



An Interactive Dynamics Learning Course

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Abstract

The key course of Dynamics, taught in all Engineering and Engineering Technology (ET) curricula, covers a broad spectrum of foundational concepts, such as velocity, acceleration, force, energy, impulse, and momentum. It is well recognized that Dynamics is a fundamental building block for many subsequent courses such as Machine Design, Applied Fluid Mechanics, Thermodynamics, and Heat Transfer. Engineering programs often focus on theory and conceptual design, while ET programs emphasize the applications of these principles. However, in Engineering and ET, successful learning of Dynamics demands several interrelated skills on the part of students, beginning with spatial visualization, a clear grasp and application of physical concepts in various settings, followed by mathematical skills. These skills, if developed harmoniously, should lead to the successful development of problem-solving skills in Dynamics. However, in our consistent experience, students struggle with spatial visualization as well as physical concepts, which blocks further progress in their learning. At two engineering universities, Michigan Technological University and Northern Michigan University, Dynamics courses (MET 2130 and MET 310, respectively) are high-enrollment, high-impact sophomore MET core courses. 2004-2013 GPA data for MET courses offered at Michigan Technological University confirm the statement made by Magill [1] that Dynamics is “one of the more difficult courses that engineering students encounter during their undergraduate study.”

Dynamics is essentially the study of motion, but textbooks and whiteboards, the traditional classroom teaching tools, cannot capture this motion. MET 2130 and MET 310 have traditionally been taught in “chalk and talk” mode, where the instructor presents three, 50-minute lectures or two 100-minute lectures per week. For the majority of the class duration, students passively take notes on theory and example problems presented by the instructor, while about ten minutes might be devoted to questions and answers. In this way, students are not actively engaged in the learning process. To try and remedy these deficiencies, we plan to develop an interactive class that will essentially transform the lecture-intensive course into an “Interactive Dynamics Learning Course” (IDLC) that will

- a. directly address the hands-on learning approach of ET students,
- b. enable students to clearly visualize particle and rigid body motion and forces, which they struggle with in traditional classes,
- c. enhance their comprehension of key physical concepts, and thereby
- d. improve their problem-solving skills and grasp of the subject.

To study the impact on student learning in the IDLC, a pilot study was conducted at Northern Michigan University, the results of which are reported in this article. A manipulative model of a four-bar mechanism was designed and fabricated at Northern Michigan University that students directly worked with. This pilot study allowed students to explore the relative motion of various elements of the linkage by adjusting the lengths of the various links. They were also able to trace the path of the junctions on paper. To evaluate the success of the modeling exercise in enhancing

learning, a pre-and-post- pilot statistical assessment of the improvements in student comprehension and problem-solving ability was also conducted. Overall, the scores on the post-assessment quiz show a fair improvement over the pre-assessment quiz. A similar exercise is planned in the MET 2130 Dynamics course offered in Spring 2015 at Michigan Technological University.

1. Introduction

Engineering programs often focus on theory and conceptual design, while engineering technology programs usually focus on application and implementation. Accordingly, engineering programs typically require higher-level mathematics, including multiple semesters of calculus and calculus-based theoretical science courses. Engineering technology programs, on the other hand, typically focus on algebra, trigonometry, and basic applied calculus, which are more practical than theoretical in nature. In the School of Technology at Michigan Technological University, Dynamics (MET 2130) is a required (core) course which is taught to sophomore students enrolled in the Mechanical Engineering Technology program. However, Technology students with other majors also take this course. Dynamics is a high-enrollment, high-impact, core course that nearly all mechanical, civil, and other engineering as well as engineering technology students are required to take. This sophomore-level, gateway course covers a broad spectrum of foundational concepts and principles, such as displacement, velocity, acceleration, force, work, energy, impulse, momentum, and vibrations. It is well recognized that the course is an essential basis of, and fundamental building block for, many subsequent courses such as Machine Design I and II, Applied Fluid Mechanics, as well as Thermodynamics and Heat Transfer.

