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The Impact of Modeling Instruction Based on System Toward Work-Energy Concepts Understanding

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Abstract

This study aimed to explore the effectiveness of modeling instruction based on a system for improving student's understanding of energy concepts on high school students. This Research was a mixed-method design with an embedded experimental model. The subject of this study was the 62 students of 11th grade, at Senior High School in Nganjuk, Indonesia. Modeling instruction based on system learning could significantly improve students' understanding of concepts better than conventional learning. Based on the calculation of the effectiveness of learning using N-gain obtained for 0.33 (medium or low medium category) for the treatment class and 0.18 (low category) for the control class. It concluded that improved students' conceptual understanding of the treatment class was better than the control class. This research also was identified student's difficulties especially in differentiating forces and work. Students propensity to use p-prime in solving problems rather than using energy theorems.

Keywords: modeling instruction, system model, work-energy concepts

INTRODUCTION

Research on students' understanding of energy has received widespread attention from physics educators from both secondary schools and universities. It because the energy material is a crosscutting concept as well as core ideas in science that need to be mastered by students (Lancor, 2014; NRC, 2012). Energy is a physics material that meets the NRC (2012) criteria as a core idea with an appeal to its involvement in social science issues (socioscientific issues) such as inventory, distribution, and energy utilization (NRC, 2012; Papadouris et al., 2008; Sakschewski et al., 2014). Energy has an essential role in bridging all domains of science, especially in understanding the changes in energy that occur continuously in a system.

Some researchers examine basic concepts of energy, such as potential energy (Beynon, 1990; Keeports, 2017), kinetic energy (McClelland, 2016), and work (Mustofa et al., 2016; Hicks, 1983). Some researchers combine in broader studies such as mechanics (Barniol & Zavala, 2014; Sutopo & Waldrip, 2014) and momentum (Bryce & MacMillan, 2009; Lawson & McDermott, 1987; Singh & Rosengrant, 2003). Several other studies have tried to investigate the difficulties experienced by students related to energy (Dalaklioglu et al., 2015; Kucuk et al., 2005; Singh & Schunn, 2009). Dalaklioglu et al. (2015) reported that only 35% (N = 284) were able to correctly answer the concept of work-energy, where most students had difficulty applying the concept of energy conservation law. Another report by Singh & Schunn (2009) states that most students' confusion determines the energy of a system that involves several objects and distinguishes several types of energy.

The previous studies show that although it is an important topic, it turns out that learning energy is not easy. The difficulty of understanding energy at least caused by two factors, namely (1) energy is an abstract quantity (Duit, 2014) and (2) understanding of energy in everyday life, is different from scientific explanation (Millar, 2014). Besides, the experience of students interacting with the environment before entering the class may have influenced their mindset in understanding a phenomenon. These results occur when students are given problems; they will process the knowledge they already have, even though that knowledge is wrong (Docktor & Mestre, 2014). Another result of this knowledge processing is that students are fixated on the types of phenomena presented in solving problems or by Kohl & Finkelstein (2008) named surface features. Therefore, the real challenge in energy learning is how students can view a phenomenon fundamentally based on the principle of energy in physics, not based on the type of phenomenon presented (surface feature).

Many researchers have tried to answer this challenge (For example, Scherr et al., 2013; Suhandi & Wibowo, 2012; Sujarwanto et al., 2014; Van Heuvelen & Zou, 2001). Van Heuvelen & Zou (2001) and Suhandi & Wibowo (2012) utilize multiple representations to teach energy, the result of which is an increase in students' understanding of concepts after they can move from various representations (figural, diagram, graph, mathematical). Scherr et al. (2013) teach energy through outside-class activities to discuss and clarify how substances and energy flow, energy transfer, and energy transformation. They claim that to understand how transformation and transfer of energy, physicists are better off just paying attention to the energy changes that occur in the system rather than in the environment. Research by Sujarwanto et al. (2014) shows that through modeling instruction, students' problem-solving abilities experience a higher increase than students who are taught conventionally.

From previous studies that have succeeded in increasing understanding of concepts and students' problem-solving abilities related to energy, researchers are interested in trying modeling instruction learning to improve understanding of the concept of energy. Modeling instruction (MI) was chosen because, in this learning, students are invited to develop mathematical models that fit the phenomenon. Besides, the learning syntax of MI can be easily collaborated with the main principles in explaining natural phenomena based on the principle of energy, namely choosing a system and modeling the interaction between the system and the environment and between components in the system. The system model is understood as a way to make it easier to describe and explain observed physical phenomena, but it is also useful for predicting new phenomena that may arise (Etkina et al., 2006).

