The Effect of STEM-based 7E Learning Cycle Model with Formative Assessment on Concept Mastery in Work and Energy Topic

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Abstract. Work and Energy are important physics concepts and considered difficult by students. In this regard, it is necessary to have good mastery of concepts. A solution is needed to overcome student's difficulties by designing appropriate learning model to improve students' concept mastery. One of the suitable method is the STEM-based 7E learning cycle with formative assessment. This study aims to determine the effect of STEM-based 7E learning cycle with formative assessment on concept mastery in the topic of work and energy. This study used a embedded experimental mixed method design. The research subjects were 27 of tenth grade Laboratory UM high school, Indonesia. The research instruments were multiple choice with reasons of 15 items concept mastery test with 0.704 reliability and interviews. The quantitative data were analyzed using paired sample t-test, N-gain, and d-effect size. While the qualitative data were analyzed using data collection procedures, data reduction, coding, data presentation, and building a conclusion. The results showed that STEM-based 7E learning cycle with formative assessment was able to significantly increase students' concept mastery in medium category. The result of effect size showed a major impact on concept mastery. Moreover, students still experienced difficulties on determines the direction of work and associates work with energy conversion in a system such as evaluate the relation between work and kinetic energy. For further research, researchers can add aspects of 'Art' in STEM and 9E Learning Cycle to improve concept mastery or other 21st century abilities for students.

Keywords: 7E learning cycle, STEM, formative assessment, concept mastery, work and energy

1 Introduction

Physics have quite a number of concepts that are interrelated with one another [1]. Many studies related to physics education found that students have difficulty in learning scientific concepts as a result of errors in understanding most of the initial knowledge's concept [2-3]. In this regard, a good ability of concept mastery in a topic is needed [4]. A good concept mastery in physics will make it easier for students to understand other

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topic's concepts that are more complicated and complex [4], and to be able to explain and conclude the phenomena around them [5].

Work and energy is important concepts in learning physics [6]. This topic is one of the physics concepts that crosses all disciplines and related to the situation of daily life [7-8], namely in solving motion problems such as Newton's law and momentum-Impulse [9]. Work and energy are known as difficult concepts [10-11] in addition to mechanics, thermodynamics, and quantum mechanics [12] among students all ages [13-14]. Students assume that work and energy topic is abstract [5, 15] and uses many mathematical formulas [5]. Based on previous research, students have difficulty in determining positive, negative, or zero of work [16-17], associating work with energy changes in a system [18], explaining the relation between work and kinetic energy [10,19], and tends to using primitive thinking or rather than using the work-energy theorem [5]. Difficulties in mastering work and energy topic occurred because of a mismatch between daily understanding and scientific explanation of the concept [8.20].

Several solutions have been made to overcome the difficulty of concept mastery in physics. The model that has been used is Discovery Learning aided by Practicum Tools [21]. Discovery Learning is able to increase students' concept mastery better as a result of one of the stages that connecting the practicum results with work and energy right concepts [21]. However, this learning model has weakness in developing aspects of the concept as a whole. This is because the discovery model focuses on the concept of material based on a series of data or information obtained through only observation or experiment [22]. Another learning that can overcome physics difficulties is STEM-based inquiry [23]. However, inquiry-based learning has weaknesses in changing student knowledge because they have been equipped with a lot of knowledge both at school and at home that affect learning [24]. Meanwhile, the development of concepts overall and exploration of students' initial knowledge can be optimized through Learning Cycle 7E [25-26]. Thus, some of the weaknesses of previous studies can be overcome with applying 7E Learning Cycle.

The 7E learning cycle has a syntaxes that builds new knowledge structures, updates misconceptions [26], and expands concepts [27]. The 7E learning cycle is constructivist, that is give students opportunity to build their own knowledge based on the concepts they already know [26,28]. Students' conceptual understanding can be developed through the Elaborate and Extend phases, where students have the opportunity to apply the understanding they have acquired to new concepts [28] and expand their understanding [29]. However, the 7E learning cycle has not been able to connect existing concepts with new concepts optimally [25,30]. The addition of STEM is useful for completing the weakness of the 7E learning cycle in connecting existing concepts with new concepts optimally by incorporating everyday problems into learning [25]. Based on previous research and observations made in schools, STEM-based 7E learning cycle on the topic of work and energy still rarely done.

