AC 2008-1562: USING LEGO BASED ENGINEERING ACTIVITIES TO IMPROVE UNDERSTANDING CONCEPTS OF SPEED, VELOCITY, AND ACCELERATION

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Using LEGO-based Engineering Activities to Improve Understanding Concepts of Speed, Velocity and Acceleration

Abstract

Analysis of the educational research both theoretical and experimental indicates that traditional teaching methods are not very effective in helping students to understand science concepts and transfer the principles learned in the classroom to other situations. Innovative interventions are needed to supplement science curriculum and to improve students' comprehension through active engagement in the learning process. We developed several LEGO-based activities to be implemented in the secondary schools and first year college science curriculum. LEGO and ROBOLAB are an effective set of tools for learning physics with this hands-on approach. We conducted a pilot study to test the effectiveness of usage of LEGO models to teach the concepts of motion. This work will present the results of quantitative and qualitative analysis of the impact of this instructional module on students understanding of concepts of speed, velocity, acceleration and projectile motion. The outcome will also be correlated with results of analysis of students' engagement and motivation.

Introduction

The content for introductory physics courses includes Motion, Forces, Energy, Waves, and Electromagnetism. Students can explore and build understanding of these concepts through designing and conducting experiments based on the physics principles through inquiry, collaboration and hands-on learning. We developed several LEGO-based activities to be implemented in the secondary schools and first year college science curriculum. LEGO and ROBOLAB are an effective set of tools for learning physics with this hands-on approach. LEGO bricks, wheels, and other parts make it possible for students to make their own simple experimental apparatus, and LEGO robotics microprocessor (RCX) and associated sensors, together with the ROBOLAB software, create an environment for data collection and analysis. We have found that the LEGO workbench provides enough flexibility that the students can be creative in their engineering solutions, yet advanced enough that they can get quantitative data from their experiments.

We conducted a pilot study to test the effectiveness of using LEGO models to teach the concepts of motion, velocity, and acceleration on the example of projectile motion. We developed survey instruments to assess the effect of this instructional approach. This module is part of the educational design experiment that we are testing and revising based upon the research results of the initial study. In previous work, we analyzed the effect of this educational module on students' engagement in the learning process.[25] This work will present the results of quantitative analysis of the impact of this instructional module on students understanding of concepts of speed, velocity, acceleration and projectile motion. The outcome will also be correlated with results of analysis of students' engagement and motivation discussed in the earlier work.

Literature Review

Analysis of published research indicates that many traditional teaching methods do not address students' preconceived notions about speed, velocity and acceleration and innovative interventions are needed to supplement science curriculum.[3, 29-30, 31-32] These works indicate that simple real-world experience with moving objects does not lead to the abstraction of principles that are consistent with the formal laws of motion, and even after the completion of high school and college physics courses, naïve principles are still prevalent. A construction of knowledge through meaningful activities, reflected in socio-constructivist ideas, rather then acquisition through transmission in formal instruction, became important for deeper conceptual knowledge development, and scientific inquiry became an integral part of the learning sciences.

Our instructional module should be effective in improving students learning based upon educational theories such as multiple intelligences and constructivism. The unit provides a learning environment based on several principles of Gardner's multiple intelligences theory. A variety of learning activities are included, such as discussions that promote student–student interactions, group projects that allow for creative elements and laboratory investigations that engage learners in the physical doing of science.[8] Our module fits into basic constructivist educational theory that learning is an active process of recreating knowledge where hands-on learning activities must be the basis of all formal educational situations. It is important for students to make their own inferences, discoveries and conclusions in dealing with new concepts. The instructional module uses a hands-on activity as one of the learning approaches based on the constructionism principle that learning happens especially well when people are engaged in constructing a product.[22]

Methods

To determine how this instructional module influenced interest, task engagement and understanding the concept of projectile motion, we designed, developed and implemented a one-time one and a quarter hour program available to first year college students. We developed survey instruments to assess the effect of the instructional unit on the student's interest, engagement about the activity and their understanding of the concept of motion, speed, velocity, acceleration and projectile motion. We collected data and quantitatively analyzed it.