At Michigan Technological University and Northern Michigan University, the MET 2130 and MET 310 Dynamics courses have traditionally been taught in “chalk and talk” mode, where the instructor presents three, 50-minute lectures or recitation sessions per week. Five to ten minutes of a class period might include interaction with the students in the form of questions and answers. Otherwise, students passively take notes on theory and example problems presented by the instructor. The class is usually structured so that the students do assigned and required homework problems out of the text and take two or three exams and 7-8 quizzes per semester. By teaching the course in this manner, students do not significantly participate in the activities deemed important in the modern engineering / industrial workplace. On the other hand, students are placed in an almost anonymous but familiar environment in which they appear to be very comfortable. The same can be said of the instructor in that his role is limited but rather well defined, and this contributes to the students’ feeling of ease.

Magill [1] suggests that Dynamics is “one of the more difficult courses that engineering students encounter during their undergraduate study.” One reason for this is that Dynamics material has traditionally been taught without discussing the concepts in a meaningful context. It is an objectively complex course requiring both a solid understanding of basic physics and an intuition regarding solution strategies. In other words, dynamics problems are such that a well-defined solution protocol applicable cannot be provided in all cases. An additional difficulty in the context of teaching the course to Engineering Technology students is that, due to the hands-on approach, learning style, and training of the students, the mathematical content of the course is typically simplified, and the emphasis put on intuitive understanding and practice or applications. One way around these difficulties is to teach dynamics using real-life industrial problems and systematic problem-solving protocols. Figure 1 shows the GPA data for various MET courses offered in the Michigan Technological University MET program from 2004 to 2013. It can be seen from the figure that the GPA average for the Dynamics course (MET 2130) is 2.73, while that for the other courses ranges from 2.87 to 3.51. The GPAs shown for every course in Figure 1 are calculated average GPAs based on 18 semesters of data from 2004 to 2013. This graph

provides further support to the statement made above that Dynamics is “one of the more difficult courses that engineering (or technology) students encounter during their undergraduate study.”