Several studies have found that STEM-based 7E cycle learning can improve various learning outcomes [25,31-32], but students still have difficulty understanding the application of physics in daily practice [25]. The solution to these difficulties can be overcome with a formative assessment. Formative assessment gives students more stimulation by adding problems, choosing solutions [33], and providing feedback to find out and improve students' understanding levels [34-36]. Formative assessments are able to train students to reflect on their own understanding [37] and teachers can help to improve the practice of applying physics that is not yet understood. Learning Cycle 7E based on STEM and formative assessment is predicted to be able to improve students' concept mastery through learning activities. Currently, research that examines the topic of work and energy through the STEM-based 7E learning cycle model and formative assessments is still rarely conducted. Thus the purpose of this research is to investigate the influence of STEM-based 7E learning cycle with formative assessment on mastery concepts in the topic of work and energy.

2 Method

This study uses a mixed method with an experimental embedded design [38]. This study collected quantitative and qualitative data simultaneously so that it can support each other in providing a deeper understanding of research problems. The research sample was 27 students of class X MIPA 3 UM Laboratory High School, consisting of 13 male students and 14 female students. The research subjects were selected through purposive sampling techniques. The types of data in this study are quantitative and qualitative. Quantitative data obtained from concept mastery test on work and energy topic. The student concept mastery test consists of 15 multiple choice with reasons questions with a reliability value of 0.704 or reliable with a high level of reliability [39]. The subtopics tested include work, potential energy, kinetic energy, and the law of conservation of mechanical energy. The concept mastery in the test used in this study is in accordance with the adaptation of Bloom [40] which includes five levels namely understanding (C2), application (C3), analysis (C4), evaluate (C5), and create. (C6). Qualitative data were obtained through interviews with students.

Learning is arranged by integrating STEM and formative assessment into learning 7E Learning Cycle. Stages of 7E Learning Cycle by Eisenkraft consist of: Elicit, Engage, Explore, Explain, Elaborate, Evaluation, and Extend [27,41]. This STEM approach is a process that focuses on the educational process as a problem solver in daily life [42]. Science is used by scientists to answer questions using the scientific method [44], while engineering and technology are taught with engineering design processes [43-44]. Mathematics is used in science, engineering, and technology [44]. Formative assessment is an assessment that aims to improve learning by showing student progress in relation to basic standards, concepts, and skills [45]. There are seven strategies in formative assessments, namely 1) equipping students with a clear and easy to understand learning target vision; 2) using examples and work models; 3) providing effective feedback; 4) teaching students to assess themselves and set goals; 5) designing lessons to focus on one learning target or quality aspects at one time; 6) teaching the focus of student revision; and 7) involve students in self -reflection, and let them track and share their learning [46].

Quantitative data analysis is obtained from the results of pretest and posttest, while qualitative data is obtained during and after the treatment process. Quantitative data analysis uses descriptive statistics and different paired tests, N-Gain, and Cohen's D-

Effect Size [47-48]. While qualitative data analysis uses data collection procedures, data reduction, coding, data presentation, and making conclusions. Then the data obtained from the concept mastery test was analyzed descriptively to find out the level and category of concept mastery for multiple choice questions by Saglam-Arslan & Devecioglu [25,49]. The concept mastery category was divided into: 1) No Response (NR), namely students do not mastering the concept with criteria such as they do not choose answers and do not give reasons; 2) No Understanding (NU), namely students experiencing misconceptions with criteria such as they choose the wrong answer and give reasons for answers that are not in accordance with the concept; 3) Incorrect Understanding (IU), namely students have partial understanding with misconceptions by criteria such as they choose the correct answer but the reasons for the answers given are wrong and show misconceptions; 4) Partial Understanding (PU), namely students have partial understanding with criteria such they choose the correct answer but the reasons for the answers given indicate that only some are understood but there are concepts that are not appropriate in explaining answers; and 5) Sound Understanding (SU), namely students have a complete understanding with criteria such as they choose the correct answer, give reasons for the answers according to the concept, and can meet the indicators of mastery of the concept.

To calculate the percentage of student concept mastery values on work and energy, used formula by Sudjiono [50] below:

$$N = \frac{\sum result\ score}{\sum maximum\ score} \times 100\% \qquad (1)$$

Criteria obtained from the results of the percentage score of concept mastery on work and energy fulfill the requirements according to Arikunto [51] with score range (%) of in low category; in medium category; and in high category.

3 Result and Discussion

Quantitative data analysis is obtained from the results of the pretest and posttest scores. The normality test results for the pretest has a significant value of 0.118 and for posttest has a significant value of 0.239. This shows that both data on students' concept mastery is normally distributed. The results of the pretest and posttest score data are presented in Table 1.