Participants

This case study was conducted with a group of 19 undergraduate students. The students were majoring in the disciplines of management, marketing, advertisement, journalism, English, and interior design. Students provided written consent in response to explanatory letters that were given prior to the study.

Module Description

The module was made up of several standard educational activities, including a brief introduction, demonstration, group discussion and experimentation. The goal of the instructional unit was to teach students the concept of motion, velocity and acceleration using the example of projectile motion through exploration, demonstration and the design process. Students were introduced to the concept of projectile motion through a brief explanation of concepts of motion, velocity and acceleration. Participants were given a problem to determine the landing position of the projectile launched directly upward from the car moving at a constant velocity. Participants had to come up with their predictions and discuss them in the class. Demonstration of the LEGO model was used to illustrate the solution. Students were given time to reflect on what they have seen from the model and asked to explain the results of this experiment. After the demonstration, students were divided into groups that were randomly assigned. Each group used LEGO Mindstorms kits to design and build a simple model to experiment with motion. The programming of the model was done using ROBOLAB language with the help of the instructor. The hands-on part of the activity consisted of the problem identification, discussion of different solutions to the design problem, building and testing their models and discussion of their results that helped them to verify or contradict their ideas about the concept.

Data Collection

At the start of the module, students were asked to fill out a pre-questionnaire to determine their initial knowledge about motion and interest about motion and hands-on learning. At the conclusion of the program, students were asked to fill out a post-questionnaire evaluating their learning of content and the effectiveness of the program. The pre and post-questionnaires were coded by researchers that were blind to the experiment. Of the 19 participants, two did not completely fill out the pre-questionnaire and post-questionnaire.

Results

The results to the content part of pre-questionnaire and the post-questionnaire are shown in the tables below. There were 17 completed pre-/post- questionnaires.

TABLE 1: Multiple–choice results collected from questionnaires given before the workshop. The results indicate the percent value for each answer.

1. A car is moving along a horizontal highway in a straight line at a constant rate of 25 m/s. Its acceleration is [A] 9.8 m/s^2 [B] 9.8 m/s. [C] zero. [D] 25 m/s.	47 [A] 0 [B] 41 [C] – correct answer 12 [D]
2. A ball is thrown straight upward. What is the acceleration of the ball at the highest point? [A] zero [B] 9.8 m/s^2 , upward [C] 9.8 m/s^2, downward [D] Insufficient data given for determination	53 [A] 12 [B] 35 [C] – correct answer 0 [D]
3. A projectile's vertical velocity component [A] changes most rapidly near the top of its trajectory. [B] changes at a constant rate. [C] changes most rapidly near the bottom of its trajectory. [D] does not change.	31 [A] 25 [B] – correct answer 38 [C] 6 [D]

4. Ideally, a projectile's horizontal velocity component [A] does not change. [B] changes most rapidly near the bottom of its trajectory. [C] changes at a constant rate. [D] changes most rapidly near the top of its trajectory.	35 [A] – correct answer 29 [B] 29 [C] 6 [D]
5. A car is moving along a straight line at a constant speed. It launches a projectile straight up. Where the projectile will land? Neglect air resistance. Explain. [A] in front of the car. [B] behind the car. [C] on the launcher. [D] Insufficient data given for determination.	0 [A] 65 [B] 29 [C] – correct answer 6 [D]

TABLE 2: Multiple–choice results collected from questionnaires given after the workshop. The results indicate the percent value for each answer.

