Effect of conceptual change texts on physics education students’ conceptual understanding in kinematics

S Syuhendri*

Physics Education Department, Universitas Sriwijaya, Palembang, Indonesia 30662.

*hendrisyukur@yahoo.com

Abstract. The purpose of this research was to determine the effect of conceptual change oriented instruction using Conceptual Change Texts (CCT) toward the physics education students’ conceptual understandings in kinematic. The research used quasi-experimental method with pre-test and post-test control group design. The sample was selected based on purposive sampling technique comprised of two groups of students from two different campuses of a public university in South Sumatra, Indonesia. The instrument used was the Indonesian version of the Force Concept Inventory (FCI). The data was analyzed to determine the mean N-gain of the experimental and control group while the independent sample U-test by α = 0.05 were used to test the hypothesis. The findings showed that 1) there were some students’ alternative conceptions with the level of their conceptual understanding 26.2%, 2) the mean N-gain of experimental and control group were 41.85% and 1.60% respectively, and 3) there was a significant difference increases in students’ conceptual understanding between who were taught using conceptual change texts and conventional one. Therefore, in terms of alternative conceptions held by students, teachers can use conceptual texts teaching materials to facilitate students’ conceptual change.

1. Introduction

Concepts and principles are two kinds of building blocks that construct scientific knowledge [1]. Novak [2] defined concepts as “perceived regularity in events or objects, or records of events or objects, designated by a label”. In general, concepts are constructed by assimilation and accommodation process, as explained by Piaget’s theory [3]. Misconception occurs when there is a lack of concept construction process or when a concept is incorrectly understood [4]. Therefore, it is not just a lack of knowledge or an error when answering a given question [5]. Misconception is simply defined as disagreement between someone’s idea with the scientific explanations of the idea [6]. Many terms are used by researchers and science educators to label this condition, such as preconceptions, students’ conception, child’s conceptions, naive beliefs, alternative frameworks, alternative conceptions, alternative conceptual frameworks, prior knowledge, and intuitive theories. In this research, researcher prefer to use the term “alternative conceptions” to refer to Physics Education students’ incorrect ideas that they construct in the wrong way in their scheme of cognitive structure.

Kinematics is a sub-topic of physics which describes how objects move without consideration of the causes and effects of the motions. Kinematics consists of basic concepts of physics that students must master before learning other concepts. Almost all part of physics topics such as electricity, magnetism, vibration, waves, optics, thermodynamics, nuclear physics, and solid state physics depend on the understanding of the concepts such as distance, displacement, velocity, speed, acceleration,
linear motion and projectile motion that are learned in kinematics. Kinematics which is included in the Basic Physics course is offered in the first semester in the Physics Education Study Program.

However, there are many alternative conceptions experienced by students in this topic. Mutsvangwa [7] revealed that Physical Sciences at a university in South African have strong misconceptions in uniform circular motion. Similarly, Rane’s study [8] in India shows that students have serious difficulties in understanding of kinematics concepts as well as how to interpret kinematics graphs in position, acceleration, and velocity. In addition, Piten et al [9] in Cambodian revealed that students hold misconceptions about projectile motion. Moreover, they found students convinced that in projectile motion case the direction of vector of velocity follows the curved path at every point. Students also thought that in this case the acceleration direction of an object is the same with its motion direction. Furthermore, Govender and Dega [10] have conducted a study in Bachelor of Education degree at a South African university, specializing in the subject Physical Science and found students have a lack of conceptual understanding in vector-kinematics. Another study by Özcan and Bezen [11] found that prospective teachers have three different mental models about concepts of force and velocity, two models were determined to be misconceptions and called as Aristotelian and impulsive models.

Similarly, Syuhendri [12] also revealed the low of students’ conceptual understanding and many alternative conceptions experienced by Physics Education students of a public university in Sumatra, Indonesia, where the average of their understanding of concept of Newtonian mechanics was very low, i.e. 18.08%. The students hold misconceptions for example in free falling objects and circular motion. Based on teaching experience, the students have a strong misconception such as the heavier objects will fall faster [12]. The existence of these alternative conceptions is dangerous for those prospective teachers. On the one hand, this will be an obstacle in the learning process because alternative conceptions affect the understandings of the next concept. It is a consensus that alternative conceptions are the most important factors affecting the achievements of students in science education. On the other hand, they are prospective teachers who will teach the concepts to their students later, so that they have to hold the correct concept. Therefore, these alternative conceptions must be overcome and students’ conceptual understanding should be increased.