Table 1. Descriptive Statistics of Students's Concept Mastery

	N	Min	Max	Mean	Std.Dev
Pretest	27	2	15	7.63	3.671
Posttest	27	22	39	31.70	4.419

Based on Table 1 it can be seen that the average value of students' concepts mastery on pretest is very low. Then after the intervention, students' concept mastery increases in moderate criteria [51]. To find out the difference in mastery of the concept of pretest and posttest is further analyzed by t-test. Paired t-t-test results obtained a significant value of 0,000 ($p < 0.05$), which detects a significant difference between the mastery of concepts in the pretest and posttest as a result of intervention. This means that the application of STEM-based 7E Learning Cycle accompanied by formative assessments can increase mastery of student concepts on work and energy. In addition, this research also conducts N-Gain calculations to find out how much increase in student concepts at the time of pretest and posttest. The calculation of the N-Gain value shows a score of 0.644. This means that the intervention affects the students' concept mastery in the medium category [48]. Effect size calculation shows a score of 4.163, which means STEM-based 7E Learning Cycle accompanied by formative assessments have the effect of practical implementation in the field in strong effect [47] on mastery of student concepts on work and energy. This is in line with previous research which reveals that the STEM-based 7E Learning Cycle can effectively increase students' concept mastery [25].

3.1 Level of Students' Concept Mastery

Pre-test and post-test answers are analyzed based on five aspects of concept mastery by Saglam-Arslan & Devecioglu [25,49]. The results are shown in Table 2.

Table 2. Level of Students' Concept Mastery from Pretest and Posttest

Level	Pretest		Posttest	
	Frequency	%	Frequency	%
No Response	17	61.48%	1	3.70%
No Understanding	1	4.20%	7	25.93%
Incorrect Understanding	8	30.37%	3	11.11%
Partial Understanding	1	3.95%	3	11.11%
Sound Understanding	0	0%	12	44.44%

Based on Table 2 shows that there are no students at Sound Understanding level in concept mastery during pretest. Most students are at low level, which is 61.48% not mastering the concept; 4.20% experience misconceptions; 30.37% have partial understanding with misconceptions; and 3.95% have partial understanding. In the posttest it can be seen that the majority of students are already at the Sound Understanding level which is equal to 44.44%.

3.2 The difficulties of Each Scientific Literacy Indicators

The difficulty of concept mastery on work and energy after learning can be seen based on the N-Gain value for each subtopic. The N-Gain values for each subtopic can be seen in Table 3. From Table 3 it can be seen that the work subtopic has a high N-Gain of 0.804784. While other subtopics such as potential energy, kinetic energy, and the conservation law of mechanical energy have moderate N-Gain. This shows that students have no difficulty in the work subtopic and have a little difficulty in the potential energy, kinetic energy, and the conservation law of mechanical energy subtopics. The most difficult topic for students was kinetic energy.

Table 3. N-Gain Value of Concept Mastery in Each Subtopic of Work and Energy

Subtopic	N-Gain	Category
Work	0.804784	High
Potential Energy	0.641975	Moderate
Kinetic Energy	0.551698	Moderate
Conservation Law of Mechanical Energy	0.626543	Moderate

Work Subtopic. On the work subtopic, students are able to fulfill indicators with N-gain scores in the high category including: calculating effort through the F-x chart (C3), evaluating problems with the concept of work and force (C5), and analyzing the concept of work in everyday life (C4). While the N-gain value is in the medium category, which is equal to 0.472 on the indicator analyzing the value of work in physics (C4). Students' difficulty with these indicators is shown by the distribution of levels of mastery of the concept on posttest in the following table.

Table 4. Problem on Work Subtopic

Problem	Concept Mastery Level Distribution (%)				
	NR	NU	IU	PU	SU
A child pulls a trolley on a flat plane so that the trolley is transferred. The work made by the weight of the trolley is … a. Not the same as zero **b. Same as zero** c. In the direction of the displacement direction d. In the direction of the earth's gravitational force Reason: ……………………………………..	0	44.44	18.52	0	37.04

Based on Table 4 it appears that most students are still at the Not Understanding (NU) level indicating that students experienced misconceptions. Most of the students' reasons indicated that the work was not the same as zero and in direction of the displacement's. Students have not been able to determine the direction of a work against a given force, where in this problem what is being discussed is weight. Students have difficulty identifying the forces acting on an object, students experience errors in determining the direction of the force vector such as weight force (w) and pulling or pushing force ($\vec{F}$) on the object system. This is in accordance with previous research where students tend to experience difficulties in determining the sign or direction of a work [16-17]. In addition, students also experience difficulties in determining the value of cos for certain angles, which actually taught this material on Vectors and Newton's Laws before. This proves that low mastery of concepts in one subject will make it difficult for students to understand the concepts of other subjects that are more complicated and complex [4].