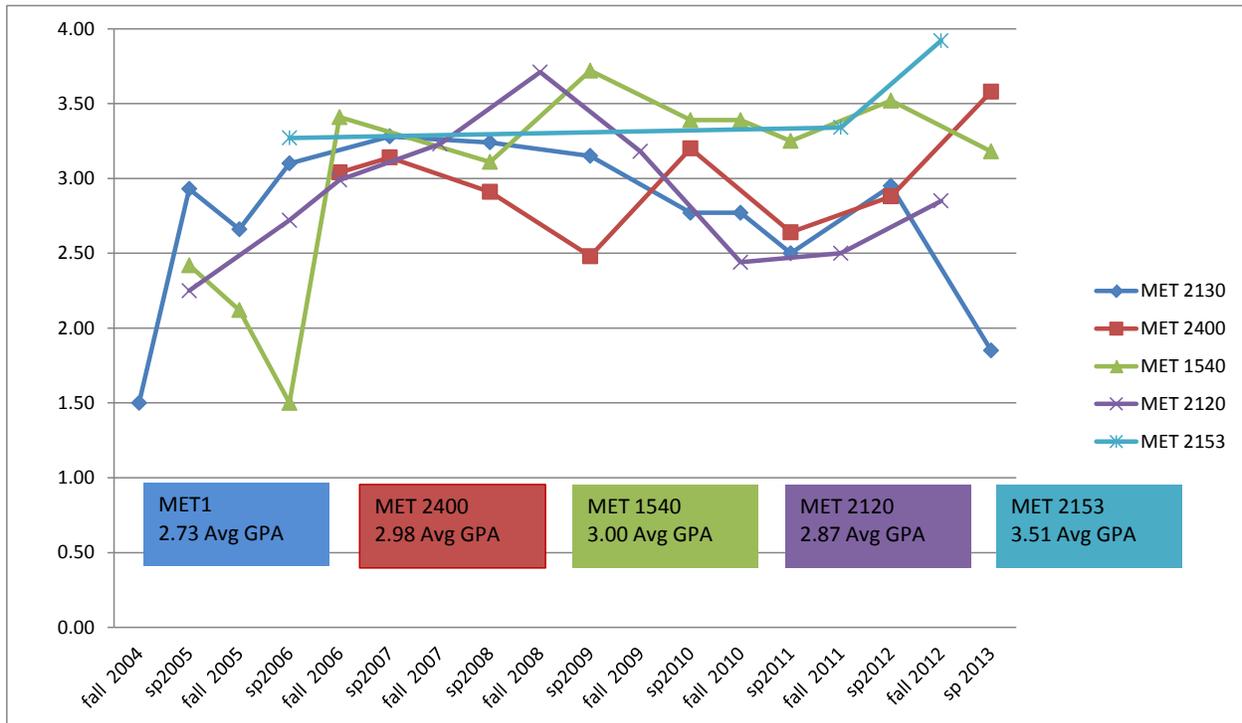


Figure 1 2004-2013 GPA data for MET courses offered at Michigan Technological University

Across the United States as well as other countries, while some faculty have responded to the inherent difficulties of teaching and learning Dynamics by adopting procedural problem-solving methods [1, 2], others have applied a variety of active learning approaches in dynamics (and statics) classrooms [3, 4, 5, 6]. Asokanathan [3] for example, reports on the use of simulations using software, physical models, and videos to involve students in the learning process. Examples of Dynamics simulations can also be found on the NSF-sponsored website <http://www.engageengineering.org/>, which provides everyday examples in various engineering disciplines.

2. Proposed Interactive Dynamics Learning Course

However, all the references cited above are in the context of engineering curricula, and not tailored to the needs / learning styles of Engineering Technology students, which, as we have seen above, are as a group typically drastically different from those of Engineering students. To address the hands-on learning style of Engineering Technology students, we propose an interactive Dynamics class, which will essentially transform the lecture-intensive course into an “Interactive Dynamics Learning Course” (IDLC). The IDLC will also assign homework problems, have two or three exams per semester, and even use basic lectures 60–70% of the time. It is the other 30–40% of the class that will fundamentally distinguish it from a traditional dynamics course. An IDLC class will typically begin with a 5-minute introductory

lecture in which the instructor presents the goal of the day's IDLC activity. This introduction is intended to (a) point out important things students should look for during the activity and (b) provide a context for the students' work so that they see that what they do in class is indeed related to "real-life" problems. After the introductory lecture, the activity begins. An activity may typically consist of solving a problem or problems involving a kinematic and / or kinetic analysis of a mechanism or linkage. The students will work in groups of four and work directly with the manipulative models of the mechanism or linkage (e.g., a four bar linkage). The models will allow the students to explore the relative motion of different points of the linkage by adjusting different length ratios of the mechanism. Thus, instead of leaving the subject matter comprehension largely to the imagination and intuition of the students, the students can understand the dynamics of the mechanism much better than before. Once the students have had some time to explore different facets of the model's motion, the instructor can then present a logical, step-wise, systematic solution to the problem starting from the basic physical laws and their application to the problem at hand. In addition to the manipulative devices, simulations of different mechanisms studied in the IDLC will also be made available to the students on the course web site. Thus, these simulations are available for access even outside regular class times, and will help substantially in fixing the concepts in the students' minds.

Typically, there might be ten to twelve such interactive activities with manipulative devices per semester. Every activity is based upon the fundamental theme of writing the correct equations of motion and then solving them in a systematic, logical sequence, with the manipulative devices and accompanying simulations helping to enhance the learning for the practically oriented Engineering Technology students. The inclusion of the manipulative mechanisms and simulations will make the IDLC classroom a place that is much closer to the work environment that the students will experience when they leave school and also better prepare students for many of the classes they will take in the remainder of their undergraduate career.

Dynamics is essentially the study of motion, but textbooks and whiteboards, the traditional classroom teaching tools, cannot capture that motion. Mechanical models of mechanisms and linkages are helpful for students, but have inherent limitations; they are relatively inflexible and qualitative, not quantitative. With the goal of improving the teaching and learning of dynamics, we propose a three-year study incorporating the use of Dynamics simulations as well as physical manipulative models.

Simulations (e.g., something similar to the "BEST" software described in [7], [8], [9], and [10]) will be integrated into the curriculum in the first year to reduce the emphasis on a largely intuitive understanding of Dynamics. Several different problem simulations, representing a selection of typical kinematics and kinetics problems for both particles and rigid bodies, will be completed. These problems will be designed to enable the user to vary inputs to view a wide variety of configurations and behavior.

