Development of a hands-on model embedded with guided inquiry laboratory to enhance students' understanding of law of mechanical energy conservation

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Contents

Abstract

This paper attempts to investigate the understanding of the law of mechanical energy conservation using a guided inquiry approach. A simple hands-on model was constructed and used to demonstrate the law of mechanical energy conservation. A total of 30 grade ten students from one of the middle secondary schools in western Bhutan participated in this pilot study. A single group pretest-posttest design was used. The participants were selected by purposive sampling method. The means of the pretest and posttest were determined to find the understanding of the law of mechanical energy conservation. The attitude survey questionnaire was used to explore the students' attitude towards the guided inquiry laboratory teaching using the hands-on model. A paired sample t-test showed that there was a statistical significant difference in the means of pretest (M = 13.43, SD = 3.766) and posttest (M = 21.67, SD = 2.893) at t(29) = -10.739, p =.000, α =.05 indicating an improvement due to the treatment. The attitudes of the students towards the developed learning unit were also found positive.

Keywords: Physics, the law of mechanical energy conservation, hands-on model, guided inquiry laboratory, Bhutan.

Introduction

Like any other scientific concepts, the law of mechanical energy has remained as a subject of interest for many physicists. It is arguably one of the most fundamental laws of physics (Featonby & Jeskova, 2012; Hassani, 2005) and that teaching about it requires a careful plan and effective pedagogy (Hassani, 2005). A numerous attempt has been made to explain and demonstrate the phenomenon of energy conservation using diverse methods and alternatives based on different circumstances. There are also abundant theoretical examples either imaginary or real that are massively discussed in various books and information sources to explain it. However, even by using these examples, in most cases, the law of mechanical energy conservation is never clear in the minds of the students and therefore has been largely misconstrued.

For instance, the students generally assume energy to be a concrete entity rather than an abstract idea (Feynman, 1963; Trumper, Raviolo, & Maria Shnersch, 2000). It is also perceived as an entity that can last for some time and gradually ends up completely (Tatar & Oktay, 2007). The physicist meaning of conservation is that the total amount of energy remains constant despite any energy transfer or transformation that takes place during any physical phenomena. However, for students, the synonymous use of the terms like "conservation" and "saving" casually have caused them to understand this law in a non-scientific manner (Tatar & Oktay, 2007). Such factors have rather challenged the students in realizing the scientific way of the understanding law of mechanical energy conservation. As an educator for the last ten years, based on our personal experiences in teaching physics for the middle secondary students in Bhutan, it was observed that the students were not able to relate the law of mechanical energy conservation into their daily life situations other than being able to state its definition. Thus, there was an urgent need to develop some approach that can enhance the students' understanding regarding this law that forms the foundation for appreciating the universe.

Since the law of mechanical energy conservation forms an integral part of any introductory physics, it is appropriate to include an experiment to demonstrate the phenomenon (Hwu, 1980). A various approach has been made to study the law of mechanical energy conservation such as the case of video analysis (Bryan, 2010) or using an inclined ramp with a spring launcher (Dilles, Hughs & Shrestha, 2009). However, a very little information is available regarding the development of a hands-on model embedded with a guided inquiry laboratory to investigate the conceptual understanding of the students. This gap in the literature formed as the basis to undertake this study by developing a simple, handy and relatively cheaper hands-on model to demonstrate the law of mechanical energy conservation.

The fundamentals of energy, energy transfer and energy transformation forms an integral part of the Bhutanese science curriculum. But the concept of mechanical energy conservation is introduced only in the tenth grade. The textbook which still serves as the main source of information contains imaginary or hypothetical examples that are difficult for the students to study the law of mechanical conservation at the classroom level. Therefore, this study developed a simple hands-on model out of the locally available materials to demonstrate the law of mechanical energy conservation using a guided inquiry laboratory.

Research questions

This study was guided by two research questions:

1. What extent has the learning laboratory helped the students in understanding the law of mechanical energy conservation?
2. What are the students' views and attitudes towards the developed learning laboratory?

Literature Review

Law of Mechanical Energy Conservation

The law of mechanical energy conservation has gained so much attention (Solbes, Guisasola, & Tarín, 2009) due to which it remained as a subject of interest for many physicists. Although the conservation of mechanical energy forms a fundamental part of any introductory physics (Hwu, 1980; Hassani, 2005; Santos, Soares, & Tort, 2010; Li, 2012; Bambill, Benito, & Garda, 2004) and classical mechanics (May, 1936), the students are able to solve only the simple energy problems and not the ones that involves principles of energy conservation (Speltini & Ure, 2002). Further, the concept of energy conservation is widely misunderstood and accepted in a manner that is not parallel with the scientific point of view (Solbes et al., 2009). This is often because the students are unaware in the usage of the word while describing the law of mechanical energy conservation. Students are often confused with the term *"conservation"* because they assume it as a synonym to *"saving"* (Tatar & Oktay, 2007; Mweene & Mumb, 2012) or *not wasting* energy. The students are able to remember and recite the law of mechanical energy conservation with a relative easiness, but are unable to apply correctly in real situations (Tatar & Oktay, 2007; Mweene & Mumb, 2012). As asserted by Driver and Warrington (1985), students consider energy not as a conserved quantity, but something that is active for a short while and disappears.