Potential Energy Subtopic. On the potential energy subtopic, students are able to fulfill indicators with N-gain values in the high category including: evaluating the concept of gravitational potential energy in physics (C5), analyzing the amount of potential energy of a system (C4), and designing solutions to obtain potential energy (C6)). The smallest N-gain value is in the medium category which is equal to 0.361 on the indicator explaining the factors that affect potential energy (C2). Students' difficulty with these indicators is shown by the distribution of levels of mastery of the concept on posttest in the following Table.

Table 5. Problem on Potential Energy Subtopic

Problem	Concept Mastery Level Distribution (%)				
	NR	NU	IU	PU	SU
Arin moved the suitcase from the floor to the table. In addition to the weight of the suitcase, what factors determine the work by the earth's gravitational force to the suitcase are shown as follows: How to lift a suitcase from the floor to the table vertically or through another longer path The position of the suitcase when lifted, namely vertically (standing upright) or horizontal The height of the table from the surface of the floor Which statement is true? (1) only (2) only (3) only (1) and (2) (2) and (3) Reason:…………….	0	70.37	7.41	0	22.22

Based on Table 5 it appears that most students are still at the Not Understanding (NU) level indicating that students experienced misconceptions. Most of the students' reasons indicated that work by the gravitational force determined by how to lifted a suitcase from the floor to the table vertically or through another longer path. Students have difficulty identifying the direction of the force vector by gravity (w) so students draw conclusions from everyday experiences by inserting a pull or push force ($\vec{F}$). This is consistent with previous research where students tend to have difficulty in associating work with energy changes in a system [18] due to a incorrect between everyday understanding and scientific explanations of concepts [8,20].

Kinetic Energy Subtopic. On the **topic** of kinetic energy, students are able to fulfill indicators with N-gain values in the high category including: calculating the value of kinetic energy in a system (C3) and analyzing the relation of energy to work based on changes in object velocity (C4). The smallest N-gain value is in the medium category, which is 0.306 on the indicator evaluating the concept of kinetic energy (C5). Students' difficulty with these indicators is shown by the distribution of levels of mastery of the concept on posttest in the following Table.

Table 6. Problem on Kinetic Energy Subtopic

Problem	Concept Mastery Level Distribution (%)				
	NR	NU	IU	PU	SU
Sledge A and sledge B are initially stationary on a smooth, horizontal ice surface. The mass of sled A is 30 kg and the mass of sled B is 45 kg. The two sledges are pulled with the same constant force of 25 N along a straight track for 10 m to the finish line. A mechanic estimates that the kinetic energy of sled B is greater than sled A. The correct statement about the prediction made by the mechanic is…. Correct, the kinetic energy of sled B is greater because it has a greater mass Incorrectly, the kinetic energy of sled A is greater because the speed at which it moves is greater Incorrectly, the kinetic energy of the two sleds is the same which is 250 J Incorrectly, the kinetic energy of the two sleds is the same at 25 J Incorrectly, the kinetic energy of the two sleds is the same at 10 J Reason:……………	7.41	74.07	11.11	0	7.41

Based on Table 6 it appears that some students are still at the Not Understanding (NU) level indicating that students experience misconceptions. Most of the students' reasons indicated not based on the concept of the work-kinetic energy theorem.

$$W = \Delta EK \quad (2)$$

So the correct concepts of force, displacement, and total kinetic energy are:

$$Fs = \Delta EK \quad (3)$$

It is known that two objects have the same final kinetic energy if they apply the same force at the same distance. Students tend to ignore information on force ($\vec{F}$) and displacement (s) on objects and answer that the amount of kinetic energy is affected by mass (m). Some students also wrote that determining the greater mass has greater kinetic energy based on the kinetic energy formula, which is:

$$EK = \frac{1}{2}mv^2 \quad (4)$$

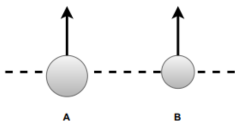
This is in line with previous research that students still have difficulty explaining the relation between work and kinetic energy [18-19], tend to use mathematical formulas and think primitively rather than using the energy theorem that has been given in learning [5].