1. A car is moving along a straight line at a constant speed of 25 m/s. It launches a projectile straight up. What is the value of the horizontal velocity component of the projectile at the highest point. Neglect air resistance. Explain. [A] zero. [B] 25 m/s [C] 9.8 m/s^2. [D] Insufficient data given for determination.	29 [A] 53 [B] – correct answer 12 [C] 6 [D]
2. A car is moving along a straight line at a constant speed of 25 m/s. It launches a projectile straight up. What is the value of the acceleration of the projectile at the highest point (point A)? Neglect air resistance. Explain. [A] zero [B] 9.8 m/s^2 , upward [C] 9.8 m/s^2, downward [D] Insufficient data given for determination	59 [A] 0 [B] 18 [C] – correct answer 24 [D]
3. A car is moving with acceleration along a straight line. It launches a projectile straight up. Where the projectile will land? Neglect air resistance. Explain. [A] in front of the car. [B] behind the car. [C] on the launcher. [D] Insufficient data given for determination.	0 [A] 6 [B] – correct answer 88 [C] 6 [D]
4. A car is decelerating in a straight line. It launches a projectile straight up. Where the projectile will land? Neglect air resistance. Explain. [A] in front of the car. [B] behind the car. [C] on the launcher. [D] Insufficient data given for determination.	18 [A] – correct answer 18 [B] 53 [C] 12 [D]

5. A car is moving in a circular path with a constant speed. It launches a projectile straight up. Where do you think the projectile will land? [A] in front of the car. [B] behind the car. [C] on the launcher. [D] inside the circle. [E] outside the circle.	 12 [A] 18 [B] 41 [C] 6 [D] 24 [E] – correct answer

Discussion

The goal of our work was to test the effectiveness of LEGO based hands on activity in physics classroom on students understanding of concept of motion. Previous research [25] on the effectiveness of this module has shown a positive effect on students' interest and engagement in the learning process. The focus of this paper is to see weather this short unit had an impact on student concept understanding as well as to correlate these results with the data analysis on engagement and motivation.

In the pre-test survey we asked students questions about acceleration and velocity. The results of their answers revealed commonly held misconceptions about these principles. When asked a typical textbook question to identify the value of acceleration when a car is moving along a horizontal highway in a straight line at a constant rate of 25 m/s, 41 percent of students were able to correctly identify the answer of zero, provided by multiple choice. In the Figure 1 we can see that 47 percent of participants stated that 9.8 m/s^2 is the correct answer and 12 percent said that 25m/s as their answer.

These results show that the correct answer is not a predominant choice among participants and stands second to using acceleration due to gravity as the preferred answer. Students are having difficulties differentiating between acceleration in linear motion and acceleration due to gravity. 12 percent who selected 25m/s as their answer show insufficient level of comprehension of the question and difficulty interpreting acceleration as the rate of change of velocity.

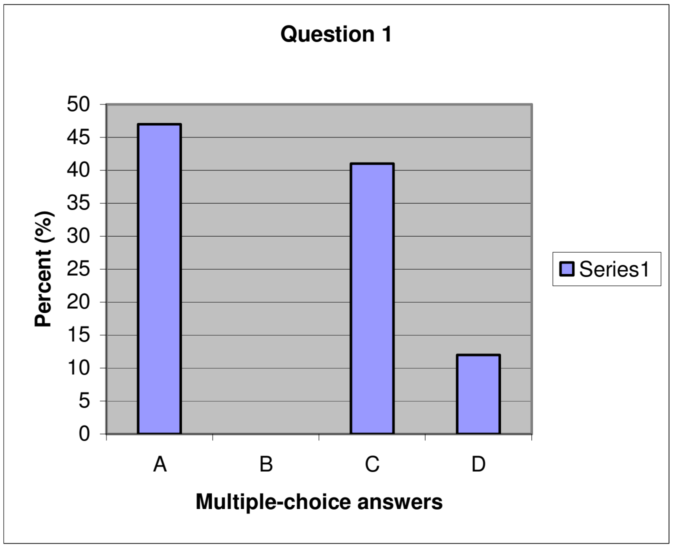

FIGURE 1: Results from the Content Pre-Questionnaire, Question 1. A car is moving along a horizontal highway in a straight line at a constant rate of 25 m/s.
Its acceleration is [A] 9.8 m/s^2 [B] 9.8 m/s [C] zero [D] 25 m/s.

