Students’ conceptual understanding and problem-solving of the Work-Energy and Impulse-Momentum Theorems in a flipped classroom

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Abstract. The study investigated the effect of using a flipped classroom approach on students’ understanding of the work-energy and impulse-momentum theorems. An intact class of Grade 12 STEM students took part in the study. The instructional materials needed for the lessons were compiled in a website that can be accessed by the students via desktop or a mobile device. The lesson calendar, study guide, modules, worksheets, and problem sets were organized in tabs and instructions were clearly stated for ease of use. Using Greeno’s model of scientific problem-solving and reasoning, the students’ solutions were analysed using maps of the problem-solving approaches they utilized. The students had difficulty comprehending problems and identifying which concepts are related to them. In terms of Greeno’s model, this implies that the students were not able to successfully translate concepts between domains. There were no traces of use of other domains apart from the abstract and symbolic domains, when an improved understanding must include translations between all four domains – namely, the concrete domain, which involves physical objects or events; the model domain, which refers to representations of objects or events; the abstract domain, which involves concepts or principles; and the symbolic domain, which is the mathematical representation of concepts.

1. Introduction
Prior to the implementation of the K-12 Basic Education reform in the Philippines during the year 2013, the science curriculum consisted of a 72-minute Physics class taken daily during the students’ fourth year of secondary education. The country, however, performed below international standards as evidenced in the Second International Science Study (SISS) and Third International Mathematics and Science Study (TIMSS) rankings. Orleans [1] noted that the poor results may be due to school-related factors, pertaining to the conduciveness of the learning environment and accessibility of learning materials, and teacher-related factor, particularly the quality of teachers. Apart from those, the study conducted by the Science Education Institute – Department of Science and Technology identified that the teaching-learning process, science curriculum, and administrative support are also factors in the low achievement of Filipino students in science [2].

To address the issue on the quality of science education, the Department of Education released new standards for science in the K-12 Curriculum [3], with its main goal of cultivating scientific literacy among learners. It set the focus on building scientific skills patterned after the needs of the 21st century and around three domains of learning science: comprehension and application of scientific knowledge, performance of scientific process skills, and development of scientific attitudes and values. The
curriculum is designed around situations and problems that are relevant to society and the learner. Further, it recommends pedagogical approaches that promote active learning and are learner-centered and inquiry-based. Science lessons shall be more hands-on and with more demonstrations that touch on cognitive, affective, and psychomotor domains of learning. It is structured in a spiral curriculum that encourages deep and meaningful understanding in concepts and eventual application of them to real-life scenarios and gives emphasis to the building and connecting of prior knowledge and integration across all sciences. In this spiral approach, instead of having only one physics class during the final year of secondary education, there will be one quarter per school year of physics instruction during Grades 7 to 10 (junior high school).

In the private secondary school where the second author undertook her practice teaching for her Bachelor of Education, major in Physics degree, she interviewed the physics teachers in the school regarding their experience with the Senior High School students. From the teachers, she learned that a major difficulty in their students’ learning of physics is in its mathematical aspects in problem solving. They mentioned that a lack of understanding of the pre-requisite lessons in physics and mathematics is the reason for this difficulty. They also mentioned that their students generally have difficulties in understanding the word problems, thus contributing to their low performance. This is similar to the findings of Saifullah, Sutopo and Wisodo [4] working with Grade XI students solving impulse and momentum problems. The researchers put forward the observation that this was because the students failed to activate their appropriate concepts relevant to the problem. Students’ difficulties were not only caused by their deficient conceptual understanding about impulse and momentum, but also by their weak understanding about the relationship among force, acceleration, and velocity. Given the concern on the lack of pre-requisite knowledge and conceptual understanding of the physics lesson, the researchers approach is to “flip” the classroom. The Flipped Classroom is a learner-centered teaching and learning method in which the traditional classroom model is reversed [5]. Unlike the traditional lecture format where students spend majority of the time in school listening to lectures, with flipped classroom the students prepare at home by watching video recordings. The purpose of this is to provide more time during the contact hours in the school to learn the more difficult concepts, to answer student questions, and to engage each other in active learning.