Conservation Law of Mechanical Energy Subtopic. On the conservation law of mechanical energy subtopic, students are able to fulfill indicators with N-gain values in the high category including: analyzing graphs related to mechanical energy in systems that are not influenced by external forces (C4). The smallest N-gain value is in the medium category which is equal to 0.485 on the indicator applying the conservation law of mechanical energy in systems that are not affected by force (C3). Students' difficulty with these indicators is shown by the distribution of levels of mastery of the concept on posttest in the following Table.

Based on Table 7 it appears some students are still at the Not Understanding (NU), Incorrect Understanding (IU) and Partial Understanding (PU) levels indicating that students experience misconceptions and partial understanding. Students at the NU level answered incorrectly without providing an explanation in which the answer they chose was option B. Students at the IU level gave the correct answer, but the explanation given was not in accordance with the concept of conservation law of mechanical energy. Students tend to answer with their own predictions without including the physics concepts used. Meanwhile, students at PU level did not include concepts or equations for the law of conservation of mechanical energy, but directly compared the heights of the two balls based on the concept of potential energy. This is consistent with previous research where students tend to have difficulty in associating work with energy changes in a system [18].

Based on the results of interviews with students, the increase of student's understanding is shown through activities in learning such as practicum, addition of STEM, and formative assessment on work and energy topic. Students think that having practicum helps them understand the concepts explained by the teacher by proving it directly. This shows that constructivist learning is able to make students build their knowledge independently [26,28]. In addition, with practicum students are also used to memorizing quantities, units, and equations in work and energy topic. This shows that the learning provided has a syntax that updates students' preconceptions and misconceptions [26]. Giving a prototype design project assignment can help students to understand the concept of work and energy directly when applied in everyday life. This is consistent with the STEM learning objectives which require students to be able to solve everyday problems based on learning and be able to optimally connect existing concepts with new concepts [25]. This activity is also considered capable of practice conceptual mastery on the C6 (creating) in presenting problems (generating), as well as planning solutions to given problems (producing) [40].

Table 7. Problem on Conservation Law of Mechanical Energy Subtopic

Problem	Concept Mastery Level Distribution (%)				
	NR	NU	IU	PU	SU
Two balls A and B are simultaneously thrown vertically upwards from the same position. The two balls have the same initial kinetic energy (KA = KB). If the mass of ball A is twice the mass of ball B (mA = 2mB), then the maximum height that ball A can reach is.....  $h_A\ max\ =\ 4hB\ max$ $h_A\ max\ =\ 2hB\ max$ $h_A\ max\ =\ hB\ max$ $h_A\ max\ =\ 1/2hB\ max$ $h_A\ max\ =\ 1/4hB\ max$ Reason……………………………..	0	14.81	18.52	7.41	59.26

Providing formative assessments help students in knowing various types of questions, especially those that are in accordance with learning achievement indicators. Giving formative assessments is in accordance with previous research where assessments are able to provide more stimulus for students through more questions [33]. In this activity one of the formative assessment strategies is carried out in the form of effective feedback to explain student mistakes and how students improve their understanding. This can be proven by the results of the student posttest, where students who have difficulty with one of the indicators of concept mastery during the formative assessment could did it correctly on posttest. Effective feedback can improve students' level of concept mastery [34-36].

4 Conclusion

Based on this explanation, it can be interpreted that the STEM-based 7E learning cycle with formative assessment can improve students' concept mastery in medium category. The integration of STEM and formative assessment in the 7E learning cycle succeeded in changing most of the students' concept mastery from the majority being at the No Response level to Sound Understanding level. STEM-based 7E learning cycle with formative assessment can make students active in learning by building their knowledge independently. STEM helps students to be able to solve everyday problems based on learning and be able to connect existing concepts with new concepts optimally. Formative assessment makes it easier for students to learn by introducing various other examples of problems related to effort and energy, as well as correcting students' difficulties and misconceptions. Students still experience difficulties in determining the direction of work, associating work with changes in energy in a system such as evaluating the relation between work and kinetic energy. This research has a weakness that requires a lot of time so the implementation of learning cannot be carried out optimally. This becomes a factor of students' difficulties in evaluating the kinetic energy subtopic. Therefore, future research should be able to manage time better in order to carry out the learning syntax optimally. Researcher can add 'Art' aspects in STEM and 9E Learning Cycle to improve better mastery of concepts and other 21st century abilities for students.

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