Students' Understanding of the Basic Concepts of Newtonian Mechanics vis-a-vis Lecture Method: The case of Dilla University

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Abstract: This paper addresses issues about the use of lecture method in teaching and learning of the course mechanics at Dilla University and students' performance on standardized mechanics test. Students were given Mechanics Baseline Test (MBT) before instruction of the course mechanics. The method of instruction used was the 'lecture method'. After the completion of the course, students were given the same test without announcement. The MBT scores of students were collected and analysed. The analysis of the result showed that the average pre-test and post-test scores were 19.93% (Std. Dev. 6.35%) and 28.32% (Std. Dev. 6.45%) respectively. The average post test was much less than the thresholds score of mechanics test (60%) for understanding the basic concepts of mechanics.The gain in students' understanding of the basic concepts of Newtonian mechanics after instruction with lecture method was found to be negligible. The average normalized gain on mechanics test for the sample student was 0.10 (Std.Dev.0.05). This is extremely small with the maximum possible value being unity. Students have real deficiencies in understanding the basic concepts of mechanics even after the instruction of the course with lecture method. The result indicated that the use of lecture method to provide students bunches of facts, pricnciples, laws , and derivation of mathematical expressions has little benefit to students conceptual understanding.

Introduction

Several investigators (Halloun and Hestenes, 1985, McDermott, 1991 and Hake, 1998) have carefully documented college physics students' understanding of a variety of topics, and have concluded that traditionally taught courses do little to improve students' understanding of the central concepts of physics, even if the students successfully learn problem-solving algorithms. In the teaching of physics, in Dilla Universitiy context, which is also likely true in other higher learning institutions of Ethiopia, the lecture method is typically used to present bunches of facts, pricnciples, laws,

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derivations, with examples of how to solve mathematical problems. However, the use of lecture time to present derivations and solutions to mathematical physics problems was observed to be ineffective in promoting students learning of physics. This was witnessed by the fact that most students failed to solve similar problems in exams and demonstrated poor performance on the course mechanics. The study conducted by Tesfaye (2006) indicated that the performance of first year students of physics department was very low resulting in high attrition rate. The research also indicated that the students placed in the department of physics education had poor background knowledge to pursue physics courses at university level.

In Ethiopian secondary schools, the emphasis of physics teachers on numerical calculations underscores the importance of requiring students to apply the fundamental concepts of physics in a variety of different situations, as well as requiring them to explain the logic that they use in solving physics problems of all kinds (Tesfaye 2007).

Hestenes, Wells and Swackhamer (1992) made an investigation of students' understanding of the Newtonian concepts of force by comparing students' performance on a set of conceptual questions posed both before and after a first course on mechanics. They found that the use of lecture (including the assignment of mathematical problems as is in a book) produces only marginal gains in conceptual understanding.

Assessment tasks that instructors use in the course send messages to the students about what they should focus on. In the lecture method that prevails in our context of physics instruction, students' grades are totally based on mid-term and final exams that focus on quantitative problems. This method of assessment leads students to focus on how to apply equations to problem solving rather than working to understand the basic concepts. According to the findings of Lawson and Mc Dermott (1987), students' performance on mathematical problems shows that students can compute but their performance on the conceptual questions shows that they have much more difficulty explaining or interpreting their results. In Ethiopian schools, students have poor conceptual knowledge of physics; they cannot interpret and give meaning to the mathematical expressions. They are poor in numerical calculations, too (Tesfaye, 2007). This means that our emphasis on covering the content of a course as per the course description/course outline, and on controlling students' learning by giving structured information and facts, derivations through lecture as is in their text books remains fruitless.

Hestenes and Wells (1992) designed a mechanics test, which is limited to concepts that should be addressed in introductory physics at any level from high school through Harvard University in America. The purpose of the test was to assess students' understanding of the basic concepts in Newtonian Mechanics. The result of the test was used as baseline for evaluating the effectiveness of instruction at all levels. The test emphasizes concepts that cannot be grasped without formal knowledge about mechanics, and intended to assess qualitative understanding.

In his study using standardized test scores of more than 6,000 students in the subject of mechanics, Hake (1998) showed that the interactive engagement approach is twice as effective as the lecture approach in promoting students learning of physics. However, to the best of my knowledge no research is conducted in Ethiopian Universities and Colleges to see if lecture method promotes students' understanding of the basic concepts of Newtonian mechanics.