However, the main problem faced is that the characteristics of the alternative conceptions are difficult to change with traditional instruction [12, 13]. Traditional teaching is not effective to promote conceptual change in relation to Newton’s laws and motion [14]. Moreover, the traditional instruction was not sufficient for students to develop a conceptual understanding of Newton’s law [8, 15]. So, it needs a special approach to deal with [16]. Posner et al [3] proposed a theory known as conceptual change model to address the alternative conceptions. They argued that students’ conceptions might be changed if the students dissatisfaction with their old conceptions and see the new replacing concept is plausible, intelligible, and fruitful. There are some strategies and methods such as conceptual change text and refutational texts that have been developed based on this view of point, and it seems effective to reduce the alternative conceptions and to improve students’ understandings of science concepts.

Conceptual Change Texts (CCT) is reported success to overcome the alternative conceptions [17-18]. The structure of the CCT is made in such a way that at first it will cause students’ dissatisfaction with their own conceptions and in the next section it explains and guarantees that the new substitution conceptions can be intelligible, plausible, and fruitful. Nevertheless, there is a limited study to use the CCT in physics topics [16]. In addition, there is no yet CCT so far developed in Indonesian language on kinematics topics. Therefore, the objective of this study was to determine the effectiveness of developed kinematics CCT in reducing alternative conceptions and promoting conceptual understandings in kinematic topics.

2. Research Methods
This research used a quasi-experimental method with an experimental-control group pre-tets and post-test design. The research subjects were students of the Physics Education Department at a public
university in Sumatra, Indonesia. The sample was taken by using purposive sampling technique from two different campuses at the university. One class was randomly selected for the experimental group and one class as the control group.

The instrument used was the Indonesian version of the Force Concept Inventory (FCI). A valid and reliable Indonesian version of the FCI is available on http://modeling.asu.edu/R&E/FCI-Indonesian.pdf [6]. The FCI is a set of tests to measure the mastery of the concepts of force and kinematics developed by Hestenes et al [19] from the MDT (Mechanics Diagnostic Test) and its revised version by Halloun et al [20]. FCI is the first of the concept “inventory” tests. The test does not require mathematical calculations and the questions are made in non-technical sentences so that it can be understood by anyone without the need to learn mechanics formally. FCI is a multiple choice test with 30 questions. Every question comprises of five options. One option is Newtonian concept while the other four options are alternative conceptions related to the concept.

All of the questions and options provided function as a unit. The uniqueness of the FCI is that the level of conceptual understanding of certain concepts and misconceptions are determined based on the analysis of several questions and several choices, and on the other hand, one question or one choice serves as an indicator of the level of conceptual understanding of several concepts and misconceptions. Analysis and synthesis of respondents’ answers from several questions and choices based on the Table of Newtonian Concept of the FCI [20] reveal the level of respondents’ conceptual understanding for the concept of kinematics, Newton I Law, Newton II Law, Newton III Law, superposition principle, and kinds of force. Meanwhile, its analysis based on the Table of Taxonomy of Misconceptions Probe by the FCI [20] reveals the respondents’ alternative conceptions in kinematics, active force, impetus, concatenation of influences, action-reaction pairs, and other influences in motion. In this study, the students’ answers were analyzed to seven questions related to kinematics.

The data analysis techniques were in accordance with the research objectives. The level of students’ conceptual understandings and the level of their alternative conceptions are determined by Equation (1).

\[
P = \left( \frac{f}{N} \right) \times 100\% \tag{1}
\]

\(P\) is the level of students’ conceptual understanding or the level of their alternative conceptions. Then, \(f\) (frequency) is the amount of students choosing the true answers (for conceptual understanding) or the number who chose all wrong answers (for alternative conceptions), and \(N\) is the amount of all the students who participated in this study. The classifications of the level of conceptual understandings are high, medium, and low based on Hake’s criteria [15].