By conservation, Millar (2005), Featonby and Jeskova (2012) and Needham (2011) defines that the total amount of energy, both in the beginning and the end remains the same, no matter what kind of processes or events takes place. This means that energy can neither be created nor destroyed (Tatar & Oktay, 2007; Wisniak, 2008; Daane et al., 2013; Larmer, 2014; Herrmann-Abell & DeBoer, 2011; Mweene & Mumb, 2012). In principle, energy is a conserved quantity (Driver & Warrington, 1985) and that same quantity remains constant at the end as was in the beginning of the process (Daane et al., 2013). Feynman (1963) further highlights the fact that this numerical quantity does not change even when there are manifold changes of nature and its processes. Even after the tricks of the nature and repeated transformations; the quantity remains the same throughout as we calculate all forms of energy in the system again (Feynman, 1963). Precisely, the law of mechanical energy conservation means that the energy can change from one kind to another, but at the end, the total energy involved in the system always remain the same. The energy which was present in the beginning might have turned out to be in a different form during the process, but the total amount of that energy at the end of the event always remains the same as it was in the beginning.

In Newtonian mechanics, the law of mechanical energy conservation implies that the sum of the potential energy and the kinetic energy is always constant in an isolated system (Wisniak, 2008; Santos et al., 2010). This means that for the particular system, the total amount of energy can only be changed if the energy is transferred into that system or if the energy is being transferred out of that system. In an isolated system, there is no transfer or exchange of energy across the boundary of the system while transfer of energy is possible across the boundary of the non-isolated system either by one or more mechanisms (Jewett, 2008). The law of mechanical energy conservation takes place only in an isolated system. The energy and mass are always maintained constant in an isolated system because neither of these two physical quantities gets transferred across the boundary. In such system, it allows the transfer of energy within itself but restricts completely with the surroundings. However, the existence of such isolated systems is only theoretical and that they in reality do not exist at all. But for the sake of scientific experiments, most of the non-conserved forces such as friction and gravitational forces are often neglected and claimed negligible even if we know that their existence is inevitable and pervasive.

Previous studies on Law of Mechanical Energy Conservation

Neglecting the presence of the non-conserved forces, various attempts have been made to study the law of mechanical energy conservation. It was studied based on the Galilean principle of relativity focusing both on conservation of linear momentum and angular momentum (Santos et al., 2010) and by using a projectile motion (Hwu, 1980). The bowing effect on energy conservation using an inclined experiment (Li, 2012) was also studied by assuming that there exists no friction on a dynamic track used for the experiment. Similarly, in the study of the conservation of mechanical energy in the theory of inviscid fluid sheet by Shields and Webster (1989), it was found that mechanical energy is conserved. Bambill et al. (2004) has also explained the law using a conical pendulum while a video analysis was used to study the motion in the laboratory (Bryan, 2010).

Speltini and Ure (2002) have conducted a study based on an exploratory approach with 114 students to find conservation principles, meaning of conservation and examples of both conservation and non-conservation. Daane et al.(2013) involved K-12 teachers to study the concepts, including conservation, amount and forms of energy and its usefulness while Brook and Wells (1988) have surveyed the understanding of energy and energy conservation of 10 teachers and students aged 11-15 and observed that the majority of them had limited understanding of conservation. 28 students who have already studied relevant ideas in physics was also investigated to trace the extent to which students used energy conservation ideas in solving both written and practical problems (Driver & Warrington, 1985). It was illustrated that the concept of energy conservation was rarely used in analyzing a problem. In a study by Solbes et al. (2009) a teaching sequence has been designed and assessed to introduce the concepts of energy conservation at post-secondary students and revealed that the teaching sequence if combined with a methodology used in the classroom may effect a better understanding of law of mechanical energy conservation. Mweene and Mumb (2012) involved 90 university biology students to assess understanding of energy conservation using a pencil and paper test and observed that students have no concept that the energy is not lost. Also, there is a study that involved 9739 middle and 5870 high school students and 176 university students to assess about energy concepts, energy transfer and transformation and energy conservation using a standard-based multiple choice (Herrmann-Abell & DeBoer, 2011). The study revealed that the students had difficulties with items related to conservation and its application to a specific real-world.

Guided Inquiry Laboratory

In achieving scientific literacy, the inquiry-based approach of teaching have been widely regarded as an effective method (Duran, McArthur, & Van Hook, 2004) because it involves recognizing assumptions, using critical and logical thinking and also considering alternative explanations (National Research Council, 2000). Several other studies have also revealed an empirical evidence in claiming inquiry method as a medium that develops personal meaning which may boost higher science achievement (Secker & Lissitz, 1999; Duran et al., 2004; UNESCO, 2009). This method is also noted for the benefit that it builds a close relationship between the processes and conceptual ideas of science (Tytler, 2007). Moreover, inquiry based education is often supported for being effective in addressing higher basic education attainment, increased motivation of both teacher and student for science and for the positive contribution through the success in science (UNESCO, 2009). Hence, in science education the teachers are encouraged to engage inquiry on a daily basis in their teaching (Jackson & Wenning, 2010).