In addition to the simulations, manipulative devices designed to aid in understanding the kinematics and kinetics of mechanisms and linkages commonly encountered in the study of Dynamics will be developed, implemented, and evaluated in the second year. Our goal here is that students using the simulations and physical manipulative models should achieve improved ability to visualize motion, and improved problem-solving ability. This goal, if realized, should automatically result in enhanced understanding of the principles of Dynamics, and therefore, student retention.

3. Proposed Manipulative Models of Mechanisms

There are indications that technologists and engineers are active learners and therefore hands-on experiences are an important part of their education [11]. In order to facilitate hands-on learning in the MET course of dynamics, we propose to design and fabricate several manipulative physical models of selected linkages or mechanisms that students frequently encounter in their study of dynamics and will also encounter regularly in the real world. Sirinterlikci and Kerzmann [22] have described an educational initiative involving developing laboratory kits that would allow the mechanical engineering courses ENGR 1010 - Introduction to Engineering and ENGR 2160 - Engineering Graphics to utilize the same kits for numerous laboratory sessions.

Simulations and/or manipulative models of the following problems / mechanisms will be developed in this study:

1. Motion of a projectile
2. Absolute dependent motion analysis of two particles
3. Relative motion of two particles using translating axes
4. Principles of work and energy for a system of particles
5. Impact between particles
6. Principle of instantaneous center of velocity
7. Principle of linear momentum and impulse
8. Principle of angular momentum and impulse
9. Piston-connecting rod-crankshaft (or slider-crank) mechanism (also manipulative models)
10. Four-bar linkage (also manipulative models)
11. Kinematics and Kinetics of a rolling wheel (also manipulative models)
12. Kinematics and Kinetics of a simple gear train (also manipulative models)
13. Several versions of slotted link mechanisms (also manipulative models)
14. Several examples of pulley, block, and weight systems (also manipulative models)

4. Manipulative Model Pilot Study Method

The Northern Michigan University Dynamics course (MET 310) meets for 100 minutes twice a week, on Tuesdays and Thursdays. The topic of Planar Kinematics of a Rigid Body (Hibbeler 16.1-16.6) was covered in lecture on Tuesday, Nov. 4, 2014 and Thursday Nov. 6, 2014 and twelve textbook exercises were assigned as homework, of which four specifically required using relative motion and/or instantaneous centers of velocity. On the following Tuesday (Nov. 11, 2014) time was allowed for questions on Ch. 16, after which the class moved on to Ch. 17.

On consecutive class meetings, Thursday, Nov. 13, 2014, and Tuesday, Nov. 18, 2014, students were given four-bar linkage quizzes at the start of class. The first quiz was announced in the prior class, after which the assignment with the four-bar linkage was given, due the following Tuesday (Nov. 18, 2014).

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The homework exercise required students to rotate the input linkage of a four bar linkage model through a prescribed angle, and then measure the angle of rotation at the output linkage. Specific link lengths and angular displacements were assigned to each group of students so that the acceleration would be negligible so that the angular velocity would be proportional to the angular displacement. The students then were required to verify the measured angular displacements using analysis (instantaneous centers or relative velocity).

The second quiz was given unannounced, so that any improvement could be more readily attributed to the four-bar linkage homework assignment than to any additional studying by the students. The first quiz was not returned or discussed until after the second quiz was complete. The second quiz was very similar to the first quiz, with slightly different geometry, and velocities. The students had the option of using either the relative velocity or the instantaneous centers of velocity methods. This timeline has been summarized in Table 1 below:

Table 1 Timeline for four-bar linkage modeling homework and pre- and post-assessment

Date	In-class activities	Out-of-class activities
Tuesday Nov. 4, 2014 Thursday Nov. 6, 2014	Chapter 16: Planar (2-D) Kinematics of a Rigid Body 16.1 Rigid-Body Motion, 16.2 Translation, 16.3 Fixed Axis Rotation, 16.4 Absolute Motion Analysis 16.5 Relative-Motion Analysis : Velocity 16.6 Instantaneous Center of Zero Velocity	HW 8 16-3,5,7,11,13,23 (sections 16.1,16.2,16.3) 16-41,49 (sections 16.4) 16-61,81,88, and 101 (16.5, 16.6)
Tuesday Nov. 11, 2014	Chapter 16 Q & A Chapter 17 lecture	
Thursday Nov. 13, 2014	First Quiz (pre-assessment)	4-bar link modeling homework assigned, due Nov. 18
Tuesday Nov. 18, 2014	Second Quiz given (post-assessment)	

The adjustable four-bar mechanism used in the pilot study is shown in Figure 2.

