

# Investigating student understanding of simple harmonic motion

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**Abstract.** This study aimed to investigate students' understanding and develop instructional material on a topic of simple harmonic motion. Participants were 60 students taking a course on vibrations and wave and 46 students taking a course on Physics 2 and 28 students taking a course on Fundamental Physics 2 on the 2nd semester of an academic year 2016. A 16-question conceptual test and tutorial activities had been developed from previous research findings and evaluated by three physics experts in teaching mechanics before using in a real classroom. Data collection included both qualitative and quantitative methods. Item analysis and whole-test analysis were determined from student responses in the conceptual test. As results, most students had misconceptions about restoring force and they had problems connecting mathematical solutions to real motions, especially phase angle. Moreover, they had problems with interpreting mechanical energy from graphs and diagrams of the motion. These results were used to develop effective instructional materials to enhance student abilities in understanding simple harmonic motion in term of multiple representations.

## 1. Introduction

To develop an effective physics instruction, information about student dominated misconceptions and difficulties are essential. Students with misconceptions intended to not change their way of thinking after a traditional instruction [1]. Simple harmonic motion (SHM) is an oscillation subjected to a linear elastic restoring force, and is sinusoidal in time and demonstrates a single resonant frequency. Previous studies found that most students have difficulties in relating concepts with graphical representation, connecting the physics of harmonic motion with the mathematics of differential equations [1, 2] and understanding fundamental concepts of angular frequency and energy [2-4]. This study aimed to investigate student understanding on a topic of simple harmonic motion (SHM) and then to develop instructional materials based on student difficulties.

## 2. Methodology

### 2.1 Participants

Participants consisted of three groups of undergraduate students. Group 1 included 60 sophomores and

juniors taking a course on vibrations and wave. Group 2 included 46 freshmen taking a course on Physics 2. Group 3 included 28 freshmen taking a course on Fundamental Physics 2. The 2<sup>nd</sup> and 3<sup>rd</sup> groups were administered SHM-CS on the 2nd semester of an academic year 2016. All groups were taught using tutorial in simple harmonic motion.

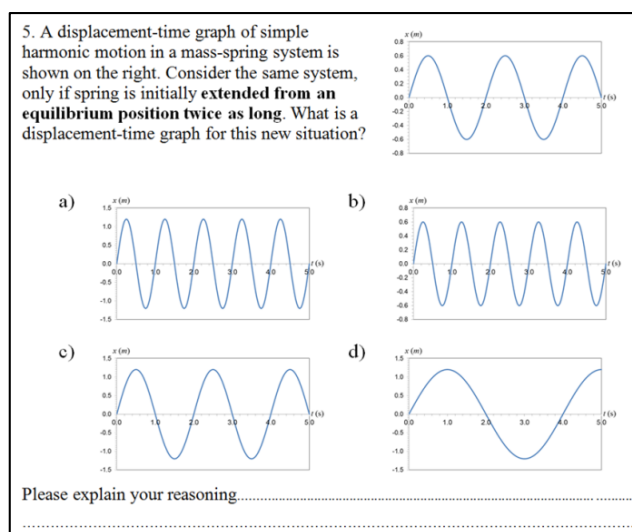
## 2.2 Data collection

Data about student conceptual understanding in simple harmonic motion were collected by administering a conceptual survey and in-class tutorial activities.

- The conceptual test was called Simple Harmonic Motion Conceptual Survey (SHM-CS) consists of 16 multiple-choice questions. The sample question was shown in figure 1. Only the 2<sup>nd</sup> and 3<sup>rd</sup> groups were administered SHM-CS. The first draft of SHM-CS consists of 18 multiple-choice questions, developed from pervious qualitative study [1]. Two questions were eliminated due to low discrimination index and the concept was about damped harmonic motion.
- The first drafts of tutorial activities were developed based on common misconceptions reported in previous literatures [1, 2]. There were 5 activities in the tutorial. However due to the time limitation, students were asked to not do activity 4. The 1<sup>st</sup> and 2<sup>nd</sup> groups were given 80 minutes and the 3<sup>rd</sup> group was given 150 minutes in working with the tutorial. During the tutorial, students were asked to write their initial answers. The instructor observed common answers and then discussed with the whole class. Student initial answers were analyzed based on grounded theory [4]. Several dominated misconceptions found from the SHM-CS and the tutorial were reported in the next section.