In inquiry-based science education, the students are engaged to develop knowledge, understand ideas and thinking processes used by the scientists in producing new knowledge (Abdi, 2014) and understanding the natural world (National Research Council, 1996). It is a pedagogical setting that depends less on textbooks as a main resource for information, but more on hands-on approach making students as the central to the learning episodes (Duran et al., 2004). So, like the scientists do, the students investigate the things or events and propose based on the findings of their investigations. In this teaching approach, the teacher provides the materials and problems for the students to solve while the teacher assists as a facilitator. In a guided inquiry classroom the students and the teachers work together collaboratively to meet the desired goals (National Research Council, 1996). The students take a lead role in investigating the problem by formulating hypothesis and frame some solutions. The data collection, interpretation and findings are also done by the learners. The students are able to generalize their finding at the end of an activity (National Research Council, 1996; Nivalainen et al., 2013).

As much as guided inquiry offers active and meaningful learning, laboratory has been yet another approach with similar benefits. It is a setting in which students learn lessons persistently by using a variety of materials with motivation (Koc, Okumus, & Özturk, 2013). It was widely used in science where there are more demonstration activities (Blosser, 1980) because the students learn through examination and manipulation of the materials to develop the concepts and knowledge of that scientific phenomenon, thus enhancing their understanding of the scientific concepts (Tsai, 2003; Hofstein & Mamlok-Naaman, 2007). The students learn to make hypotheses and follow scientific investigations, formulate and revise scientific explanations and engage in defending scientific arguments (Hofstein & Lunetta, 2004) besides obtaining skills of manipulation, observation, critical thinking, scientific interpretations and cooperation. In physics, Alimen (2009) describes such laboratory activities as a kind of a social learning process where they cooperate each other to achieve their goal. The students become active doers (Flick, 1993; Haury & Rillero, 1994) which can consequently enhance their own learning and retrieval for a longer period of time (Ruby, 2001).

In this developed guided inquiry laboratory, all those typical characteristics of both guided inquiry approach and laboratory learning are blended to provide students a better way of understanding the law of mechanical energy conservation. In this setting, the intervention of the inquiry process is planned, targeted and supervised based on the constructive approach of learning (Kuhlthau & Maniotes, 2010).

Hands-on Learning

The hands-on activity is one of the most meaningful learning strategies because it encourages the learners to directly perform the specific task in order to learn about it. It allows the students to "learn by doing" (Trivedi & Sharma, 2013) as they have freedom in making judgments after observation, interpretations and manipulations (Ruby, 2001). This mode of learning "Science by Doing" actively engage and encourage the students to investigate science which ultimately works on the principle that "doing" results in understanding and excitement (Tytler, 2007). In such learning environments, the students handle specific scientific instruments and manipulate the objects that they are studying (Rutherford, 1993). This helps them to create a relationship between the pieces of knowledge and enable the information to be compared both by its abstract meaning and physical illustration (Ruby, 2001). Another notable educational component of hands-on methodology is that the experiences of the students are placed first while other methods depend heavily on teacher experience (Stohr-Hunt, 1996). Hands-on science has been proposed as one means to increase students' achievement in science education (Ruby, 2001). Kolb (1984) in his Experiential Learning Theory (ELT) beliefs that in order to promote meaningful learning in children, they have to physically interact with the materials. Accordingly, the children can engage and have a direct experience which can improve reflective skills and retentions (Haury & Rillero, 1994). The hands-on learning encourages a learning through action, experience, discovery and exploration, thereby making the learners understand the real-life illustrations of the knowledge (Haury & Rillero, 1994).

Level of Understanding

Assessing the understanding of students is one of the most complex tasks for many educators or academic institutions, but it is necessary in order to figure out what learners know and have understood. It is useful in investigating the impact of any intervention or treatment used in teaching the concepts. It is only when the instructors understand such differences that it can meet the diverse learning needs of all the students (Felder & Brent, 2005). When the students do not understand the concepts that they are taught, they maintain their own way of learning and risks to the formation of misconceptions that are later challenging to correct. Hence, the process of assessing student learning as a part of our teaching is very important because it provides teachers a valid information on what our students are learning (Drake & Barlow, 2007).

Thus, in an attempt to investigate and classify the students' level of understanding, this study used a categorization method which was modified from Abraham, Williamson, and Westbrook (1994). Of the five levels of understanding (Abraham et al., 1994) namely Sound Understanding (SU), Partial Understanding (PU), Partial Understanding with Specific Alternate Conception (PUSAC), Specific Alternate Conception (SAC) and No Understanding (NU), the Partial Understanding (PU) was excluded since the two-tiers items used in this study was not suitable to evaluate a response that included at least one of the components of a validated response (Abraham et al., 1994). The more details on its classification is explained in the data analysis.

Methodology

A single group pretest-posttest design was employed in this study (Figure 1). This design allows the purpose of comparing and measuring the change in the group(s) due to the experimental treatment (Dimitrov & Rumrill, 2003). Using a purposive sampling, a total of 30 grade ten students from one of the middle secondary schools in western Bhutan were involved in this study.