The results of this collaboration are named as modeling instruction based on system learning. The first stage of this learning is the development model. At this stage, learning is intended to facilitate groups of students carrying out inquiry activities, which include understanding real phenomena, selecting systems, modeling systems, validating models, and evaluating. In system selection, there are no binding rules, but more important is to consistently model the system. The system model makes it easier for students to interpret what and how the system is (NRC, 2012). The next stage is the deployment model, where the resulting model is used to solve the new situation in order to improve understanding related to the mathematical model produced in the previous stage. All of these stages facilitate students in the development and development of conceptual understanding (Brewe et al., 2009; Hestenes, 1987; Jackson et al., 2008). The development of conceptual understanding can be through a graphical and diagrammatic representation of the model phenomena being studied (Etkina et al., 2006).

In Indonesia, research that focuses on energy learning through modeling instruction based on system learning is still rare. Most of them focused on exploring any misconception about work-energy, and the other research focused on how increasing student’s mastery of applying formula and solving a problem about kinetic energy, potential energy, work, and speed of an object in a situation.

Based on the situation explained above, applying modeling instruction based-system model have a massive opportunity. Therefore, this study focused on studying the effect of system-based instruction modeling learning in increasing students' conceptual understanding of energy-work material. Besides that, it will also be explored about the difficulties the concepts students have.

METHODS

This research was a mixed-method study with an embedded experimental design (Creswell & Plano Clark, 2011). Quantitative data were obtained from test scores on students 'conceptual understanding at the time of pretest and posttest (multiple-choice tests) and qualitative data obtained from students' thinking when solving test questions and events observed during learning. The pretest was held a week before the implementation of learning and the posttest was carried out after all the lessons on the topic of energy-energy were completed. Classroom learning activities are carried out for all energy-topics material, which includes work, work-kinetic energy theorem, potential energy system, and mechanical energy conservation law. Learning was carried out in the odd semester of the 2016/2017 school year (October - November 2016) in one of the High Schools, in Nganjuk Regency, East Java Province. The subject of this study consisted of 62 students of 11th grade which were divided into two classes namely treatment class and control class. Pretest and posttest use the same measurement instrument.

In this study, treatment classes were given modeling instruction based on system learning, while the control class was taught according to the national syllabus developed by the teacher. In general, the essence of treatment class learning was that teachers displayed phenomena through demonstrations, discussed classes to generate questions, in small groups students conducted experiments to answer questions and clarified answers, students presented results, validated models with teachers, applied models to new situations, and ended with quizzes and tests of understanding related to material and phenomena presented at the beginning of learning while the control class was taught by the teacher with a demonstration method of phenomena related to subtopics, discussion of information on the basic concepts of sub-topics that are being discussed, and practice questions.

Instrument research for understanding concepts was the result of an adaptation of several standardized tests such as the energy and momentum concept survey (EMCS) (Singh & Rosengrant, 2003) and mechanics baseline tests (MBT) (Hestenes & Wells, 1992) and several researchers developed to complete them. After constructing the complete construct validation and testing to find statistical values such as power difference, level of difficulty, and correlation to describe the characteristics of the problem. Construct validation was carried out by physicists who hold doctorates to confirm and provide input on the competencies to be measured. Then the items were tested on 154 high school students who had studied the topic of work-energy. The description of the questions is presented in TABLE 1. In general, the test instrument has a Cronbach Alpha value of 0.81, and it can be stated that the instrument is reliable for measuring students' abilities (Ding & Beichner, 2009). Besides, the teacher tries not to teach test questions in learning activities as suggested by Hestenes & Wells (1992).

The first research question was answered through analysis and discussion of quantitative data obtained from the students' pretest and posttest scores. The data were analyzed using statistical analysis of different tests (Mann-Whitney) and to see the increase in understanding the concept of students using normalized N-gain (Hake, 1998). While the second research question was answered through the analysis of quantitative and qualitative data from the results of the pretest and posttest answers. The analysis was carried out descriptively to identify the difficulties students had after learning in class especially on experiment class.