**Table 1.** Conceptual areas and corresponding item

Conceptual areas	Item
SHM definition	1, 6, 7
Restoring force	2, 11
SHM parameters (amplitude, frequency, phase)	3, 5, 9, 13, 15
SHM Energy	10, 14
Equilibrium position	7, 8, 11
Relationship among displacement, velocity and acceleration	4, 12, 16
Graphical representation of SHM	2, 4, 5, 6, 12, 14, 15, 16



**Figure 1.** Question 5 in SHM-CS

## 2.3 Experimental design

An experimental design for this study was a single-group experiment for both group 2 and group 3. A pre-test and post-test using the SHM-CS were given to both groups to measure the effect of an intervention, in this case, the first draft of tutorial activities based on the active-learning approach. In order to evaluate effectiveness of this intervention, we compared the pre- and post-test scores of each group by using four methods of analysis:

- 1) Percentage of correct responses—we plotted percentage of correct responses between the pre- and post-test of each group (as shown in figure 2 and 3).
- 2) A pair samples t-test of each group—we compared the mean of difference between the pre- and post-test scores of both groups.

3) Average normalized gain  $\langle g \rangle$  —is calculated from the average pre-test and average post-test scores for each group then take the normalized gain of these:  $\langle g \rangle = (\langle post \rangle - \langle pre \rangle) / (100 - \langle pre \rangle)$

4) Cohen's  $d$  effective size—we calculated  $d = (\langle post \rangle - \langle pre \rangle) / s$ , where  $s$  is a combined standard deviation of pre-test and post-test scores. An effective size is more common to report how important a difference is in social sciences research. Large effect sizes mean the difference is important ( $> 0.8$ ), medium effect sized meant the difference is somewhat important ( $\sim 0.5$ ); and small effect sizes mean the difference is unimportant ( $\sim 0.2$ ). It normalizes the average raw gain in a population by the standard deviation in individuals' raw scores, giving you a measure of how substantially the pre- and post-test scores differ.

### 3. Results and discussion

#### 3.1 Item and overall analysis

Only post-test responses from the 2<sup>nd</sup> group were used to determine item analysis and overall analysis. Item analysis composed of three measures—item difficulty index (P-index), item discrimination index (D-index) and point biserial coefficient (PBI). Overall analysis of the survey consisted of Kuder-Richardson reliability (KR-20) and Ferguson's delta ( $\delta$ ) [5].

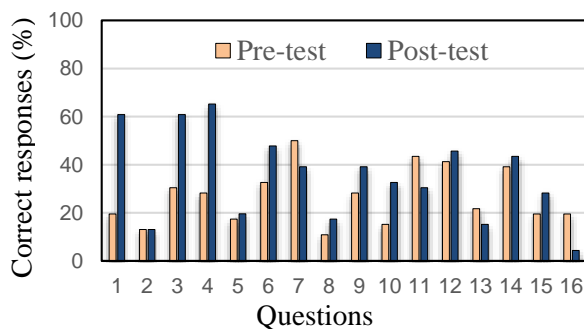
**Table 2.** Item analysis and reliability of SHM-CS

Analysis	SHM-CS values	Desired values [6]
P-index	0.36	$0.30 \leq P \leq 0.90$
D-index	0.33	$\geq 0.3$
PBI	0.30	$\geq 0.20$
KR-20	0.43	$\geq 0.70$
$\delta$	0.92	$\geq 0.90$

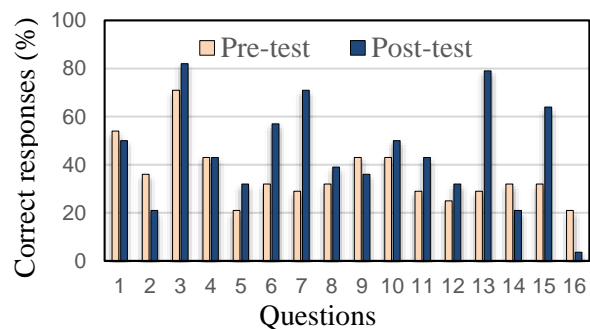
**Table 3.** Analysis of pre-test and post-test scores

