Table 1. Based on the pretest-posttest score data, the skewness value of the pretest and posttest score distribution is in the range -1 to +1, so that the pretest-posttest data can be interpreted to be normally distributed. Because the pretest-posttest data is normally distributed, paired t-tests can be used to test the significance of differences in pretest and posttest scores. The calculation results obtained t value of 12.06 and p = 0.00. This shows that the pretest and posttest scores differ significantly. Table 2 shows that the average pretest score is higher than the average posttest score, so it can be concluded that the students conceptual understanding has increased significantly after using the recitation program.

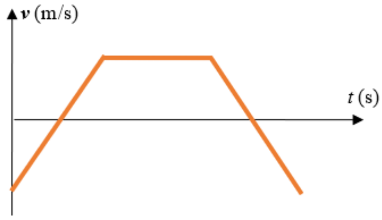
Table 2. Descriptive Statistic of Pretest-Posttest Conceptual Understanding Score

Statistic	Pretest	Postest
Minimum Score	26.67	53.33
Maximum Score	93.33	100.00
Mean	55.61	77.72
Standard Deviation	13.89	14.48
Skewness	-0.029	0.016

The increase of score can be measured by d-effect size and N-gain. The value of d-effect size is obtained at 1.559 which is categorized as "strong", while the N-gain value is 0.498 which belongs to the upper-medium category (Sutopo & Waldrip, 2014). This shows that the recitation program has a strong effect on increasing the students conceptual understanding.

Besides based on the results of statistical analysis, an increase in conceptual understanding is indicated by an increase in the ability of students in all questions, both in terms of the number of correct answers and the quality of the reason for the answers. An example is the ability of students to construct a graph ***F***(*t*) from the graph ***v***(*t*). One of pretest-posttest question that experienced a large increase after the recitation program is question number 5. This question as shown in Figure 3.

An object is moving with changing velocity as a function of time along a straight line under the influence of the force ***F***. The object's velocity follows the following graph ***v***(*t*).



The graph of the resultant force acting on the object is best indicated by ....

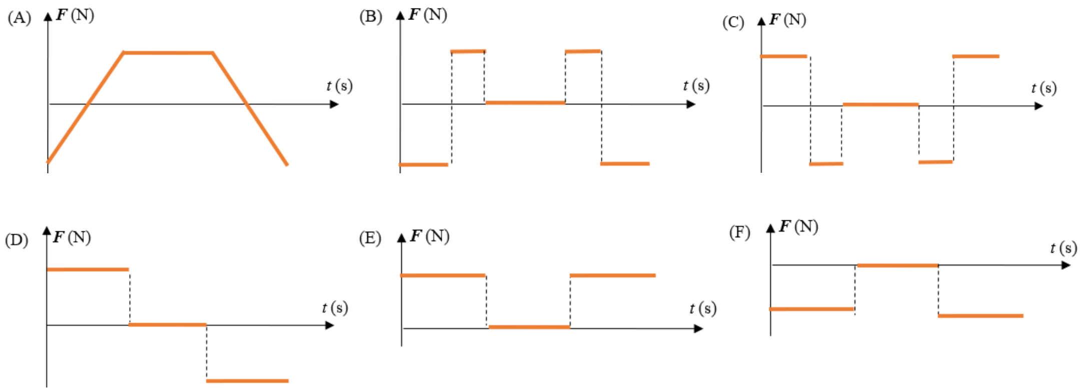


Figure 3. Pretest-Posttest Question Sample (Question Number 5)

A total of 5 (13.16%) students answered correctly, namely choosing option D. However, after giving the recitation program, 36 (94.74%) students chose option D. Changes in the distribution of student answers were shown in Table 3.

Table 3. Crosstabulation of Students' Pretest-Posttest Score for Question Number 5

		Post-test						Total
		A	**B**	**C**	**D***	**E**	**F**	
Pre-test	**A**	0	1	0	9	0	0	10
	B	0	1	0	15	0	0	16
	C	0	0	0	0	0	0	0
	D*	0	0	0	5	0	0	5
	E	0	0	0	4	0	0	4
	F	0	0	0	3	0	0	3
Total		**0**	**2**	**0**	**36**	**0**	**0**	**38**

Table 3 shows the crosstabulation of students' pretest-postest score for question number 5. At the time of the pretest, 10 (25.64%) students chose option A, 16 (41.03%) students chose option B, 5 (13.16%) students chose option D, 4 (10.26%) students chose the option E, and 3 (7.69%) students chose option F. At the time of posttest, there were still 2 (5.26%) students choosing option B, while 36 (94.74%) students chose option D. This shows that in this problem have normalized gain of 0.94 (high category).

