Paper ID #20112

Utilizing Empathy-Based Course Modules to Enhance Student Motivation in Lower Level Mechanics Courses

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Purpose:

Many students struggle with motivation in lower level engineering mechanics courses. It is not unusual for instructors to hear students make comments like "Will this be on the test?", "Can I borrow the book?", and "D's get degrees." There seems to be an underlying belief on the part of these students that they will not need this information in the future. Thus, they find it difficult to exert the hours of effort necessary to learn the material. This lack in understanding relevance logically leads to poor academic performance, repeated courses, and all too often, student dropout.

In 2013, the author was part of a team that won a grant from the W.M. Keck Foundation for a three year project to enhance education by introducing elements of wheelchair research into various undergraduate courses. The goal was to utilize research instrumentation and demonstrations to not only teach technical aspects of a course, but to increase student motivation to learn those aspects. Toward that end, the demonstrations were directly related to the human need of mobility, thus enhancing motivation with an empathetic aspect. By showing how theory presented in mechanics courses could be used to develop better wheelchairs to help people, it was hoped that students would be more motivated to learn. Therefore, the primary intent was not to determine if the students learned a technical point, but if the demonstration made them want to. This paper summarizes the results of that effort as well as suggestions for those considering such interdisciplinary activities.

Background:

Much research has been done on the use of demonstrations in various math, science and engineering courses. Some of the literature describes specific demonstration apparatus and technique, with the underlying assumption that demonstrations are of value [1, 2, 3]. Many projects go a step further and report subsequent student comments, either as verbal responses in class, special surveys, or the typical end-of-term student evalutions [4, 5, 6, 7, 8, 9]. Students generally report increased understanding of the technical concept and a better understanding of the course relevance. However, attempting to quantify the knowledge gained is rare and more complicated.

A study done at Harvard University did attempt to quantify student learning from demonstrations, with some insightful conclusions [10]. They utilized an introductory physics class of 133 students and compared the scores of an end-of-semester test focused on the topics of the demonstrations. Those who merely viewed a demonstration had scores only slightly higher than the control group, which did not have the demonstration. However, those who were required to predict the outcome in writing before the demonstration, scored much higher on the test afterward. Additionally, some students were given a chance to discuss their prediction and the demonstration with 2-3 others. The discussion aspect improved scores slightly, though at the expense of an additional 7 minutes of course time. The results indicated that, just because the instructor does a demonstration, it doesn't mean the students will learn more. However engaging students in other ways alongside a demonstration multiplies the impact.

Most of the studies in the literature present student benefits after implementing multiple demonstrations throughout the term in a particular course. In this research effort, however, the demonstrations were done in a variety of interdisiplinary courses. With that aspect, it wasn't feasible to interrupt multiple lectures of a number of faculty in various schools. Therefore, there was one chance to influence students in a particular class. The hypothesis of this paper is that students can be impacted in a single demonstration if it is emotionally engaging. So rather than just bending a pipe class, one could bend a pipe on a wheelchair by driving it into a table leg. The students should see more relevance and have more interest because of a natural desire to help people in need and improve the world. In addition to the empathetic interest, student engagement was enhanced by involving classmates and asking students to predict and explain the behavior shown.

At this university there is an active wheelchair research group with equipment readily available. Of course, many universities won't have that particular opportunity for empathetic motivation. However, there is some type of engineering project occurring for human benefit on most university campuses. It is hoped that the methods described here will inspire others to consider what they can use in their location to connect a human benefit to the demonstrations they do.

Methodology:
Three demonstration modules were developed that related to improving wheelchair function, which is of obvious benefit to humankind. (figure 1). In cooperation with the lecturer in these various courses, pre-tests were given before the 15 minute module was performed. In each of these modules, students from the class were involved in using or pushing a wheelchair. Instruments were used to collect data in order to demonstrate the topic of the day's lecture. Table 1 summarizes each module, the class it was presented in and the method used. Detailed descriptions of each module follow the table.