The second question targets students understanding of acceleration due to gravity. The questions asks to find the acceleration of the ball at the highest point when the ball is thrown straight upward. 53 percent of participants select acceleration equal to zero at this point. These results exemplify students' misconception resulting from confusion between velocity and acceleration where students assume that if the projectile vertical velocity component is equal to zero at highest point then the acceleration is equal to zero as well. 35 percent of students selected correct answer stating that the acceleration would be 9.8 m/s^2, downward and 12 percent said correctly that acceleration would be 9.8 m/s^2 but did not specify correct direction.

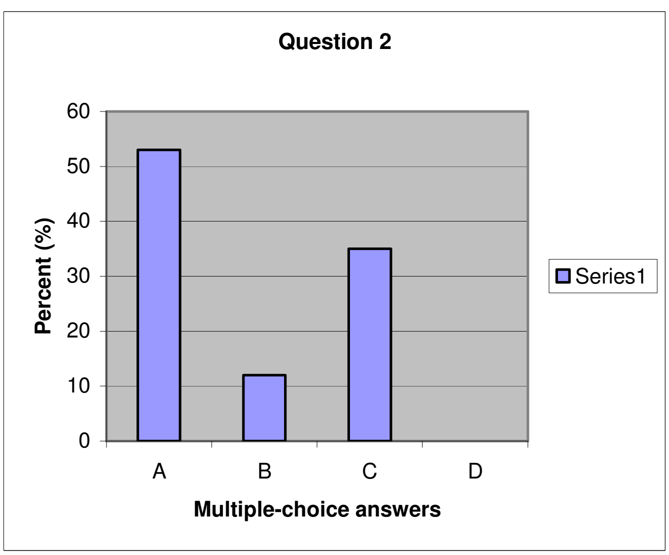

FIGURE 2: Results from the Content Pre-Questionnaire, Question 2. A ball is thrown straight upward. What is the acceleration of the ball at the highest point?
[A] zero [B] 9.8 m/s^2, upward [C] 9.8 m/s^2, downward [D] Insufficient data given for determination.

Results from these two questions agree with the research on students' misconceptions about motion showing that students have difficulties in understanding the concepts of velocity and acceleration. It is also apparent that even though many of these college students previously took high school physics courses they still demonstrated difficulties understanding these concepts. This observation is similar to the analysis of published research which indicates that many traditional teaching methods do not address students' preconceived notions about speed, velocity and acceleration, and innovative interventions are needed to supplement science curriculum. [3, 31-32] These works show that simple real-world experience with moving objects does not lead to the abstraction of principles that are consistent with the formal laws of motion, and even after the completion of high school and college physics courses, naïve principles are still prevalent. [29-30]

To gain insight into students' ideas on projectile motion we presented them with questions about vertical and horizontal velocity components. Using textbook problems we asked students to define vertical and horizontal components of velocity using multiple choice options. Figure 3 shows students' responses when asked about whether projectile's vertical velocity component [A] changes most rapidly near the top of its trajectory, [B] changes at a constant rate, [C] changes more rapidly near the bottom of its trajectory, and [D] does not change. 25 percent of participants identified the answer correctly stating that vertical velocity component changes at a constant rate. 38 percent of students said that it changes most rapidly near the bottom of its trajectory and 31 percent said that it changes most rapidly near the top of its trajectory. Both of these answers show insufficient discrimination between velocity and change in velocity and neglect of corresponding time interval.

When asked the same question about the projectile's horizontal component, 35 percent correctly identified that horizontal component of velocity does not change. 29 percent said that it changes most rapidly near the bottom of its trajectory and another 29 percent said that horizontal component changes at a constant rate. 6 percent of participants said that it changes most rapidly near the top of its trajectory.