RESULTS AND DISCUSSIONS

Comparison of Experiment and Control Classes

The results of descriptive statistical analysis were presented in TABLE 2. It was seen that the median value (Q2) in both the treatment class and the control class had increased. To test whether there was a difference in increasing concept understanding between the two groups, the Mann-Whitney test was done because the data were not normally distributed (skewness value> 1 (Morgan, 2004)). The Mann-Whitney test results showed that there were significant differences between treatment and control classes ($p = 0.000$). While the results of the analysis of the increase in understanding of the concept of students on average use N-gain for the treatment class of 0.33. This value was in the medium category (Hake, 1998) or low medium (Sutopo & Waldrip, 2014). While the control class has an N-gain value of 0.18 with a low category (Hake, 1998; Sutopo & Waldrip, 2014). This shows that system-based modeling instruction learning was better than the conventional class which was taught by the syllabus developed by the teacher. The effectiveness of this learning confirmed several previous modeling instruction studies. Some researchers reported that MI produces more significant improvement than learning that did not use modeling (Brewe et al., 2009; Halloun & Hestenes, 1987; Wells, Hestenes, & Swackhamer, 1995). Positive results in students who were taught by modeling instruction occur because in learning students were actively involved in scientific practice, including building models, validating and revising the model (Brewe et al., 2009; Mustofa & Asmichatin, 2018). By modeling instruction, student's mental models can be formed, especially skills to predict, validate, and enrichment to build the right concept of phenomena (Hermawan et al., 2015). Increased understanding of students' concepts caused by learning, students were involved in finding a system model that could explain the transfer of energy between the system and the environment or energy changes between components in the system.

TABLE 1. Description of Question Items

Items	Description of Question Items	Statistical value		
		Power different	Difficulty level	Correlation
1.	Determine the factors that influence the work by gravity on the case of lifting a suitcase onto a table (adapted from EMCS No. 1)	0.623	0.318	0.586
2.	Determine the work by the gravitational force on the satellite which is considered a regular circular motion (adapted from EMCS No. 6)	0.805	0.416	0.650
3.	Determine the work by friction force and tensile force on the case of the beam that moves at a constant speed and is on a rough floor (adapted from EMCS No. 12)	0.597	0.286	0.626
4.	Calculates the speed of objects from the force graph to position	0.364	0.539	0.307
5.	Calculates the power received by objects from the force graph against the position	0.338	0.292	0.217
6.	Compare the speed of the little girl skating from the same height but with a different slide shape (adapted from MBT No. 10)	0.883	0.357	0.725
7.	Comparing the speed of the object thrown with vertically up and down directions at the same height and initial velocity (adapted from EMCS No. 4)	0.909	0.364	0.743
8.	Comparing the work carried out by the force in the case of moving the beam by means of being pulled vertically up and over the inclined plane (adapted from EMCS No. 8)	0.701	0.247	0.681
9.	Determines the largest speed of the object thrown at the same initial speed but with different angles (adapted from EMCS No. 22)	0.857	0.338	0.742
10.	Comparing the energy of two train systems that have different positions (adapted from EMCS No. 13)	0.883	0.344	0.706
11.	Determine the potential bomb energy at the highest position in the case of parabolic motion	0.078	0.091	0.100
12.	Determine which cases of cyclists and bicycle systems can apply mechanical energy conservation laws when crossing hills (adapted from EMCS No. 9)	0.104	0.136	0.112

Items	Description of Question Items	Statistical value		
		Power different	Difficulty level	Correlation
13.	Applying the kinetic energy-theorem to the case down the ice slope (adapted from EMCS No. 20)	0.442	0.156	0.505
14.	Compare the kinetic energy of the same style and the same displacement (adapted from MBT No. 20)	0.260	0.084	0.322
15.	Applying energy conservation law to explain the movement of a system consisting of springs and objects	0.675	0.455	0.469
16.	Apply system selection and system model in case of objects released from a certain height	0.519	0.234	0.472

TABLE 2. Descriptive Statistics pretest and posttest scores

Statistics	Control Class			Experimental Class		
	Pretest	Posttest	N-gain	Pretest	Posttest	N-gain
N	32	32	32	30	30	30
Min	0.00	19.00	-0.10	0.00	19.00	0.08
Max	38.00	63.00	0.54	38.00	94.00	0.91
Mean	14.80	29.76	0.18	13.90	42.56	0.33
Q1	6.00	19.00	0.08	6.00	31.00	0.22
Q2 (Median)	16.00	25.00	0.16	13.00	44.00	0.33
Q3	19.00	38.00	0.23	19.00	50.00	0.40
SD	8.72	1.11	0.12	9.83	1.48	0.15
Skewness	0.50	1.19	0.90	0.36	1.11	1.54