On pretest session, 10 (25.64%) students choose option A. This indicates that they think if the resultant force is proportional to velocity. Many students think that to make things move faster, more force is needed, so they think that velocity is proportional to the resultant force. Even though the resultant force should be proportional to the change in the velocity of the object, not the velocity of the object. The results of this study are in line with several previous studies which showed that many students had difficulties in understanding physics in graphical representation (Klein et al., 2017; Motlhabane, 2016).

Students who choose option B on pretest session have the idea that the positive and negative signs of the resultant force indicate the direction of motion so that it corresponds to the positive and negative signs of velocity. So that when the velocity changes occur (increases or decreases), the resultant force is always positive if the velocity is positive and the resultant force is always negative if the velocity is negative. This indicates that the force acting on objects is the cause of motion. So that if an object moves to the right, it is assumed that there is always a resultant force acting in the right direction.

This finding indicates that there is a student error in interpreting the graph $\boldsymbol{v}$ (t). If we divide the graph $\boldsymbol{v}$ (t) into 3 parts, then the first part shows that there is a constant positive acceleration, the second part shows zero acceleration because there is no change in velocity, and in the third part shows that the object acceleration is constant and has a negative sign. Students assume that negative acceleration indicates slowing and positive acceleration indicates acceleration. These incorrect thoughts are often owned by students. They are difficult to store and use the knowledge that a positive and negative sign of acceleration indicates the direction, which if the acceleration direction is opposite to the velocity, the motion of the object is slowed down, and if the acceleration direction is in the direction of velocity then the object is accelerated. In learning process, we must recognize the importance of emphasizing the use of the acceleration sign as the direction of the vector (Brahmia et al., 2020). This is important because the term "acceleration" is widely used in other topics, such as static electricity, and students have many misconceptions about acceleration (Suma et al., 2018).

Students who choose the E or F indicate that they are incorrect in interpreting the graph $\boldsymbol{v}(t)$ so that it is wrong when describing the graph $\boldsymbol{F}(t)$. Students' difficulties in interpreting this $\boldsymbol{v}(t)$ graph have been found by several previous researchers (Phage et al., 2017). Students’ do not understand that the slope of the curve in graph $\boldsymbol{v}(t)$ is acceleration, which is a vector quantity. So the positive and negative signs on the slope of the curve on graph $\boldsymbol{v}(t)$ only indicate the direction of acceleration. Because their difficulty in understanding the $\boldsymbol{v}(t)$ graph causes difficulties in constructing the $\boldsymbol{F}(t)$ graph. Therefore, in understanding the topic of Force and Motion, students must understand Kinematics well.

After the provision of computer-assisted recitation programs, the number of students who answered correctly the question increased to 36 students. This increase is believed not because there are questions that have been discussed in implementing the intervention. The questions given in this recitation program are totally different from the pretest-posttest questions, but the questions raised are solved using the same physics principles. The questions given in the recitation program are also in various kinds of representations and contexts. It aims to enrich students' knowledge and strengthen the understanding of concepts. In addition, the increase in conceptual understanding is also due to the feedback given in the form of videos. Students who study with videos will be more helpful in understanding physics concepts because they can see physical phenomena that tend to be abstract

(Fadlilah et al., 2020). In addition, the provision of videos is also important to facilitate students with different learning styles. Learning style is an important aspect that has an influence on student learning outcomes (Hakim et al., 2022; Hermansyah et al., 2021; Maison et al., 2019).

On the other hand, there is a context of problems that are not raised in the recitation program but are present in the pretest-posttest problem, namely determining normal force when the system moves down while slowing down. This makes students not helped in solving problems. Their mistakes occur mostly because of errors in determining the direction of acceleration so that even though it is correct in identifying the force and using Newton's Second Law, the results of solving the problem are still incorrect. This shows that in order to fully understand the idea of mechanics, the main ideas of kinematics are very important to be well understood in the first place. Therefore, future research is expected to develop questions in more varied contexts. In addition, the discussion in feedback is expected to be able to integrate the understanding that has been obtained by students on the previous topics. For example, in this force and motion, the feedback provided can integrate relevant vector and kinematics topics.

Conclusion

Based on the results and discussion it can be concluded that the computer-assisted recitation program can improve the students' conceptual understanding on force and motion. The conclusion is indicated by an increase in the average of the students' conceptual understanding, and based on the results of the t-test which shows that the pretest and posttest scores differ significantly, with t value = 12.06 and p = 0.00. The value of d-effect size is obtained at 1.559 which is categorized as "strong", while the N-gain value is 0.498 which belongs to the upper-medium category. However, we still find it difficult for students to solve Newton's Second Law problems. Although they were successful in identifying the force and using Newton's second law, they were incorrect in determining the direction of acceleration. Therefore, we still need to develop the questions and feedback in the recitation program.

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