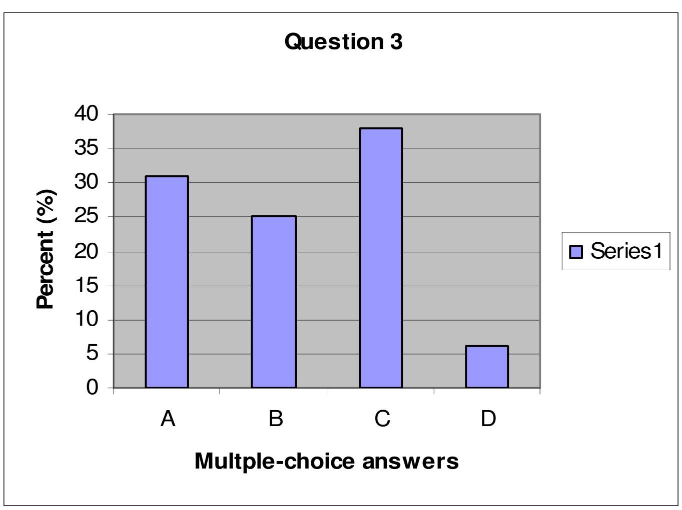

FIGURE 3: Results from the Content Pre-Questionnaire, Question 4. A projectile's vertical velocity component [A] changes most rapidly near the top of its trajectory [B] changes at a constant rate [C] changes most rapidly near the bottom of its trajectory [D] does not change.

We also asked students in the pre-questionnaire to think about the landing position of a projectile in a context of a car moving at a constant velocity that launches a projectile straight up, neglecting air resistance. Only 29 percent of participants were able to correctly select the answer that projectile will land back on the launcher if the car is moving at a constant velocity. Majority of the students, 65 percent, said that the projectile will land behind the car and 6 percent said that data given for determination is insufficient. In the study conducted by McCloskey [18] students were asked to draw the trajectory of a projectile launched horizontally, ignoring air resistance. The answers ranged from drawing showing that the projectile moves straight out and then straight down to the projectile first traveling in a straight horizontal line, then beginning to curve downward and finally falling straight down. McCloskey [18] compared students' ideas to the intuitive impetus theory that a carried object falls straight to the ground when it is dropped. This view is also maintained for situations when the carrier is moving at a high speed.

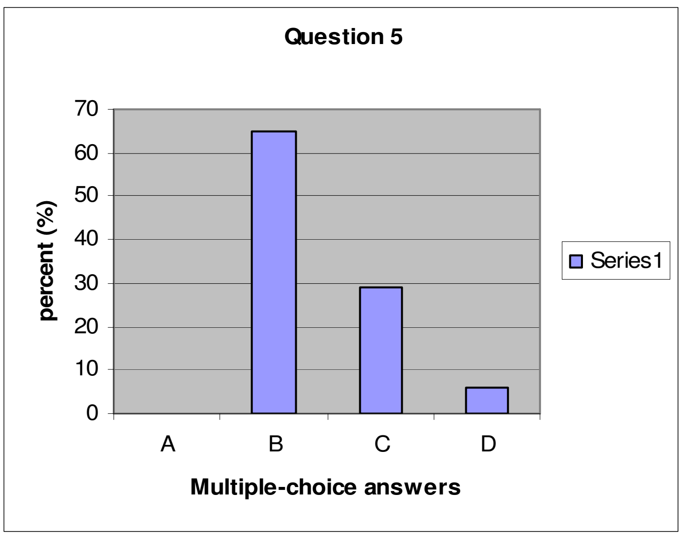

FIGURE 4: Results from the Content Pre-Questionnaire, Question 5. A car is moving along a straight line at a constant speed. It launches a projectile straight up. Where the projectile will land? Neglect air resistance. [A] in front of the car [B] behind the car [C] on the launcher [D] Insufficient data given for determination.

After the pre-test our instructional module consisted of a brief discussion of projectile motion, use of LEGO model to demonstrate the landing position of projectile when the car is moving at a constant speed and launches the projectile straight up, and a hands-on activity where students built and programmed their own LEGO models to experiment with principles of speed, velocity, and acceleration.