The use of technology in education has allowed teachers to improve the learning environment through the innovations brought about by educational technology. Such is the case for example, in the year 2000, when economic professors from the Miami University [6] used an “inverted classroom” to help in addressing their students’ learning needs and styles. They observed that their students varied in their ways of learning. Some students are highly dependent on teacher instruction, some prefer group work, and some are independent learners. The professors realized that when their teaching styles are far from their students’ learning styles, students perform poorly and gain less positive attitudes towards the subject. They hoped to teach the lessons in a manner that suit their students’ preferences, but in order to do so, more in-class time will be needed. They resolved to have activities that were originally done inside the classroom to be conducted outside the classroom, thus the term “inverted”. The materials they provided for outside-classroom work included recorded lectures, PowerPoint slides with audio assistance, and Internet sources, while practice exercises and problem solving were done in class. They found that inverting their classroom was an effective way to teach a diverse set of learners. It garnered positive perceptions from students and other teachers, as well, because the increase in in-class time allowed more time for group work and active learning activities without compromising on the coverage of the subject.

In 2006, two Chemistry teachers [7] converted their classroom into a similar way and termed it as the “flipped classroom”. Their need for the flipped classroom stemmed from problems that were prevalent in their school. There were many students having a hard time coping with the speed of lessons, students missing class because of extracurricular activities, and students who only learn to comply with class requirements for a passing mark. The teachers sought to record their lectures so that their students would be able to view lectures outside of class hours. The video lectures were able to help those students with slower learning speeds, missed classes, and in mastering content. Many teachers from different
fields and levels have implemented the flipped classroom model to solve issues in their classrooms. Majority have used the flipped classroom to simultaneously address issues such as covering a large amount of course content, teaching students with diverse learning styles, and improving comprehension and performance. Schultz, Duffield, Rasmussen, and Wageman [8] examined the effects of the flipped classroom on the academic performance of high school advanced placement chemistry students. The study had a traditional group and a flipped classroom group, with both groups receiving the same assessments that were analysed in the same way using independent t-tests. In addition, the researchers also surveyed on the perception of students of the method. It was found that the average scores for the flipped classroom group were higher and that most of the students favoured the method because they were able to revisit the lectures, the teacher had more attention on them during class hours, and that learning was more individualized.

Ryan and Reld [9] focused on the impact of the flipped classroom on student performance and retention in a general chemistry class in the undergraduate level. Two types of classes, a traditional and a flipped class, were offered in the same semester. Students were given the option to choose which type of class to enrol in and most students chose the traditional class sections, a total of 206 enrolled in the traditional sections and 117 in the flipped sections. Both types of classes were taught by the same teacher and used the same course design with the same online homework and assessment. Results for both classes were compared at the end of the term and it was found that students in the flipped class performed better than those in the traditional class. Students from the flipped class were also less likely to drop out from the course. In a high school Physics with Technology course, Bell [10] investigated on the effectiveness of the flipped classroom in helping students learn physics content and on students’ attitudes towards the flipped classroom. The study had several physics sections randomly assigned to the traditional group and the flipped group. The traditional group was taught by guided inquiry and direct instruction, while the flipped group watched videos before class and while in-class performed a group-based activity based on the video. Three end-of-unit tests were administered at the start, midway, and end of the grading period in all classes. It was found that there was no significant difference in the results of both traditional and flipped classes. A survey on the students’ attitudes towards the learning environment was also conducted and showed that there was no significant difference between the results of the traditional and flipped classes. The recent study by Limueco and Prudente [11] aimed at improving the teaching of physics in Grade IX by flipping the classroom. They investigated whether the flipped classroom succeeds in helping students master concepts by measuring their conceptual understanding using the Energy Momentum Conceptual Survey. After the implementation period that lasted for three weeks, it was found that the treatment group scored significantly higher than the control.

As the activities inside and outside the classroom change, essentially expanding the walls of the classroom, the role of teachers also changes. Teachers remain as lesson planners that ensure that all materials are aligned with the recommended curriculum. What changes is the process of preparing materials with the added educational technologies for outside class lessons and with the assessment tools needed for the inside class activities. The teacher strengthens the effects of flipped classroom activities in student learning by acting as a motivator for students to be committed to their tasks [12].