Statement of the Problem

Most first year students registered for the course Mechanics and Heat are not succesful in achieving good results. So far this course has been delivered by the lecture method supplemented with a tutorial classes where the instructor solves a number of mathamatical probems and students copy it passively. However, students' performance on this course has been very low, and this has highly contributed to attrition. The basic question raised in the study are: (1) do students learn the basic concepts of mechanics from the lecture method? (2) do students perform well on MBT after instruction with lecture method?

Objective and Significance of the Study

The objective of this research was to identify if the current physics teaching methods optimize students' understanding of the basic concepts of mechanics. The significance of this study are (1) the analysis can reveal difficulties that students may have in understanding the concepts in mechanics, and (2) it also gives teachers insight and guidance for future teaching and to question the effect of their use of the lecture method on students' learning.

Research Methods

Research Type

This research was quantitative. It involves testing and retesting where quantitative data scores of students on MBT was used to see the effect of lecture method on students' understanding of the concepts of Newtonian mechanics.

Sample and Sample Size

This study was conducted on first year mathematics students, who were registered for the course Mechanics and Heat in the academic year 2007, in Dilla University. The sample size of the study was 40% (22 students) of the total freshman mathematics students. The sample was randomly selected.

Data Source and Instrument of Data Collection

The source of data for this study was students' result on the mechanics test. Mechanics Baseline Test (MBT) was used as an instrument of data collection.

Limitation and Delimitation

This research was delimited to first year students who were registered for the course mechanics. There was no relevant research paper to this study particularly in physics education in Ethiopian context and thus the research was limited in local resource material. The author of this article was not the course instructor of the sample students and hence there was no worry of the self-defeating practice of "teaching to the test", which is considered as limitations or biases in the research that involves test and retest.

Procedure of Data Collection

To collect data for this research pre-and post-tests of Mechanics Baseline Test (MBT) was administered. Before the start of instruction of the course Machanics, the Mechanics Baseline Test (MBT) was randomly distributed to 30 students of the 55 students registered for the curse. This test was called pre-test in the paper. One week after the end of the semester class, which is after instruction of the course, the test was administered without announcing to the students. This test was called post-test in this article. On the post-test exam only 22 students out of the 30 students who sat for pre-test exam were available. Thus, the 8 students' pre-test result was annulled and the pre-test and post-test scores of 22 students were collected and analysed. In addition, the subsets of the mechanics test items were broken into three categories: those questions that involve calculation, force diagrams for their solutions, and kinematics questions. Students result on these subset items were collected and analysed.

Data Analysis and Presentation

In this research, the percentage averages scores of pre-test with its standard deviation, average scores of post-test with its standard deviation, the absolute gain, g (%), which is the difference between the percentage scores of post-test and pre-stest, with its standard deviation, and normalized gain <g> with its standard deviation were analyzed. Furthermore, the correlation between the pre-test and post-test scores, individual student's absolute gain, individual student's normalized gain were calculated and presented in Table 1. In addition to these, average scores and gains of questions that requised calculation, force diagrams for their solutions, and the kinematics questions, were categorically calculated and presented in Table 2.

In the calculations, the following formula were used:

$$Absolute\ \ gain\ (\%) = \%post - test - \%pre - test$$

$$Normalized\ \ gain,\ g = \frac{\%post - test - \%pre - test}{100 - \%pre - test}$$

$$Average\ normalized\ \ gain, < g >= \frac{< \%post - test > - < \%pre - test >}{100 - < \%pre - test >}$$

Table 1: The Results of Students' Pre and Post test Data, Gains with Standard Deviations and the Correlation Coefficient between Pretest and Posttest, Gains on MBT

Code	Pretest (%)	Posttest(%)	Absolute gain (%)	Normalized gain, g
M-01	23.08	26.92	3.85	0.05
M-02	15.38	34.62	19.23	0.23
M-03	19.23	30.77	11.54	0.14
M-04	15.38	23.08	7.69	0.09
M-05	19.23	34.62	15.38	0.19
M-06	23.08	26.92	3.85	0.05
M-07	19.23	23.08	3.85	0.05
M-08	19.23	26.92	7.69	0.10
M-09	19.23	26.92	7.69	0.10
M-10	19.23	23.08	3.85	0.05
M-11	23.08	26.92	3.85	0.05
M-12	23.08	30.77	7.69	0.10
M-13	19.23	30.77	11.54	0.14
M-14	34.62	46.15	11.54	0.18
M-15	19.23	23.08	3.85	0.05
M-16	15.38	26.92	11.54	0.14
M-17	26.92	30.77	3.85	0.05
M-18	0.00	11.54	11.54	0.12
M-19	26.92	34.62	7.69	0.11
M-20	23.08	30.77	7.69	0.10
M-21	19.23	26.92	7.69	0.10
M-22	15.38	26.92	11.54	0.14
Average	**19.93**	**28.32**	**8.39**	**0.10**
Standard deviation	**6.35**	**6.45**	**4.22**	**0.05**