Our previous results on students' motivation about this module have shown a positive effect on their interest and engagement in the learning process. 94 percent of participants said that hands-on part was most engaging for them. Also when asked what part of the instructional module helped them the most to understand the concept of projectile motion, 71 percent indicated hands-on part as the most influential and 29 percent selected demonstration part (see Figure 5 and 6).

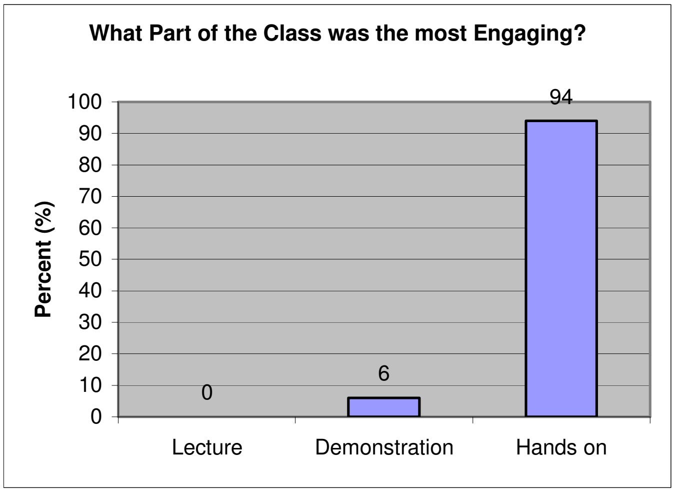

FIGURE 5: Results from the Engagement Post-Questionnaire, Question 2.

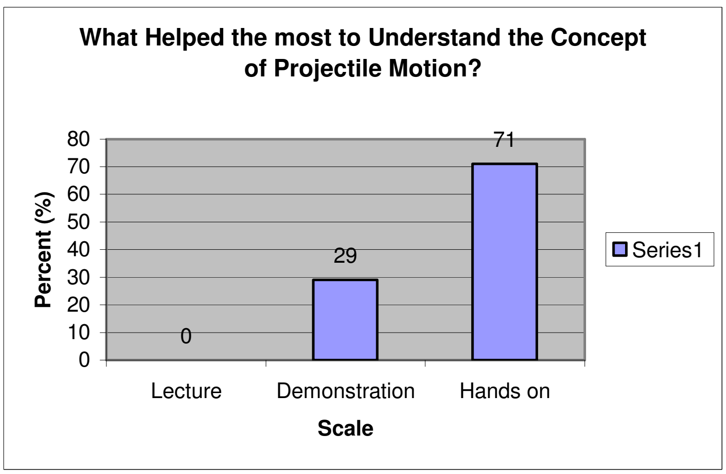

FIGURE 6: Results from the Engagement Post-Questionnaire, Question 1.

Looking at students' results on the post-test content questions, we found that participants' perception of concept understanding differed from their performance on the post-test.
When we asked students' to find the value of acceleration of the projectile at the highest point, using an example of a car moving at constant speed, only 18 percent identified the correct answer of 9.8 m/s^2, 24 percent said that data provided is not sufficient, and 53 percent said that the value of acceleration is zero. Comparing these results with content pre-test, we can see that number of students selecting the value of acceleration to be zero at the highest point of parabolic trajectory did not change. But the number of correct responses decreased from 35 percent in pre-test to 18 percent in post-test. There was also a change in distribution of results from 12 percent selecting the value of acceleration as 9.8 m/s^2 with the upward direction in the pre-test, to 24 percent in the post-test stating that data provided is insufficient to determine the answer. These results point out to the strongly held misconception about acceleration and to the fact that demonstration and hands-on part of our module did not address directly many of students' misconceptions. Inclusion of quantitative measures of acceleration could enhance our instructional module by providing students' with a contradiction to their beliefs.