2. Methodology

2.1. Context and Participants
The research participants were from one intact class of Grade 12 STEM students from a private Catholic school in Manila, Philippines. Twenty-three students gave their consent in participating in the study. However, only fifteen students (8 males and 7 females) completed all the tasks, consisting of four (4) modules, and were included in the analysis. The other students in the class were not able to complete all the tasks because they were not fully committed to doing the assigned homework.

2.2. Instruments
The following research instruments were used for the study:
2.2.1. **Worksheets.** Each worksheet is composed of 5 to 8 questions about the video and captured key conceptual ideas presented. The worksheets check whether students were committed in completing home tasks and if they understood the videos while watching them. The four (4) worksheets correspond to the four modules, namely, Kinetic and Potential Energy, Conservation of Energy, Momentum, and Impulse and Momentum. The figure below shows an example of the answers to the questions on kinetic and potential energy.

![Worksheet Example](Figure 1. Sample Student Response for the Module on Kinetic and Potential Energy)

2.2.2. **Word Problem Quiz.** After every two modules, the students answered a word problem quiz consisting of six (6) word problems. This is to measure the students’ understanding of the relationship between the concepts they have learned.

2.2.3. **Students’ Perception Survey and Journal Log.** The students were asked about their perceptions on the flipped classroom and provide insights on how they felt about the class. They gave feedback regarding what they liked about the experience and what could be further improved.

2.3 **Implementation of the Flipped Classroom**
Before the start of the lesson, all instructional materials needed for the four modules were compiled in a website which can be accessed by the students anytime as long as with Internet connection. A mobile phone version was also designed in order that the website could be accessed through both a computer
and through a smartphone or tablet. The lesson calendar and study guide, modules (including the videos), worksheets and problem sets were organized, and instructions were clearly stated for easy use.

![Figure 2. Screenshot of the Class Website [bit.ly/GPStHubert].](image)

After the students watched the video at home and used the learning module prepared by the teacher-researcher, they answered the worksheet before going to class. In-class, there was guided discussion about the topics/concepts that the students found difficult to learn. The misconceptions that came out in the worksheets were also addressed. Problem-solving session was also conducted in class as application of the concepts that the students learned. During problem-solving, the teacher-researcher walked around the room to attend to students who encounter difficulties.

### 3. Results and Discussion

#### 3.1. Conceptual Understanding

The student worksheets provided evidence that the students were able to learn the conceptual part of the lesson from the instructional videos provided. As shown in table 1, looking at the key concepts that the students needed to learn for the Module on Kinetic and Potential Energy, majority of the students in the class obtained satisfactory scores. The students show adequate initial understanding as the scores show that most students were able to arrive at correct answers. The students who did not get the correct answer failed to convert to standard units. The sixth item has the lowest percentage of correct answer because many students provided an answer which is unrelated to the question asked. While the question only asked about the total mechanical energy of a body (or how it is found in relation to kinetic and potential energies), many provided a numeric answer without any solution how this was computed.

#### 3.2. Problem-Solving

Using Greeno’s model [13] of scientific problem-solving and reasoning, the students’ solutions were analyzed using maps of the problem-solving approaches they utilized. Figure 1 shows the solution map for the word problem on kinetic and potential energy. Majority of the students (11 solutions, 73%) were able to apply the concept by making reference to the kinetic energy concept. The solutions that did not arrive at the correct final answer made mismatched substitutions, considering weight in Newtons as mass in kilograms or substituting the kinetic energy data for mass.
Table 1. Key Concepts for the Module on Kinetic and Potential Energy.

| Number of Students with Correct Answers | Percentage Correct |
|-----------------------------------------|--------------------|
| 15                                      | 100%               |
| 12                                      | 80%                |
| 15                                      | 100%               |
| 12                                      | 80%                |
| 12                                      | 80%                |
| 6                                       | 40%                |
| 9                                       | 60%                |

1. Kinetic energy is energy in moving objects. Potential energy is energy stored in objects with respect to relative vertical position
2. Work is related to energy through force
3. Kinetic energy is directly proportional to mass and the square of velocity. Increase in velocity will result to an increase in kinetic energy
4. Kinetic energy = \( \frac{1}{2} mv^2 \)
5. Potential energy = \( mg \) h
6. The total mechanical energy of a body equals to the sum of kinetic and potential energies.
7. Energy is always conserved within a system.