The increase of students’ conceptual understanding was decided based on the normalized gain score (N-gain) by Hake [15], where the N-gain or \(<g>\) is determined by Equation 2.

\[
<g> = \frac{(S_{\text{post-test}} - S_{\text{pre-test}})}{(S_{\text{max}} - S_{\text{pre-test}})}
\]

(2)

The criteria for the \(<g>\) value are [15]:

- **High** \(<g> \geq 0.7\)
- **Medium** \(0.7 < <g> \geq 0.3\)
- **Low** \(<g> < 0.3\)

The effect of the strategy used toward the increase of Physics Education students’ conceptual understanding in kinematics was determined by testing a hypothesis, where Ho: there is no significant difference in students’ conceptual understandings between the control group and the experimental group. The test was carried out with non-parametric statistics in the form of a two-sided independent sample U-test with \(\alpha/2 = 0.025\). The test was carried out after carrying out the test of distribution normality and the homogeneity of the data variance.
3. Results and Discussion

Based on the students’ correct answers to every specific item and synthesis of several choices from several FCI items that were consulted to the Table of Newtonian Concept of the FCI [20], it was found the level of students’ conceptual understandings in kinematics as shown in Table 1.

### Table 1. The level of Physics Education students’ conceptual understandings in kinematics

| Dimensions                              | FCI items | The number of students who answered correctly | F | %  | Level | % mean |
|-----------------------------------------|-----------|-----------------------------------------------|---|----|-------|--------|
| Velocity discriminated from position    | 19E       |                                               | 27 | 37.0 | Medium |        |
| Acceleration discriminated from velocity| 20D       |                                               | 8  | 11.0 | Low    |        |
| Constant acceleration entails           |           |                                               |    |      |        |        |
| parabolic orbit                         | 12D       |                                               | 35 | 47.9 | Low    | 26.2   |
|                                        | 14D       |                                               | 7  | 9.6  |        |        |
|                                        | 21E       |                                               | 10 | 13.7 |        |        |
| changing speed                          | 22B       |                                               | 12 | 16.4 | Low    |        |
| Vector addition of velocities           | 9E        |                                               | 35 | 47.9 | Medium |        |

In the second column of Table 1, it is stated the correct answer for the related question. In column 3, 4, and 5, are stated the number of students who chose the correct answer. There are four sub-concepts of kinematics, namely distinguishing velocity and position, distinguishing acceleration and velocity, constant acceleration, and vectorial addition of velocities. Table 1 shows that students were more difficult to distinguish between acceleration and velocity than to distinguish between velocity and position. There are only 11.0% of students who can distinguish between acceleration and velocity, and 37.0% who can distinguish between speed and position. Overall, the level of students’ conceptual understanding for kinematics topics is very low, i.e. 26.2%.

Meanwhile, based on the analysis and synthesis of students’ wrong answers from several items and several choices and consulted to the Table of Taxonomy of Misconceptions Probe by the FCI [20], it was obtained the level of students’ alternative conceptions in kinematics as in Table 2.

### Table 2. The level of Physics Education students’ alternative conceptions in kinematics

| No | Alternative conceptions               | FCI items and choices | F | % mean | Level |
|----|--------------------------------------|-----------------------|---|--------|-------|
| 1  | Position-velocity undiscriminated     | 19B, C, D             | 38 | 52.05  | Medium |
| 2  | Velocity-acceleration undiscriminated | 19A; 20B, C           | 46 | 31.51  | Medium |
| 3  | Non-vectorial velocity composition   | 9C                    | 7  | 9.59   | Low   |
| 4  | Ego-centered reference frame          | 14A, B                | 66 | 90.41  | High  |

Table 2 shows that 52.05% of students cannot distinguish between position and velocity. FCI number 19 states that: “The positions of the two blocks for an interval of 0.20 seconds are shown in sequence by the numbered boxes in the figure below. Both blocks are moving to the right.

Do the two blocks ever have the same speed?” A total of 50.75% of students chose option D: Yes, namely in positions 2 and 5; 1.36% of students chose B: Yes, namely in position 2; and 2.74% of them chose C: Yes, which is in position 5. It can be concluded that the majority of students think that when
objects meet where one object follows another, both objects have the same velocity. The number of respondents choosing D indicates that they believe the alternative conception is due to the momentary position of the object and not because of a change in its position, because the same factor between points 2 and 5 is the position of the object while the displacement is different. Thus, it can be concluded that an alternative conception adopted by students is: “When an object crosses another object, both objects have the same velocity, on the grounds that both objects are in the same position”.