Correlation coefficient, r, between	
pretest and individual's g	**-0.12**
pretest and absolute gain	**-0.25**
pretest and posttest	**0.78**

Table 2: Students' Average Score of Pre and Post- tests, and Gain in each of the Subsets of MBT: Questions that Involve Calculation, Force Diagrams, and Kinematics questions

	Calculation		Diagram		Kinematics	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Average score %	23.38	32.47	11.69	20.13	20.45	25.00
Absolute gain%	9.09		8.44		4.55	
Normalized gain	0.12		0.10		0.06	

Discussion of the Results

The analysis of the result showed that the average pre-test score was 19.93% (Std. Dev. 6.35%). This result is too low. It may be because students did forget the basic concepts of Newtonian mechanics they learned in preparatory class or they did not understand these concepts then. The average score of the post-test was 28.32% (Std. Dev. 6.45%). In the course mechanics for which the sample students were registered the concepts of Newtonian Mechanics was expected to be treated in detail. However, the result of the post-test was exteremely low. Students' difficulties with the test appear to stem from real deficiencies in understanding the basic concepts of the course. The post-test result reveals widespread deficiencies in the qualitative understanding of the basic concepts of mechanics. The post-test average score on the mechanics test was reported to be 66% (Std. Dev. 14%) for Harvard University regular students, 61% (Std. Dev. 18%) for Arizona State University students. Reports show that the threshold score of mechanics test for Newtonian understanding is 60%.

The average absolute gain in the mechanics baseline test in this study was found to be 8.39 % (Std. Dev.4.22). This means, after instruction students' performance on the basic concepts of Newtonian Mechanics increased by 8.39% (4.22). This is very low when compared to the maximum possible average gain which is about 80.08 % for the sample student. The results indicate that the method of instruction used (lecture) is hardly promising to enhance students' conceptual understanding in the course. As we can see from Table 1, the average normalized gain was 0.10 (Std. Dev. 0.05). This result is negligible because it is 10 times lower than the maximum possible average normalized gain. This insignificant average normalized gain suggests that the lecture method, which focuses on transforming facts about laws, principles, and mathematical derivations, does not guarantee the development of students' understanding of the basic concepts of Newtonian Mechanics.

Table 2 presents the analysis of the data collected from the subsets of mechanics test items: those questions that involve calculation, force diagrams for their solutions, and kinematics questions separately.

The average scores of the pre-test and post-test on questions that require calculations were 23.38% and 32.47%. This indicates that the absolute gain of students on mechanics concepts that involve calculations was 9.09%. As discussed in the previous section, the use of lecture time to present derivations and solution to mathematical physics problems was found to be ineffective in promoting students' learning of physics as witnessed by the students' low average normalized gain (0.12) in the subsets of mechanics test that involved even calculations. The average post-test result on mechanics that involves calculations was reported to be 54% for Harvard University regular students, and 51% for Arizona state University students.

The average scores of pre-test and post-test for questions for which the force diagrams facilitate the solution were 11.69% and 20.13%, respectively. The absolute gain of students on these categories of MBT was calculated to be 8.44%. The average post-test result of questions for which force diagrams facilitate the solution was reported to be 46% for Harvard University regular students, and 45% for Arizona state University students.

The average pre-test and post-test scores on kinematics questions were respectively 20.45% and 25%. This gives an absolute gain of 4.55%. The

average post-test result on this test was reported to be 62% for Harvard University regular students and 57% for Arizona state University students.
We see in general that the absolute gain of the students in these three categories of MBT was quite low. However, relatively absolute gain of kinematics questions was disappointing when compared to the absolute gains of questions that require calculations and force diagrams. This indicates that the kinematics instruction as well as student understanding of kinematics were very weak. However, we see from Table 2 that the students' pre-test and post-test was relatively low on questions that require the knowledge of force diagrams for their solution. This shows that our students are very poor in representing a given problem with force diagrams and in understanding mechanics concepts that involve force diagrams at large.