Figure 3. Solution map of students’ approaches to word problem on Kinetic and Potential Energy.
Figure 4. Solution map of students’ approaches to word problem on Impulse and Momentum.

For the word problem on impulse momentum, majority (89%) of the students made references to the momentum concept. The students were able to arrive at the correct final answer, with only small differences in values because of rounding-off errors. There was one solution that made no reference to the momentum concept, wherein the student immediately multiplied both given data together. The student was not careful and made errors in the values converted. We have noted that for the word problems given to the students, it is frequent that they neglect to convert units into standard form or are not careful in recalling the units for each quantity. A similar observation is presented by Prihartanti, Yuliati, and Wisodo [14] in their study about eleventh-graders’ concept of the momentum conservation law. They noted that the student’s problem-solving skill was still less optimal for the indicator of applying the strategy and evaluating the solution.

3.3. Students’ Perception of the Flipped Classroom

The students’ responses in the survey and journal log revealed that the flipped class has helped them learn ‘through informative video’ and ‘[the video] makes me understand the lesson easier when watching the movie on how to do it’. There were some who communicated more with classmates or the teacher than others because they like group discussions and group collaboration or needed more technical assistance. They shared ‘I like the way we help each other in solving problems and answering the modules’, ‘I like having group discussions with some classmates’, and ‘I like how approachable the teacher is’. Some students explored his or her own strategies of learning and those who prefer working alone benefited from the availability of online content. They expressed ‘it was easy to access which helped me to do it anywhere and anytime. It also helped me learn to work by myself’ and ‘the method helped me in a way that I can be independent in understanding the lesson’. There are some who found it easy to work in an online environment and did not need as much technical assistance. One student shared ‘I was able to explore more on the topic [with the flipped classroom] because of the availability
of the internet and because of its accessibility'. The students mentioned that what they liked most about the flipped classroom is how ‘it is quite faster in terms of discussion’, ‘[lessons] can be accessed even at home’, ‘I can listen to the lesson repeatedly’, and how ‘we have a lot of time to learn by ourselves’. However, the available time for the class was also limited and the amount of workload possibly forced the students to work harder in the class. They also mentioned that they struggled because of ‘too much worksheets and workload in a very tight schedule’ and ‘because of too much tasks done in school, having a flipped classroom will increase my workload when I get home so in the end I don’t have time to watch all the videos that enable for me to understand the lesson’, implying that although maximizing time in class and expanding the classroom to outside of class activities seem effective, it is still additional work for students and it can still tire and demotivate them.

4. Conclusion
This study examined how the flipped classroom can improve Grade 12 students’ conceptual understanding and problem-solving in energy and impulse-momentum concepts. Worksheets were given after students viewed the selected instructional video. The data was analyzed through identifying how much of the initial concepts was understood from the worksheets and checking for gaps, missing links, or missing translations in their understanding of the concepts. This information about the missing links were used to design the class lessons in order to bridge the gaps in students’ understanding. The students also answered word problems involving work-energy and impulse-momentum theorems. Their solutions were analyzed through solution maps which traced the diverse approaches the students used in solving the problem. Although the results from their worksheets show that they have understood the concept, their performance in problem-solving showed that they were not able to translate from what Greeno [13] calls the symbolic domain to the concrete domain and from the abstract domain to the symbolic domain. This may explain their poor performance in understanding the problem or question asked, in recognizing the principle used to solve the problem, and in associating standard units for specific quantities. Overall, the students reported that they were able to benefit from the flipped classroom. The flipped classroom approach was a meaningful experience for them, because apart from the subject content that they learned, they became more responsible for their own learning. They were able to find ways to learn despite the limited amount of time. The method has given the students an opportunity to be an independent and responsible learner, which could lead to more successful learning experiences in the future.

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