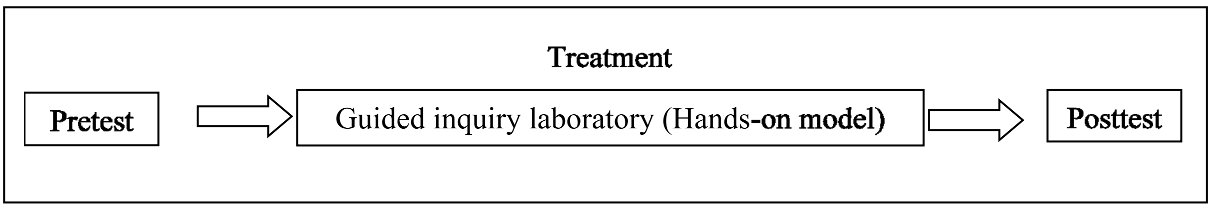


Figure 1. Single group pretest-posttest design

Developed learning laboratory

A learning laboratory based on a guided inquiry approach that falls under the framework of constructivism theory was used as a treatment. Under this approach, a simple hands-on model that formed an integral part in demonstrating the law of mechanical energy conservation was introduced. The guided inquiry laboratory that was designed for 120 minutes comprised of four main phases: (i) posing scientific questions; (ii) formulating hypothesis; (iii) gathering data through experiment and, (iv) presenting findings and conclusion. Before the intervention, the pretest that comprised of 13 two-tier multiple items were administered for 20 minutes. The participants were then allowed to explore and demonstrate the law of mechanical energy conservation under the framework of a guided inquiry method for 80 minutes. Students were divided into a group of 5 members each. The role of a teacher was to facilitate and direct the students towards achieving the objective of their experiment. Strictly based on the four phases, the teacher first posed a couple of scientific questions and encouraged the students in formulating the hypothesis. The set of question was related to what they were supposed to find out and explain after doing the experiment using the hands-on model. The students were then directed to investigate their hypothesis in groups by using the hands-on model following the guided laboratory instructions provided in each group. Through the experiment, each group gathered and analyzed the data they obtained using the hands-on model and compared with the set of hypothesis they made during the first phase. Each group then compiled their findings and presented to the entire class for discussion and confirmation. The students were made to attend the posttest that comprised of parallel two-tiers multiple-choice items used during the pretest for 20 minutes.

Furthermore, Figure 2 shows the framework of this study, and following are the scientific questions posed to the students in students' worksheets. The questions are used to facilitate the students for setting of hypothesis and gathering data to test their hypothesis.

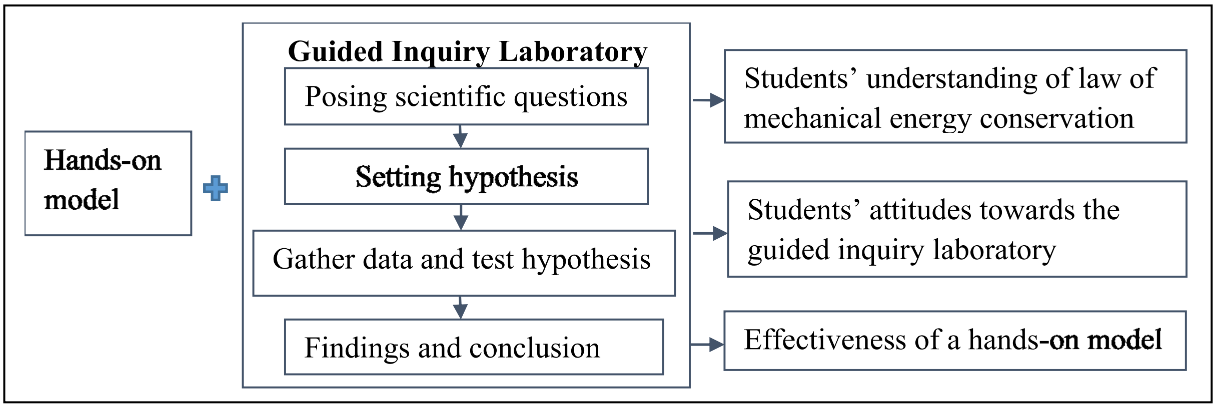
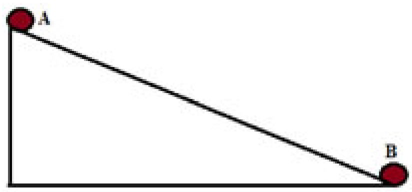


Figure 2. Framework of the study

Activity I: Setting Hypothesis

(To save time, the teacher will guide the students to set the hypothesis)

Based on the diagram below,



1. What form of energy is there when the ball is at point A?

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2. What kind of energy change takes place when it moves from point A to point B?

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3. How can you explain that the energy of this object is conserved?

4. Can you define the law of conservation of mechanical energy?

Data Collection:

1. Trolley mass, *m* =………....kg
2. Acceleration due to gravity, $g = 9.8\ ms^{-2}$
3. Length of the picket fence, d= 0.04 m

The table to calculate total mechanical energy

Potential Energy			Kinetic Energy			Total Mechanical Energy
Points	Mass ***(kg)***	E_p=mgh ***(J)***	t ***(s)***	v ***(m/s²)***	E_k=½mv² ***(J)***	$E_{total}= E_p + E_k$ ***(J)***
1						
2						
3						
4						
5						

(Graph paper will be attached here)

Now let us answer the following questions:

Questions	**Answers**
1. Can we create the energy?	
2. Can we destroy energy?	
3. Do you think that the total mechanical energy is conserved?	
4. Can you give some examples of conservation of mechanical energy	
5. How can you define the law of conservation of mechanical energy after your experiment?	
6. Is the energy conserved according to your experiment? How did you know that the energy is conserved?	