There are two questions that reveal alternative conceptions “cannot distinguish between velocity and acceleration”, namely FCI numbers 19 and 20. There are 31.51% of respondents holding this alternative conception, where 8.2% of them chose A: No for questions 19 and 54.8 % chose B and C for the following question number 20: “The positions of the two blocks for an interval of 0.20 seconds are depicted in sequence by the numbered boxes in the image below. Both blocks are moving to the right. The relationship between the acceleration of the two blocks is”

![Image of two blocks](image_url)

Option B: Acceleration of the block “a” equals to acceleration of the block “b”. Both acceleration “a” and “b” are greater than zero; and option C: The acceleration of the block “b” is greater than the acceleration of the block “a”, more clearly expressing the alternative conception of not being able to distinguish velocity and acceleration. Because the position of the object is constant to the right, the respondents think the object is accelerating to the right. Respondents with option B assume the acceleration is the same because the change in distance for the same time interval is always the same for both objects. Meanwhile, respondents who choose C consider the acceleration of object “b” to be greater than the acceleration of the object “a” because the change in distance for object “b” is greater.

Both options reveal the alternative conceptions of changes in position to velocity and acceleration. It can be concluded that the Physics Education students holds the conceptions

1. An object moving in a certain direction is always being accelerated in that direction.
2. An object that has a greater change in position has always a greater acceleration.

The non-vectorial addition of velocity is the alternative conception that is the least experienced by the students. The majority of students (90.41%) understand that velocity is a vector quantity. This means that an understanding of vectorial addition is good enough. It can be assumed that the delivery of vector quantities and scalar quantities has been done well. The curriculum in Indonesia places vector and scalar material from the primary and secondary school levels. The term velocity as a vector quantity has also been taught from basic education.

The alternative conception most experienced by Physics Education students is the frame of reference, where 90.41% of the students considered themselves to be the center of the frame of reference. This was revealed by FCI question number 14 options A and B: “A bowling ball accidentally falls from the cargo area of an airplane that is flying horizontally. Which choice in the image best describes the trajectory of the ball after leaving the airplane is seen by a stationary observer on the surface of the Earth”. Students with the concept of a self-centered frame of reference place themselves in a plane that is moving forward so that the ball falls to form a trajectory behind the plane or falls vertically under the plane (options A and B). So, even if one asks the observer's observed trajectory on Earth, she/he still takes the plane as a reference and she/he’s on the plane. The reason the respondent gave for option A was “the ball forms a trajectory like A because the plane is moving forward and the ball falls behind the plane”. Meanwhile, the reason for choice B is “because the object is in free fall motion, the object will fall straight down when air friction and wind are ignored”.

Learning based on conceptual change using CCT is carried out for three weeks on sub-material 1) Quantities and Units, Vector, 2) Kinematics 1: General equations, motion in one dimension, 3) Kinematics 2: Motion in two and three dimensions. The pre-test and post-test were carried out, respectively, before and after the intervention. The CCT teaching materials are used as supplements in learning. Some of the cases in the CCT were used as material for initial and final discussions. Students
read the correct explanation of concepts in the CCT after the learning process to strengthen the conceptual change process that occurs.

The results of data analysis of the control and experimental groups are in Table 3. Based on Table 3, it is known that the highest score for the experimental group changed from 4 in the pre-test to 6 in the post-test and the minimum score increased from 0 to 2 for the ideal score of 7.

**Table 3. The descriptive statistics of students’ conceptual understandings of kinematics**

|                  | Pre-test | Post-test | Gain | N-gain | Pre-test | Post-test | Gain | N-gain |
|------------------|----------|-----------|------|--------|----------|-----------|------|--------|
| **Experimental** | 2.05     | 4.12      | 2.05 | 1.07   | 1.28     | 1.45      | 0.17 | 0.27   |
| **Control group**| 18.23    | 20.69     | 2.46 | 0.46   | 1.10     | 1.12      | 0.97 | 0.18   |

In the control group there was no increase either the maximum score or the minimum score. The mean score of the experimental class almost doubled from pre-test to post-test, while for the control group it increased from 18.23% to 20.69%. The N-gain comparison for the control and experimental groups is shown in Figure 1.

![Figure 1. The mean pre-test, post-test, and N-gain scores of the control and experimental groups.](image)

The mean N-gain for the control and experimental groups from pre-test to post-test was 41.85% and 1.6%, respectively. Thus the increase of students’ understanding of the concept to the true concept of the experimental group was in the medium category and for the control group in the low category. In other words, learning with conceptual change strategies is better in improving conceptual understandings and reducing alternative conceptions in kinematics topics.