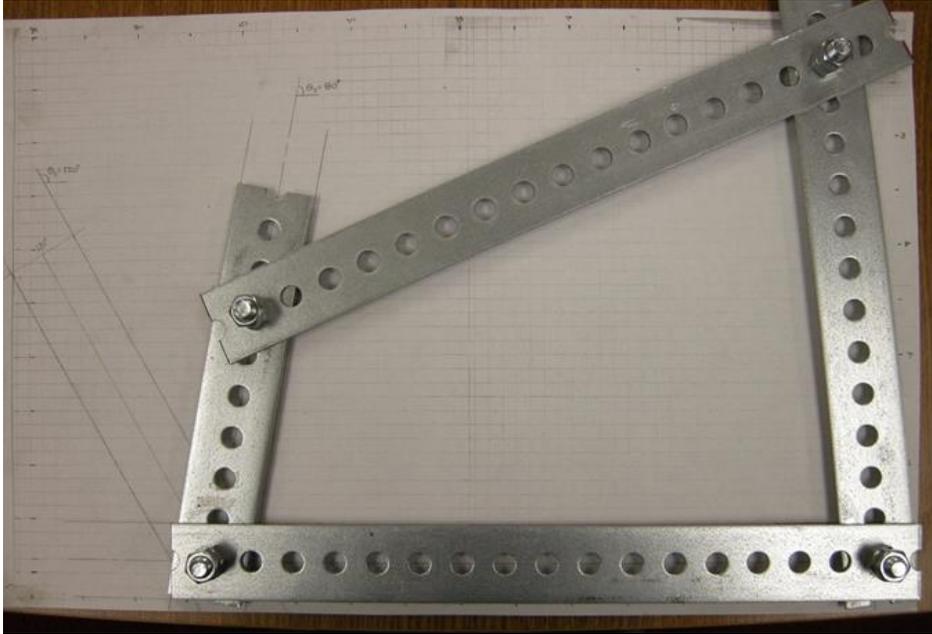


Figure 2 Adjustable four-bar mechanism used in IDCL pilot study

5. Pilot Study Results

Figure 3 shows the pre-and post-assessment scores for 26 students who participated in the pilot study, while the differences in their scores as a result of the modeling exercise are displayed in Figure 4.