Developed hands-on model

A simple hands-on model designed in a form of an inclined plane was used to demonstrate the law of mechanical energy conservation. Inclined plane is one of the most commonly used examples in the textbooks of the Bhutanese science curriculum to explain the law of mechanical energy conservation. Hence, doing an experiment to demonstrate the law of mechanical energy conservation with a realistic hands-on model would be easier and fun learning for the students. A long acrylic ramp of 0.78 m was used to make an inclined plane for the object to move. Acrylic was preferred for its durable and frictionless nature when compared to other locally available materials. Five photogate sensors which were used to detect the time (Δt: $\Delta t \rightarrow 0$) for calculating the instantaneous velocity of a moving trolley (v_{int}) were embedded in the ramp. Photogates were used because the determination of physical quantities like velocity and acceleration are almost precisely done by it (Galeriu, 2013). Each end of the photogate sensors were connected to the timer that displayed the time (Δt) taken by the object to pass through the arms of each photogate sensors in milliseconds. The sensors were located at a distance of 0.05 *m* from each other and represented five different heights (h_{int}) represented as h_1, h_2, h_3, h_4 and h_5 as shown in the Figure 3. An object here was a frictionless wheeled trolley with a fixed mass (m). The mass of an object (in this case the trolley) was fixed so that the students can concentrate more on demonstrating the law of mechanical energy conservation rather than calculating mass of an object. Underneath the trolley, a picket fence of 0.04 *m* (Δd) was attached for the purpose of time detection (Δt) when the trolley passing through each sensor point to calculate the instantaneous velocity ($v_{int}= \Delta d/\Delta t$). The mass and the acceleration due to gravity ***g*** were constant with 0.301 *kg* and 9.8 ms^{-2} respectively. As the students allow the trolley to move from the top of the ramp, the picket fence attached beneath the trolley passes through the arms of the photogate sensors. The sensors instantly record the time at which the trolley passes and this time in milliseconds is shown in a monitor. Using these variables, they were guided to calculate the potential and kinetic energy using the relations $E_p=mgh_{int}$ and $E_k=½mv^2$. The sum of these energies at each point represented the total mechanical energy for the corresponding heights ($E_{total}= E_p + E_k$).

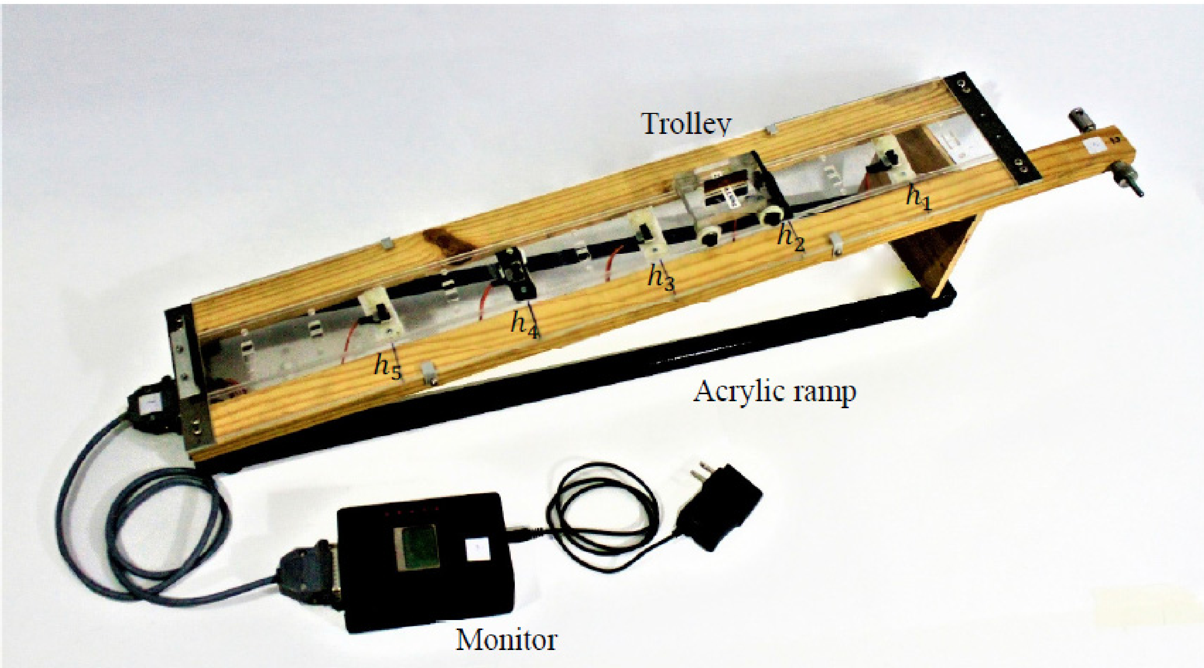

Figure 3. A hands-on model developed to demonstrate the law of mechanical energy conservation.