To understand the effectiveness of this learning, it was very useful to elaborate quantitatively and qualitatively the changes in students' understanding of the results of the pretest and posttest in the treatment class. The results of the students' pretest and posttest answers were presented in FIGURE 1. Based on Figure 1 only questions number 4, 6, 7, 9, and 16 were able to be answered by more than 50% of students during the post-test. The questions that have been answered more than 50% of students are questions related to the conservation law of mechanical energy in general. Students' understanding related to the work concept by the average style (items 1, 2, 3, and 8) amounted to 28.33%. The students' understanding was related to the function graph of the position and force (items 4 and 5) of 55.00%. The average of students' understanding of work-kinetic energy theorem (items 13 and 14) was 28.33%. The average of students' understanding of the system energy (items 10, 15 and 16) was 47.78%. The average of students' understanding related to the energy conservation law of mechanical energy on system under study (items 6, 7, 9, 11, and 12) was 51.33%

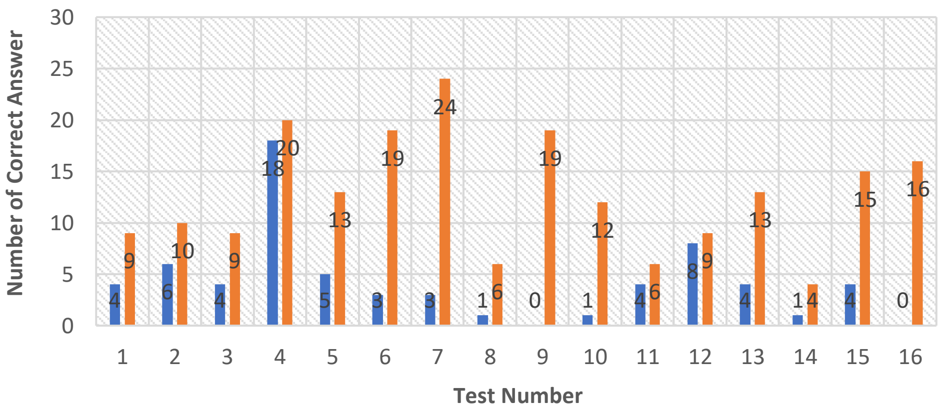

FIGURE 1. Distribution of the number of students who answered correctly. Bluestem (pretest) and redstem (posttest).

TABLE 3. Crosstabulation number 7 pretest and posttest answers.

		Pretest				**Total**
		A	**B**	**D**	**E***	
Posttest	A	3	0	0	0	3
	B	0	0	1	0	1
	D	0	2	0	0	2
	E*	10	3	8	3	24
Total		13	5	9	3	30

*key answer

One item that experienced a significant increase was item number 7. In this item, students were asked to compare the speed of objects thrown in a vertical direction up and down at the same height and initial speed (adapted from EMCS No. 4). The results of the crosstabulation analysis of question number 7 were presented in TABLE 3. Based on TABLE 3 there appeared to be a change in the number of students' correct answers, namely from 3 students (10.0%) to 24 students (80.0%). Based on the analysis of the distractors in the answer choices, it appeared that students no longer use partial knowledge in answering questions. These results support previous research, which states that most students can answer correctly questions related to energy conservation law, although some respondents have not been able to explain why this is so (Singh & Rosengrant, 2003; Singh & Schunn, 2009).

Although there was a significant increase in the understanding of mechanical energy conservation law, the low N-gain value showed that most students still had difficulty understanding the basic concepts of mechanical energy-work until learning was completed. It might occur because, in learning, there are still several groups of students who have difficulty choosing a productive system to describe the phenomenon and model it to solve problems. This was in line with the argument that to develop models for students was still difficult (Etkina et al., 2006). Therefore, it was necessary to know which concepts most students still have difficulties and how students think about the concept.

Student difficulties related to work concepts

Question items to uncover students' understanding of the work concepts carried out by certain style components were questions number 1, 2, 3, and 8. Based on the results of the analysis of pretest and posttest data, it appeared that the increase in the percentage of correct answers was relatively low. The percentage of students' correct post-test answers on each question was 30.0%, 33.3%, 30.0%, and 20.0% respectively. This relatively low percentage of answers was thought to be the cause of not achieving high N-gain. The items that have the lowest percentage were presented in item number 8. In question number 8 students were asked to compare the work made by the force in the case of moving the beam by pulling vertically up and over the inclined plane (adapted from EMCS No. 8). Based on the results of the crosstabulation analysis presented in TABLE 4, it appeared that most students answer option E. This shows that after learning, most students still have difficulty distinguishing between work and force.

TABLE 4. Crosstabulation of Pretest and Posttest Answers Problem Number 8.