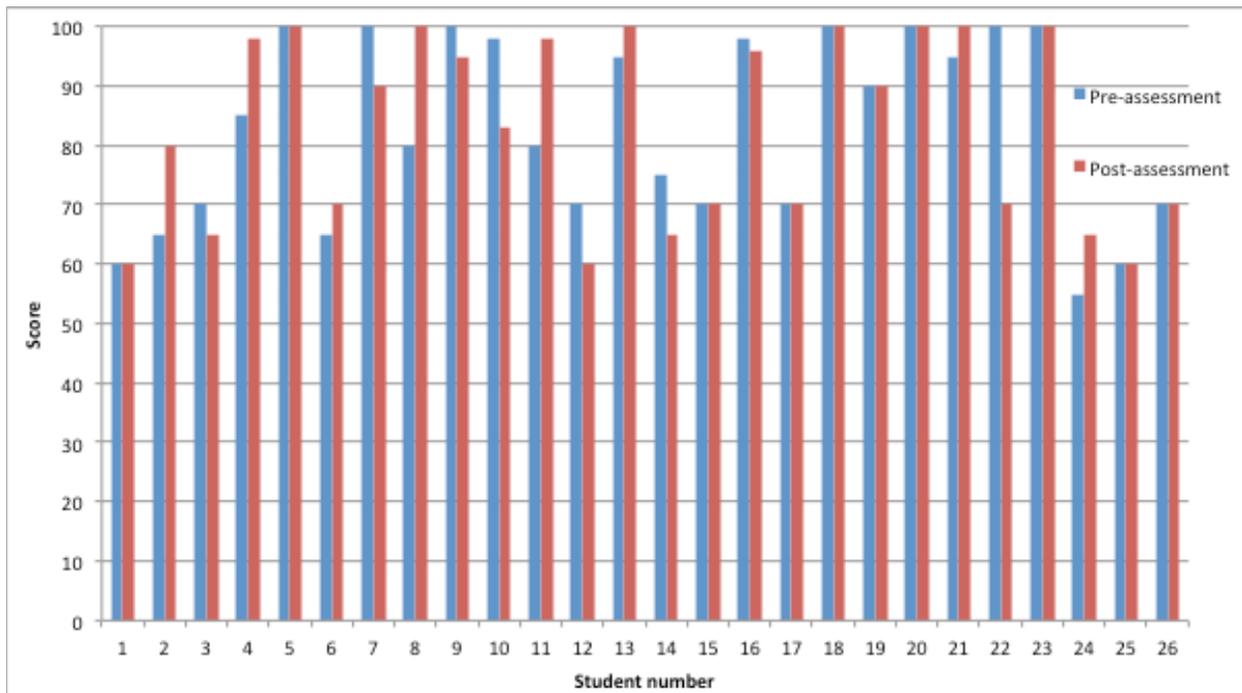


Figure 3 Pre- and post-assessment scores for students who were exposed to the pilot study