Instruments and data collection

The data were collected using the research instruments namely Conceptual Evaluation Test for Law of Mechanical Energy Conservation (CETMEC) and the Learners Attitude Questionnaire for Law of Mechanical Energy Conservation (LAQMEC). The CETMEC which consisted of 13 parallel two-tier multiple-choice items was used to investigate the students' conceptual understanding of the law of mechanical energy conservation. There were 13 parallel items in a form of the two-tier multiple-choice format used for both pretest and posttest. Except for three items (item 1, 7 and 12), the remaining 10 items were adapted from American Association for Advancement of Science (AAAS Project 2061). The items 1, 7 and 12 were self-created. The ten items adapted from AAAS Project 2061 were in the form of multiple-choice questions that were used to study the understanding of energy and energy conservation for grade 7-12 (Herrmann-Abell & DeBoer, 2011; Trumper et al., 2000). However, in this study, those items have been modified into two-tier multiple choice based on the format discussed by Treagust (1986). In doing so, the adapted items were either used to find the conceptual understanding in the first tier or to determine the reasoning and thinking skills in the second tier. But in both the tiers, it was a multiple choice that had only one correct answer. The first tier had three choices including "I don't know" since the subjects during the pretests were assumed to be unfamiliar with concepts because they were not exposed to treatment (Yu, 2001). In the second tier, it consisted of five possible reasons to support the choice the students made in the first tier but only one of these reasons was correct. The rest of the reasons were either the misconceptions gathered from the literature (AAAS, 2016) or through the personal classroom teaching experiences. The CETMEC items were used before the treatment of a developed guided inquiry laboratory as the pretest and as the posttest after the treatment by reshuffling the items. The Table 1 shows how each item was constructed to measure the different constructs in this study.

Table 1. The three constructs and the corresponding items of CETMEC.

Items	Constructs
1, 2, 3, 4, 9	Energy conservation
5, 6, 7, 8	Energy is created or destroyed
10, 11, 12, 13	Energy is transferred or transformed

The LAQMEC consisted of 20 closed-ended items based on the five-point Likert scale and included an open-ended item. All the items were constructed considering the characteristics of a guided inquiry approach which falls under the constructivist view of learning. This instrument was used after the treatment to investigate the views and attitudes of the students towards the learning laboratory and also to find the effectiveness of the developed hands-on model. For the Likert scale rating, the lower the number students score, greater was the degree of non-agreement with the statement. So, the score 1 meant "Strongly Disagree", 2 as "Disagree", 3 to be "Neutral", 4 denoted "Agree", and 5 meant "Strongly Agree". The scores for the negative statements were interpreted using a reverse coding. There were six constructs (see Table 2) out of which the five constructs namely Topic of the Lesson, Teacher, Classroom Activities, Learning Method and General Classroom Impression exclusively determined the views and opinions of the students towards the guided inquiry laboratory while the theme labeled Hands-on model assessed the students' attitudes towards the model used to determine the law of mechanical energy conservation. The open-ended item was created to encourage the students to write any matters that they found it missing related to the law of mechanical energy conservation based on the three domains like contents (cognitive), attitude (affective) and skills (psychomotor) and etc.

Table 2. The six constructs and the corresponding items of LAQMEC.

Items	Constructs
1, 2, 3	Topic of the lesson
4, 5, 6	Teacher
7, 8, 9	Classroom activities
10, 11, 12, 13	Learning method
14, 15, 16, 17	Hands-on model
18, 19, 20	General classroom impression

A sample of two-tier item used in the CETMEC is shown below:

Directions: Read the statements carefully. There are TWO parts in each item. In the first part, you can Tick [√] whether the statements are TRUE, FALSE or DON'T KNOW based on your opinion. In the second part, you can Tick [√] for the reason that best supports your opinion in the first part.

1. Imagine that an object moves from point A to B which are at a same height in a horizontal direction. Suppose that there is no transfer of energy from ball to the track or from ball to the air, the total mechanical energy of a ball at point B will remain same as the point A.

a) True b) False c) I don't know the answer

The reason for my answer is

a. Whether more or less, it will depend on the speed of object.
b. The energy is more because it went down the steep side of the track.
c. The energy will be less because it is used as it travels.
d. The total energy remains unchanged in a system.
e. I don't know the reason.

12. A teacher releases a book from a height of 1m and asks the students to compare the potential energy at points 1m, 0.5 m and on the ground. One student answered that the potential energy will be highest at 1m, less in 0.5m and zero when it is on the ground.

a) True b) False c) I don't know the answer

The reason for my answer is

a. The potential energy depends on height of the object. The height is zero when the book is on the ground, hence potential energy is zero.
b. The potential energy does not depend on height. So, it is equal in all the points.
c. The potential energy is maximum when the book is on the ground since it travels with a huge velocity.
d. The potential energy is lost as the book slowly falls on the ground.
e. I don't know the reason.

Validity and reliability

The instruments were thoroughly validated by five experts from Bhutan and Thailand who had experiences of teaching Physics for a minimum of 3 years in higher and university levels respectively. The Item-Objective Congruence index (IOC) were determined and the majority of the items from the CETMEC and LAQMEC were determined to have IOC Index more than 0.8 which signified a strong correlation (Rovinelli & Hambleton, 1976). Hence, those items were accepted while few items having IOC index lower than 0.8 were revised according to the expert's comments. After validation was over, it was piloted with 30 higher secondary science students who have already learnt about the law of mechanical energy conservation. The reliability coefficient (Cronbach's alpha) of the pilot study was 0.77 indicating that the items were favorable for the implementation (Tavakol & Dennick, 2011; Bland & Altman, 1997).