The average normalized gain on questions that involve calculations, and force diagrams for their solution/answer were 0.12 and 0.10, respectively. These are very low; the range of normalized gain was from zero to one, inclusive. But the average normalized gain of students on kinematics questions was 0.06, which actually indicates a negligible gain. These low results confirm that students derive little benefit from watching a physics teacher solving mathematical problems.

According to the reports of Crouch and Mazura (2001), there are dramatic differences in student achievement between courses taught with lecture and those taught with peer instruction. For example, where quantitative problem solving is de-emphasized in lecture, the average score on mechanics in the calculus-based course increased from 66% in 1990 (with lecture) to 72% in 1991 with the introduction of peer instruction. This average score continued to rise in subsequent years, reaching 79% in 1997. Furthermore, student performance on the subsets of mechanics questions that require algebraic calculation also improved from 62% to 66% on changing from lecturing to peer instruction.

The correlation of individual student g's and pre-test scores is found to be -0.12. Reviewed resources indicate that a significant positive correlation of individual student g's and pre-test scores would suggest that the instruction tends to favour students who have more prior knowledge of the subject as judged by the pre-test score ("Matthew effect"[†]). A significant negative correlation of individual student g's and pre-test scores would suggest that the instruction favours students judged by the pre-test score ("anti–Matthew effect"). An insignificant correlation of individual student g's and pre-test scores would suggest that the instruction was at about the right level for students who have an average prior knowledge of the subject as judged by the pre-test score. This means that the correlation coefficient -0.12 suggests that the instruction is at about the right level for students who have an average prior knowledge of the subject.

Thus, using the meanings given by Scholars for correlation of individual student g's and pre-test scores, the low gain result of the students in the exam was not only due to the nature of instruction but also due to students poor background as evidenced by their low average pre-test (19.93%). These students were unable to understand the concepts of the Newtonian mechanics even after instruction as witnessed by their low average post-test (28.32%) This low average post-test result which is less than the threshold score of mechanics test for Newtonian understanding, 60%, by 31.68%.

This needs further investigation whether the low performance of students on the basic concepts of mechanics stems from the nature of instruction or from the pre-requisite level students are lacking. The lecture method is typically used to present derivations, and to show examples of how to solve problems. The study conducted by Tesfaye (2006) indicated that the new curriculum students placed in Physics education department lack prerequisite knwoledge to understand first year physics courses given at university and their performance was very low resulting in high attrition rate.

[†] Matthew, *First Gospel of the New Testament* (Gutenberg edition) "to him that hath shall be given, but from him that hath not shall be taken away even that which he hath."

The use of lecture time to present derivations and solution to mathematical physics problems was actually ineffective in promoting students understanding of the basic concepts of Newtonian mechanics as revealed by the poor performance of students on the mechanics tests even including the items that involve calculations for their soluitions. This means that the emphasis of physics instructors on mathematical manipulations of mechanics course underscores the importance of requiring students to apply the fundamental concepts of Newtonian mechanics in a variety of different situations to solve physics problems of all kinds. In this regard, Kim and Pak (2000) used the mechanics as a mid-point of a study comparing students' self-reported copiousness in solving textbook problems in preparation for university entrance exams with their results on conceptual quizzes. They found that solving a great number of textbook problems proved to be no aid in performing well on the mechanics test.The result of the current study showed clearly that our emphasis on content coverage by providing bunches of facts, principle, laws, mathematical derivations, and the use of lecture time to reiterate the text book contents as they are has negligible effect on promoting students' conceptual understanding.

Conclusion

The gain in students' understanding of the basic concepts of Newtonian mechanics after instruction with the lecture method was found to be disappointing, with the average normalized gain on mechanics test being 0.10. The average post-test result of the sample students on this test was below half of the threshold score of mechanics test (60%) for Newtonian understanding with the average post-test result of the sample students in this study being 28.32%. Students' difficulties with the test appear to stem from real deficiencies in understanding the basic concepts. It means that our emphases on content coverage by providing bunches of facts, principle, laws, mathematical derivations through lecture, and the use of lecture time to reiterate the text book contents as they are has negligible effect on promoting students conceptual understanding. Thus, the result of the study indicates that there is little progress in students' conceptual understanding of

Newtonian mechanics and physics teachers must question as to whether the method of instruction they are using helps students learn the basics concepts of physics.

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