We asked student about the landing position of a projectile launched straight up, when the car is moving along a straight line with acceleration. Later we modified this question to ask about the landing position of projectile when the car is decelerating. In the question with acceleration, 88 percent of students said that the projectile will land back on the car. Only 6 percent selected correct answer, saying that it will land behind the car. 53 percent of students said that it will also land back on the car when the car is decelerating and 18 percent correctly stated that the projectile will land in front of the car. We changed the question to when a car is moving in a circular path with a constant speed, where the projectile will land when it launched straight up? 24 percent said that the projectile will land outside the circle, 41 percent said that it will land back on the launcher, 18 percent said that it will land behind the car, 12 percent selected position to be in front of the car, and 6 percent said inside the circle.
In answering the question about the landing position of the projectile when the car is moving with acceleration or deceleration, looks like that majority of students related this question to the class demonstration of a LEGO car moving at a constant speed and launching a projectile straight up that landed back on the car. Students did not differentiate between the values of the car acceleration in these examples.

In an example with a car moving in a circle, the wide range of answers to a more difficult question could be attributed to the insufficient time for experimentations with the LEGO model. In a question about the value of horizontal velocity of a projectile, when it launched straight up from a car moving in a straight line at a constant speed of 25m/s, 53 percent of students said that horizontal velocity component of the projectile will be the same as the constant speed of the car (see Figure 7). These results indicated an increase in students' correct responses compared to the Content Pre-Questionnaire, where only 35 percent of answers stated that projectile's horizontal velocity component does not change.

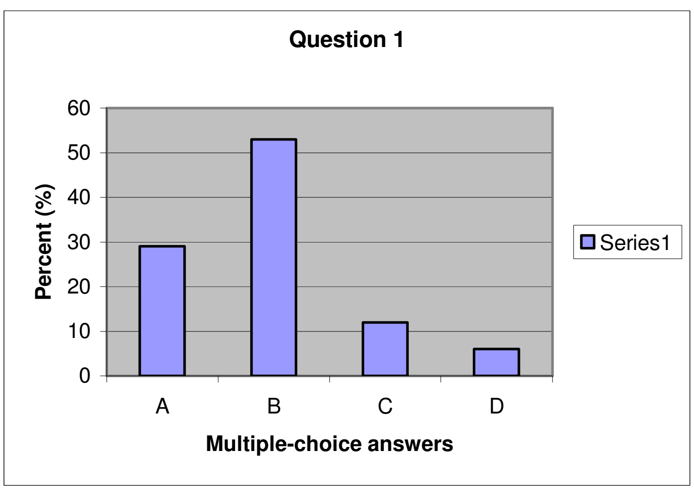

FIGURE 7: Results from the Content Post-Questionnaire, Question 1. A car is moving along a straight line at a constant speed of 25m/s. It launches a projectile straight up. What is the value of the horizontal velocity component of the projectile at the highest point. Neglect air resistance.
[A] zero [B] 25 m/s [C] 9.8 m/s^2 [D] Insufficient data given for determination.

It is worth noting that the LEGO demonstration and experiment had a strong impact on students' interpretations of projectile motion. Due to the short duration of the module, students were not able to experiment with LEGO models by varying parameters. This resulted in many incorrect responses to the post-test questions. It became apparent from our experiment that in order for students to develop better understanding of the concepts they need to experiment more with variation of parameters in order to see the tendencies rather then generalize from a specific result.

Conclusion

The positive effect of our instructional unit on students' engagement in the process is a first step in creating an environment where students can develop a deeper conceptual understanding of physics principles. Our results on conceptual understanding revealed common misconceptions held by students about speed, velocity, and acceleration. Our preliminary results and observations indicate that integrating of demonstrations and hands on activities as part of the curriculum are necessary components to engaging students in educational interaction with their instructor, peers, and technology. Due to the short duration of our instructional module it is difficult to draw conclusions about students' conceptual change, but it became clear that knowledge construction through meaningful activities is a more powerful approach to teaching physics rather then knowledge acquisition through transmission in formal instruction. Providing students with opportunities for being active learners we empower them to become important stakeholders in their learning experiences. The next step in our research is to investigate how hands on activities with LEGO materials can be enhanced to better address students' misconceptions on speed, velocity, and acceleration.

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