Data Analysis

The means of both pretest and posttest were compared using a paired sample *t*-test. To further support the findings, the level of students understanding (Abraham, 1994) were determined. The CETMEC items were analyzed using the assessment criteria modified from Chou, Chan, & Wu (2007) as shown in Table 3.

Table 3. The assessment criteria for two-tier items.

Points for the response	Assessment criteria
0 points	Wrong / No / I don't know in both the tier
0 points	Only the reason in the second tier is correct
1 point	Only the choice in the first tier is correct
2 points	Both the choice and the reason are correct

Since this study included "I don't know" as an option in both the tiers, students who opted this option in both the tiers were given 0 points. On the other hand, 1 point was awarded only when the choice in the first tier was correct with wrong/no or I don't know in the second tier. If the reason in the second tier was correct with incorrect/no or I don't know as the choice in the first tier, then it was marked 0 points. This was because in reality it had very limited chance to happen owing to the nature of second tier items that were based on reasoning and demanded higher thinking and analytical ability. Even if the reason was correct, it was assumed as students guessing the reasons without first knowing the simple choice in the first tier.

The students' responses were then further classified into levels of understanding which was modified from Abraham, Williamson, and Westbrook (1994) as shown in Table 4.

Table 4. Interpretation of levels of understanding.

Level of understanding	Interpretation	Tier 1	Tier 2
Sound Understanding (SU)	Responses that included all	Correct	Correct

	components of the validated response		
Partial Understanding with specific alternate conception (PUSAC)	Responses that showed an understanding of the concept, but also made a statement, which demonstrated misunderstanding	Correct	No/ Incorrect/ I don't know
Specific alternate conception (SAC)	Responses that included illogical or incorrect information	No/ Incorrect/ I don't know	Correct
No understanding (NU)	Repeated the question, contained irrelevant information or an unclear response; left the response blank	No/ Incorrect/ I don't know	Incorrect/ I don't know

The four levels of understanding namely Sound Understanding (SU), Partial Understanding with Specific Alternate Conception (PUSAC), Specific Alternate Conception (SAC) and No Understanding (NU) were used in this study. Thus, the students' answers that included all components of the validated response with correct choice in the first tier and correct reason in the second tier classified as Sound Understanding (SU). The responses with a correct choice in the first tier but with an incorrect or no/I don't know reason in the second tier were grouped as Partial Understanding with Specific Alternate Conception (PUSAC) because these responses showed understanding of the concept but also showed some misunderstandings due to incorrect reasons in the second tier. Similarly, the responses that had incorrect/no choice or I don't know in the first tier but with a correct reason in the second tier were considered as Specific Alternate Conception (SAC) because such responses indicated an illogical and incorrect information. Logically, it was deemed impossible for the students to get correct reasons in the second tier that demanded higher analytical ability without having clearly understood the first tier that contained only knowledge statements. Such kind of learning is not meaningful but rather it is due to a rote learning or superficial learning (Bayrak, 2013). Thus, even if the responses were correct, it was attributed to be simply a guess. Likewise, if the responses contained wrong or I don't know in both the tiers, incorrect choice with I don't know in the second tier or I don't know in the first tier with incorrect reason in the second tier, it was classified as having No Understanding (NU).

Similarly, for the LAQMEC, the means and the standard deviations of each construct were determined to examine students' attitudes toward the guided inquiry laboratory. The mean of the items with negative statements was reversely coded.

Results

a) Analysis of CETMEC

Based on the Shapiro-Wilk's test, the data were normally distributed with p value of 0.297 which was greater than $p>0.05$ and skewness of -.259 (SE = .427) and kurtosis of -.244 (SE = 0.833). Thus, a parametric hypothesis test was done.

Table 5. Paired sample statistics.

		Mean	N	SD	SEM
Pair 1	Pretest	13.43	30	3.766	.688
	Posttest	21.67	30	2.893	.528

Table 6. Paired sample t-test.

		Mean	N	SD	t	df	Sig. (2 tailed)
Pair 1	Pretest -Posttest	-8.233	30	4.199	-10.739	29	.000

As shown in Table 5 and Table 6, the paired sample t-test showed that there was a statistically significant difference between the mean of the pretest (M=13.43, SD= 3.766) and posttest (M=21.67, SD= 2.893) at $t(29) = -10.739$, $p=.000$, $\alpha=.05$. The mean difference was 8.233 and the p-value was less than the alpha level ($\alpha=.05$), indicating that there was an improvement in the posttest due to the treatment.
Moreover, as was modified from Abraham (1994), Table 7 shows the level of understanding of the students for each individual items.

Table 7. Level of Understanding.