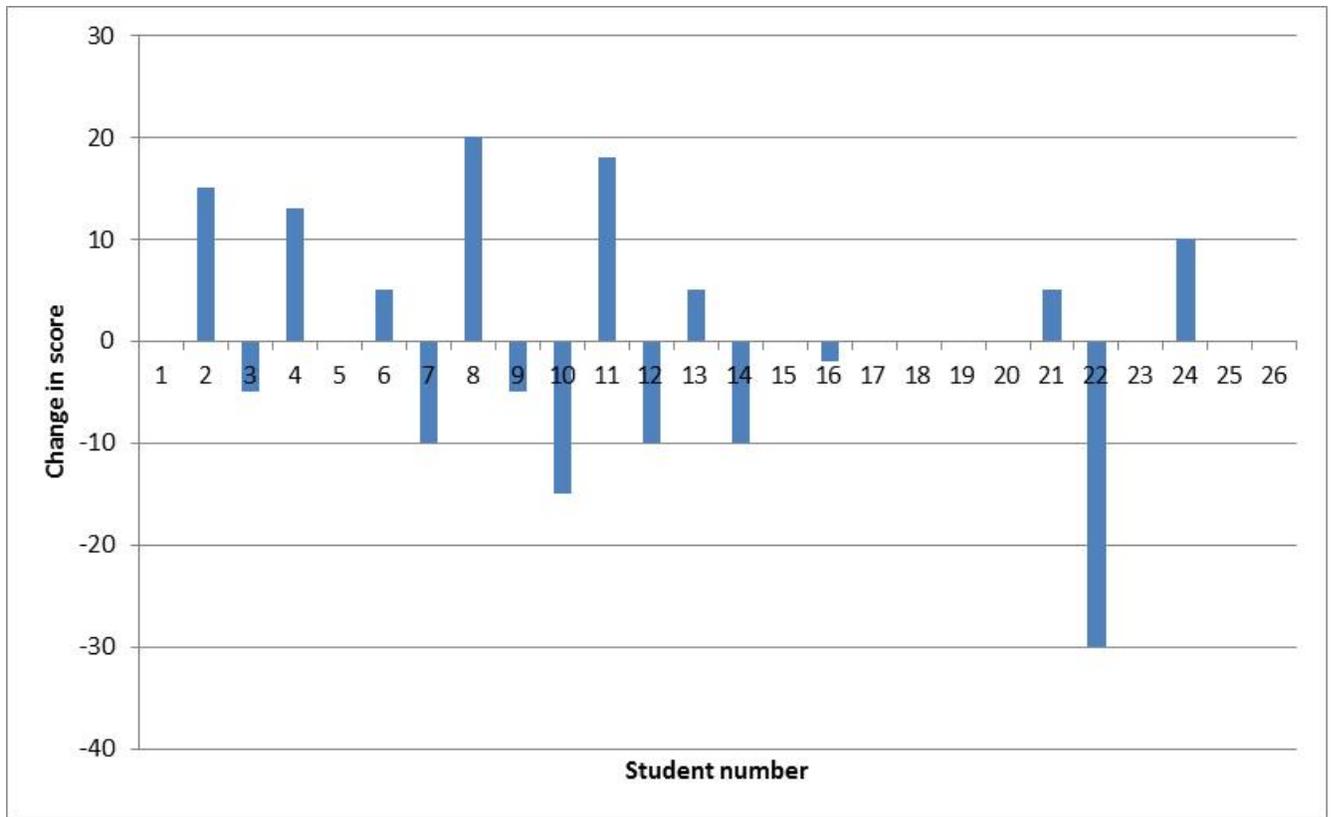


Figure 4 Student score changes resulting from pilot study

Table 2 shows the observed changes in a score of 100 for 26 students who were exposed to the pilot study.

Table 2 Observed changes in a score of 100 for 26 students who participated in the pilot study

Number of students	Change in score	Comment
4	0 (scored 100 on both quizzes)	Little to no change in score
6	0 (scored < 100 on both quizzes)	
3	improved by ≤ 5 points	
3	decreased by ≤ 5 points	
1	improved by 6-10 points	Noticeable improvement in score
4	improved by > 10 points	
3	decreased by 6-10 points	Noticeable decrease in score
2	decreased by > 10 points	

6. Pilot Study Conclusions

Given that no additional instruction was provided, other than the modeling homework, the scores on the post-assessment quiz show a fair improvement over the pre-assessment quiz. 10 students out of 26 had no change in score, and an additional 6 scores changed by less than 5 points, which at least shows good retention of the knowledge without further instruction after a span of 5 days.

5 students showed noticeable improvement of their score (by 6 points or more), 4 of those by 10 or more points. Another 5 students had a decreased score of 6 or more points, 2 of those by more than 10 points. One factor working against improved quiz scores was the second quiz was given unannounced, while the first quiz was announced. As noted above, this was done intentionally to avoid any grade improvement solely due to specific studying immediately before the quiz, so that any improvement in score could more likely be attributed to the modeling experience, and associated analysis homework.

After the homework assignment was turned in, an error was found in the computations the instructor used to create the homework assignment, so that instead of the student getting similar results from the physical model and analysis (instant centers of relative velocity), the results were very different. This likely caused a decrease in students' self-confidence/efficacy, but it also caused student to do the calculations more than once to trouble-shoot the problem.

Since this was a pilot study with only one exercise including the manipulative models, the data collected was limited in quantity. Hence, a detailed statistical analysis of the data would not be value-added. However, the pilot study definitely showed sufficient improvement in learning to encourage the continued development of a complete Interactive Dynamics Learning Course.

7. Conclusions

Dynamics is essentially the study of motion, but textbooks and whiteboards, the traditional classroom teaching tools, cannot capture this motion. Sophomore Dynamics courses MET 2130 and MET 310 at Michigan Technological University and Northern Michigan University respectively, have traditionally been taught in “chalk and talk” mode, where the instructor presents three, 50-minute lectures or two 100-minute lectures per week. In this lecture-based mode of teaching Dynamics, students are not actively engaged in the learning process. To try and remedy this deficiency, we plan to develop an interactive class that will essentially transform the lecture-intensive course into an “Interactive Dynamics Learning Course” (IDLC) that will

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Details of the proposed IDLC course can be found in the article. As a first step toward implementing the IDLC course, a pilot study was conducted at Northern Michigan University. Manipulative models of a four-bar linkage were used in the pilot study. A homework assignment that required students to work with the manipulative model, and pre- and post-assessment quizzes were the key elements of the pilot study, details of which are given in the present article. Although the data obtained in the pilot study was limited, analysis of the pre- and post-modeling quiz scores showed sufficient improvement in learning to encourage the continued development of a complete Interactive Dynamics Learning Course.

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