Figure 1. Presenting the impulse-momentum module to physics class.

Table 1. Module descriptions

Module	Performed in Courses	Method
Impulse-momentum 2015	University and General Physics 1	Used strain-gage instrumented "SmartWheel^{TM}" on wheelchair to show force of wheel stroke and time interval resulting in change of momentum
Impulse-momentum 2016	University and General Physics 1	Modified previous year demonstration to be pushing a wheelchair with two load cells and measuring velocity with laser sensor
Newton's second law (F=ma) 2016	Engineering and Eng.Technology Dynamics	Pushed wheelchair with two load cells and measured acceleration with accelerometer on wheelchair. Used curve-fit to find mass.
Stress due to impact 2016	Mechanics of Materials and Strengths of Materials	A strain gage was installed to the footrest of a wheelchair and strain measured as wheelchair was run into a curb. High speed photography was used to measure deformation.

a) *Impulse-momentum module in physics (freshman level).*

In physics courses, the impulse-momentum principle is typically less intuitive than other topics and was therefore chosen for a demonstration module. The principle states that a body will have a change in momentum proportional to the impulse, or stated in equation form:

$$m\vec{v}_1 \qquad + \sum \int_{t_1}^{t_2} \vec{F} dt \qquad = m\vec{v}_2$$

In 2015, a module was developed using an instrumented wheelchair wheel (SmartWheel^{tm}) that measures 6-axis loading on the hand rim and wheel velocity. A volunteer from class was asked to sit in the wheelchair and give it a propulsion stroke. Data was displayed real-time via wireless computer link. The moment supplied to the wheel was used to find the traction force on the tire. Multiplying the force times the sampling time and summing over the entire stroke provides the applied impulse. Students were asked why the final velocity was always lower than calculated with the impulse from the propulsion stroke. They eventually correctly suggested that there is also rolling resistance slowing the wheelchair. While this module resulted in slight improvement in student motivation (see Results section), technical understanding showed little improvement. It was postulated that the wheel impulse in the module was unclear. Thus, the following year, the module was modified to show a more obvious impulse.

In 2016, the impulse-momentum module was modified to utilize hand held load cells to push a vertical plate mounted on the wheelchair (figure 2). A laser sensor was used to measure position and thereby derive velocity. Volunteers from class were recruited to perform the demonstration and data was gathered real-time on Labview™ software. Again, momentum measured was lower than predicted by the calculations, due to rolling resistance.

Figure 2. Impulse momentum module.

As part of the grant project this module was converted into a video format on youtube.com so that other schools can use it. In 2017 the module in physics will be done with the video and the outcomes measured again. The video is available at: https://youtu.be/xpbp9hfFIjk.

b) F = ma module in Dynamics (Sophomore).

The Dynamics courses for engineering and engineering technology focus on Newton's second law of motion, which states that force is proportional to acceleration or "$\vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$". A module was developed to demonstrate this relationship.

As with the impulse-momentum module, load cells were used to push on a vertical plate mounted to wheelchair handles. However instead of measuring velocity, an accelerometer was attached to the load plate. Volunteers in Dynamics classes were recruited to push and ride in the wheelchair. Load cell and accelerometer readings were shown real time, though analysis was prepared previously to save time in class. Typical data are shown in figure 3.

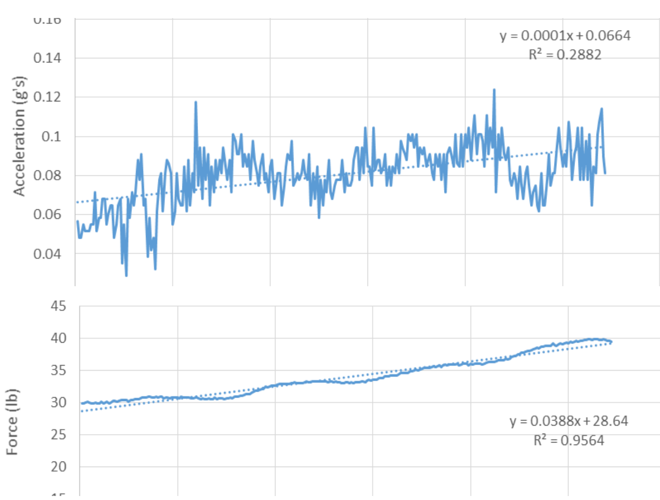

Figure 3. Data from accelerometer and load cells for "F = ma" module.