Items	The Level of Understanding (%)			
	SU	PUSAC	SAC	NU
I1	86.7	13.3	0.0	0.0

I2	70.0	13.3	16.7	0.0
I3	73.3	10.0	13.3	3.3
I4	80.0	6.7	10.0	3.3
I5	73.3	10.0	13.3	3.3
I6	70.0	13.3	10.0	6.7
I7	66.7	16.7	10.0	6.7
I8	76.7	16.7	3.3	3.3
I9	70.0	20.0	10.0	0.0
I10	66.7	20.0	6.7	6.7
I11	66.7	16.7	13.3	3.3
I12	76.7	13.3	6.7	3.3
I13	90.0	3.3	3.3	3.3

It was found that the items 1, 4 and 13 have more than 80 percent *Sound Understanding* while the lowest is for items 7, 10 and 11 at 66.7 percent. However, for all the items, the percent of *Sound Understanding* was more than 60 percent (74.37 percent in average).

b) Analysis of LAQMEC

The mean and the standard deviation of each item corresponding to its constructs were determined to find the students' attitudes and opinions regarding the developed learning laboratory. The average mean score for each construct was also defined separately as shown in Table 8. For those 4 negative statements (item 3, 6, 9 and 13), the reverse coding was followed. The average mean of the constructs ranges from 4.68 to as high as 4.98 which indicated that the students had positive attitudes towards the guided learning laboratory.

Table 8. Mean Score for each item and constructs.

Items	Constructs	Mean	SD	Avg. mean
I1	Topic of the lesson	4.77	0.43	4.59
I2		4.50	0.82	
I3		4.50*	0.35	
I4	Teacher	4.77	0.63	4.68
I5		4.73	0.58	

I6		4.53*	0.90	
I7	Classroom activities	4.83	0.53	4.77
I8		4.67	0.80	
I9		4.80*	0.48	
I10	Learning method	4.90	0.40	4.83
I11		4.73	0.58	
I12		4.97	0.18	
I13		4.70*	0.60	
I14	Hands-on model	4.97	0.18	4.98
I15		5.00	0.00	
I16		5.00	0.00	
I17		4.97	0.18	
I18	General classroom impression	4.77	0.50	4.81
I19		4.87	0.43	
I20		4.80	0.48	

** The mean of the negative statements obtained after the reverse coding.*

Discussion

The statistical analysis revealed that the developed learning laboratory based on guided inquiry approach along with a hands-on model has enhanced the conceptual understanding of the law of mechanical energy conservation. On doing a pair sample t-test, the means of the pretest (M=13.43, SD=3.766) and posttest (M=21.67, SD=2.893) were significantly different by 10.73 with the p-value less than the alpha level (α=.05). This indicated that the treatment due to a guided inquiry laboratory has enhanced the conceptual understanding of the participants. The teaching of science using the inquiry-based method is widely regarded as an effective method (National Research Council, 2000; Duran et al., 2004). In an inquiry-based approach teachers and students collaborate in the pursuit of ideas but it is the student who works to investigate the hypothesis, collect data, generate knowledge and justify their findings for the generalizability while the teacher guides and encourage them in all stages (National Research Council, 1996). The students carry out the task and solve them giving a great deal of experience in learning and problem-solving. Even in the case of this study, students were contented with the developed laboratory that gave them the firsthand experience in problem-solving. This is clearly understood from the analysis of the LAQMEC that more than 60 percent of the students possessed sound understanding in all the items. This further supported that the conceptual understanding of the participants was enhanced using a guided inquiry laboratory approach.

Similarly, the individual mean and standard deviation of each item in LAQMEC revealed that the students have positive attitudes towards the developed guided inquiry-based laboratory. The average mean score for all the six constructs ranged from 4.59 to as high as 4.98 indicating the positive attitude towards the developed learning laboratory. The highest average mean score was towards the construct of the hands-on model. The lowest mean of the items in the construct of the hands-on model was 4.97 while the highest was 5.0 showing a strong positive attitude towards the developed hands-on model, which formed the main component of the guided inquiry laboratory. This can be attributed to the fact that hands-on model provides learners to directly involve and learn by doing. By doing the hands-on activity, the learners become active doers (Flick, 1993; Haury & Rillero, 1994) which can consequently enhance their own learning and retrieval for a longer period of time. The findings of this study were in consistent with Ateş and Eryilmaz (2011) where it observed that the understanding of the students was enhanced and have developed positive attitudes toward learning science due to hands-on activities. Science by doing aims to work on the principle that doing leads to understanding and excitement (Tytler, 2007) as hands-on science particularly uses physical materials to give students firsthand experience in scientific methodologies (Triona & Klahr, 2007). The guided inquiry approach, on the other hand, encouraged the students to carry out the investigations that were challenging because when complex matters were encountered, the teachers always facilitated and guided them in acquiring and interpreting information (National Research Council, 1996). This approach allows the students to manifest the characteristics of scientists in focusing challenge for gathering new idea, experience the process of knowing and the justify the knowledge (Abdi, 2014).

Discussion

The law of mechanical energy conservation is an important aspect of any introductory physics and to make it comprehensible and simpler is even more significant. Several approaches to demonstrate this law can be instated as guided inquiry laboratory with a hands-on model being used in the case of this study. The hands-on model developed as a major part of the guided inquiry laboratory for this study was statistically evident to have enhanced the conceptual understanding of the students. The model designed in a form of an inclined plane was developed from those low-cost materials available in the locality. Besides being considerably precise and because of its easy approach in the operation process, the hands-on model has impacted the students level of understanding the law of mechanical conservation and have resulted in gathering positive attitudes towards the developed learning laboratory as revealed in LAQMEC. The study has revealed that the developed hands-on model was effective and suitable using a guided inquiry approach in enhancing the conceptual understanding of the students. Thus, the result of this study can only support the fact that in science education, teachers are encouraged to engage inquiry almost on a daily basis in their teaching (Jackson & Wenning, 2010).

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