		Pretest						**Total**
		0	**A**	**B**	**C***	**D**	**E**	
Posttest	B	0	0	1	0	1	0	2
	C*	0	0	0	2	0	5	7
	D	0	0	0	0	0	2	2
	E	1	2	0	0	1	16	20
Total		1	2	1	2	2	23	31

*key answer

The results of this study were following the research conducted by (Singh & Rosengrant, 2003) which stated that there was no significant increase in all posttest results for this type of problem. Most students had difficulty distinguishing between force and work done by force. This issue was categorized as difficult. Other studies also justified the difficulty of this problem (Dalaklioglu et al., 2015; Singh & Schunn, 2009). When answering questions with different situations, students experienced a failure to activate their knowledge into working memory. Based on cognitive model theory, their failure to activate knowledge was due to the accumulation of knowledge in working memory, so that working memory worked slower (Redish, 2003). Even if the knowledge they have was not appropriate, they would only rely on their intuition. This was evidenced by interviews conducted with students who answered E.

G : for question number 8, you choose answer E, Why is that?
S : because pulling up is heavier, whereas through the incline more easily
G : Are you sure?
S : Sir, after I thought about it, at figure (i) there is no normal force, while at image (ii) there is a normal force, so the number is more force in figure (ii), so the correct answer is D.

Students mixed an understanding of work with normal terms of weight and force. If seen from TABLE 1, this item is also an item with a high degree of difficulty (0.247).

Student difficulties related to work-kinetic energy theorem

The questions used to explore students 'understanding regarding this concept were questions number 13, and 14. Based on the results of data analysis, the students' correct answers obtained a percentage of 43.3% and 13.3%. The biggest difficulty experienced by students in answering questions related to the work-kinetic energy theorem was question number 14. In question number 14 students were asked to compare the kinetic energy of objects experiencing the same force and displacement (adapted from MBT No. 20). The results of the crosstabulation analysis of question number 14 were presented in TABLE 5. Based on these data, only 4 students appeared to be able to understand that kinetic energy was affected by the mass and square of the speed and the kinetic energy-work theorem.

TABLE 5. Crosstabulation of Pretest and Posttest Answers Problem Number 14.

			Pretest				Total
			A	B	C*	D	
Posttest	A	N	3	3	0	1	7
	B	N	3	13	0	2	18
	C*	N	1	2	1	0	4
	D	N	1	0	0	0	1
Total		N	8	18	1	3	30

*) key answer

Most students still had difficulty applying their understanding of the kinetic energy-theorem $W = \Delta Ek$ for different cases than when studying in class. These results supported the study (Hestenes & Wells, 1992), which stated that question number 20 included relatively difficult questions proven by <50% of students and students who were able to answer correctly. Based on students' answers, it appeared that most students use p-prime in solving problems, rather than using work-kinetic energy theorem. Students assumed that the greater the mass of the object, the greater the kinetic energy, and the greater the velocity of the object, the greater the kinetic energy. Students who use p-prime could provide logical reasons based on partial experience (Fotou & Abrahams, 2016; Hammer, 1996). This was supported by the results of interviews with students who answered incorrectly in choice B.

G : in question number 14, your answer is B,
why did you answer that choice?
S : of the two objects that have energy
the largest kinetic is the second object because of mass
object II three times the mass of the first object.
G : Why do larger objects have energy
big kinetic?
S : because the kinetic energy of the formula is ½ mv2, so it's the mass
take effect. Besides it, we know that in everyday life
mass affects energy, for example, mass
we use 50 kg to run then more energy
smaller than 80 kg mass.

CONCLUSIONS

The conclusion obtained was that modeling instruction based on system learning could significantly improve students' understanding of concepts better than conventional learning (p = 0,000). Based on the calculation of the effectiveness of learning using N-gain obtained for 0.33 (medium or low medium category) for the treatment class and 0.18 (low category) for the control class. The effectiveness of instruction modeling learning based on system that was most prominent was that students have succeeded in understanding the laws of mechanical energy conservation with a percentage of 51.33% and the graph of the function of the average position and force with a percentage of 55.00%. Besides, this study also succeeded in identifying student difficulties. The difficulties experienced by students, among others, arise because students had difficulty distinguishing force and work and their tendency to use p-prime in solving problems, rather than using energy theorems.

We recommended on next research to utilize system model for exploring phenomena. The model of system was very important to sharpen student's understanding of an abstract concept. Besides, model system and environment were very essential to enrich conceptual understanding related to mechanic, heat, thermodynamics, and transfer matter and energy.

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