To test the difference of the average N-gain of the experimental and control groups was significant or not, a statistical test was performed. The normality test was carried out using the Kolmogorov-Smirnov method. It was obtained $D_{cal} = 0.123$ for the experimental group, while $D_{table} = D (0.05; 43) = 0.1351$, thus $D_{cal} < D_{table}$ which meant that the experimental group data were normally distributed. This is confirmed by the probability (sig.) = 0.091 > 0.025. Meanwhile, it was found that $D_{cal} = 0.258 > D_{table} = 0.161$ for the control group. It meant that the data of control group was not normally distributed. Furthermore, from the homogeneity test obtained sig. = 0.134 > $\alpha = 0.05$. This means that the provisional assumption that there is no difference in the variance of the experimental group and the control group data is accepted, or the data variance is homogeneous. Because not all data were normally distributed, the test for the difference in the mean N-gain was carried out by using the non-
The success of the experimental group in increasing concept understanding because the group is given learning that follows the procedure for how conceptual change can take place (see Posner et al. [3]. Hewson et al [21] argued that conceptual change learning is learning that is explicitly intended so that students have a conceptual change experience and it must meet the conceptual change model procedure. In contrast to the control group, conventional learning resulted in a slight change in students’ conceptions. Based on observations of the learning process carried out by the teacher in the control group, it focuses on deriving formulas and applying formulas to solve calculation problems. Such an approach cannot improve conceptual understandings although knowledge of equations and skills to apply the equations to solve quantitative problems (calculation problems) can be increased. Kim and Pak [22] found that there is very little correlation between the number of calculation questions completed by children with an increase in their conceptual understandings where after completing an average of 1500 calculation questions students no longer experience significant difficulties in using physics equations but still have major problems with their basic concepts. Hestenes et al [19] states that in conventional teaching, problem solving skills are considered as sine qua non of understanding of physics, and although it is not a serious problem but it should be emphasized that the understanding of concepts and other reasoning skills must be developed before developing the problem solving skills.

The difference in strategy has also led to the difference in the class atmosphere of the two groups. Based on observations, learning in the experimental group appeared to be of higher quality where students were much more actively involved in discussing ideas with multidirectional interactions. The discussions that are carried out further enhance the student's role such as in the prediction phase, giving reasons for answers, and the observation phase. Increased understanding of concepts will occur if learning is emphasized on active student participation [23]. Combination of using CCT with group works will activate students’ preconceptions [24]. Mercer [25] argued that dialogue between students is a media to change their old concepts. He further argues that in order to reach the next equilibrium discussion about beliefs with peers will be productive as long as there are differences in beliefs between them and tasks are made to resolve these differences.

The use of CCT also contributes to improving understanding of the concept. First, the CCT provides information about various forms of misconceptions, where some of them may be what the students hold. The list of alternative conceptions reminds them that their conceptions are incorrect. The scientific arguments provided with the explanation of the substitute concept are correct and the consequences that will arise if sticking to the old concept make students aware that the new concept is a worthy concept. Second, the CCT is a suitable tool for large class sizes and time constraints where the teacher cannot interact in detail with each individual for every conceptual problem she/he has. Finally, Özmen and Naseriazar [17], Ültay et al. [18], Özmen and Nasiriazar [26], and Dorsah and Acquaye [24] also found that CCT increase in a significantly better acquisition of scientific concepts than the traditional teaching approach. The CCT is an effective tool in reducing alternative conceptions.

4. Conclusion
This research disclosed that the level of Physics Education students’ understandings of concepts on kinematics is low. The research also revealed misconceptions that are held by the students on the kinematics topic. The students have some alternative conceptions, i.e. undiscriminated between position and velocity (52.05%), undiscriminated between velocity and acceleration (31.51%),
additional velocity not based on vectorial composition (9.59%), and holding self-centered frame of reference (90.41%). Furthermore, the research has also proven that the conceptual change-oriented learning using CCT succeeded in improving students’ understanding of related concepts from an average of 31.49% to 60.71% with an N-gain of 41.85%. The statistical test showed that the average N-gain increase in the concept mastery of the experimental group was significantly different than the control group. The low N-gain of the control group gives opportunity to test the hypothesis in subsequent studies that only conceptual change-oriented learning based on the conceptual change theory can promote learners’ understanding of the concept and overcome their misconceptions.

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