Analysis	Sample groups	
	Group 2 ( $N = 46$ )	Group 3 ( $N = 28$ )
Pre-test	$\bar{x} = 5.19, s = 1.54$	$\bar{x} = 6.18, s = 2.11$
Post-test	$\bar{x} = 5.82, s = 2.31$	$\bar{x} = 7.93, s = 1.90$
t-test	$t(45) = -1.49,$ $p = 0.001$	$t(27) = -3.49,$ $p = 0.001$
$\langle g \rangle$	0.11	0.21
$d$	0.32	0.87

From Table 2, all item analysis including P-index, D-index and PBI of SHM-CS were higher than the desired values. The SHM-CS is considered to be a medium difficulty test and has satisfactory discrimination index and reliability for individual items. For the overall analysis, the SHM-CS has satisfactory discrimination ability but quite low reliability of the whole test as indicated by a KR-20 value.



**Figure 2.** Percentages of correct responses on pre- and post-test of group 2



**Figure 3.** Percentages of correct responses on pre- and post-test of group 3

### 3.2 Comparison between pre- and post-test scores

From all four analyses, both groups did better after the instruction. The average post-test scores of both groups slightly increased. From analysis results of pair samples t-test, average normalized gain and effective size, the pre- and post-test scores difference did important to a certain extent. Interestingly, the 3<sup>rd</sup> group did significantly better than the 2<sup>nd</sup> group. These results suggested that tutorial activities did help students improve their conceptual understanding in SHM.

### 3.3 Student misconceptions and difficulties

Results of student misconceptions were qualitatively analysis from their initial written answers in the tutorial sheets. Here are a few dominated misconceptions.

- *Periodic motion versus simple harmonic motion.* SHM is a special case of periodic motion where the restoring force is linearly dependent on displacement, which is a sinusoidal function of time. However, most students thought that SHM is a periodic motion. From question 1 in the first tutorial, students answered that the triangle function represents SHM and explained that this restoring force makes an object oscillating around an equilibrium position. Most students did understand this concept better after the instruction from increasing correct responses in question 6.
- *Difficulties with restoring force.* Many students did not realize that the restoring force in SHM has to be a linear function with the displacement. On question 2 in the tutorial, they answered incorrectly that the motion with a restoring force  $F = -kx^3$  could be considered SHM. From question 2, students had difficulties with plotting restoring force as a function of displacement.
- *Incorrect intuition relating frequency with amplitude.* Many students thought that amplitude depends on frequency or period. This misconception has been reported in previous studies [2-4]. They tended to think that some energy has to be used in order to have larger amplitude, so frequency has to be lower [2] or the period has to be larger. On question 5, most students chose incorrect answers (choice d) indicating this misconception.
- *Difficulties with defining an equilibrium position.* Both groups also performed poorly on question 7 and 8, which focused on a concept of an equilibrium position. When a mass-spring system is place on an inclined plane, many students did not realize that a new equilibrium position can be located to easily solve an equation of motion.
- *Difficulties with interpreting graphs.* Many students had difficulties in relating displacement-time, velocity-time and acceleration-time graph. On question 16, most students could not correctly identify a correct velocity-time graph from given information. Moreover, most students did not fully understand meaning of phase and could not plot a graph with correct phase.

## 4. Conclusions

In this study, the SHM-CS and the SHM tutorial were developed and implemented to identify student conceptual understanding. Undergraduate student misconceptions in SHM were identified. The dominated one is “incorrect intuition relating frequency with amplitude,” which was found in previous studies [1, 2]. Moreover, most students had difficulties in understanding restoring force, representing SHM in a graphical form and in defining an equilibrium position. The first draft of tutorial activities were addressed most of these misconceptions and difficulties. As a result, students did fairly better on the post SHM-CS. Students should have at least 2 hours in working with the tutorial in order to better develop well-rounded understanding in SHM concepts.

## 5. References

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