Of course, acceleration is not as high as predicted, again due to rolling resistance. This generates class discussion in how “real life” is more complicated than textbook problems, while demonstrating that the principle works. In the end students observed that using instruments and calculations like this could be used to improve wheelchairs.

c) *Stress due to impact module in Mechanics of Materials and Strength of Materials (Sophomore/Junior).*

Analysis of impact loading is typically given little attention in undergraduate engineering and engineering technology mechanics courses. Of course, in industrial settings, falling and colliding objects are common and are often the cause of structural failure. The third module was developed to illustrate stress due to impact loading in engineering Mechanics of Materials and engineering technology Strength of Materials courses.

Figure 4. Strain gage setup for impact module.

In the impact module, a strain gage was installed on cantilevered structure of a wheelchair foot rest (figure 4). Foot rests of wheelchairs often impact curbs, stairs, and walls. How does the designer ensure safety and strength in such conditions? In addition to measuring strain on the foot rest tube, high speed photography was used to illustrate structure deflection. In the class, one volunteer rode in the wheelchair while another propelled the wheelchair into a desk or stair (taking precautions not to strike the rider’s feet). Strain gage readings were demonstrated real-time and then film footage from previously recorded impacts were shown. Several scenarios were recorded with/without cushions on the foot rest or curb to demonstrate how structural compliance spreads and lowers the impact stress. Students observed the significance of impact and how it could be measured and mitigated. The real purpose of the module, however, was to show the students that the material they learn in this course gives them the tools to solve problems for people in need.

Results:
Impact of these modules was measured with pre-test and post-test ratings, student comments, and test scores.

A pre-test survey was given to the students just before the module was presented that asked them to rate two questions on a scale of 1 to 10, from “very little” to “very much” (figure 5). The post-test with the same questions was given approximately four weeks later. The questions were

1. Please rate the significance of the material in this course to your career.

   Very little   Very much

   1 2 3 4 5 6 7 8 9 10

2. Please rate how well the material in this course will help you make a positive impact in the world.

   Very little   Very much

   1 2 3 4 5 6 7 8 9 10

Figure 5. Pre/post test

worded general in nature, and the post-test was given long after the demonstration in order to avoid leading the student into a desired answer. The intent with the 1-10 numerical scale was to simulate a visual analog scale without the need to measure lengths of tally lines. Thus no intermediate titles were included on the scale, just two extremes. A total of 435 students participated in these modules and completed surveys. Table 2 shows the mean scores for each course, with the overall averages weighted by number of students in each section at the bottom.

Table 2. Average values of pre-test and post-test surveys.

		PreTest		PostTest			
Class:	# Students	Quest. 1 Career	Quest. 2 World	Quest. 1 Career	Quest. 2 World	% Gain Career	% Gain World
F=ma module for Sophomores:							
Dynamics E.Tech '16	20	7.45	7.30	6.76	6.67	-9.2%	-8.7%
Dynamics Eng. '16	31	8.19	7.77	8.19	7.63	-0.1%	-1.9%
Impulse-momentum for Freshmen:							
UniPhys sec.1 2015	37	7.69	7.06	7.83	7.40	1.9%	4.9%
UniPhys sec.2 2015	36	7.61	7.21	7.13	7.41	-6.4%	2.7%
UniPhys sec.3 2015	43	7.12	6.63	6.67	6.80	-6.3%	2.6%
UniPhys sec.1 2016	51	7.75	7.31	8.48	7.90	9.4%	8.1%
UniPhys sec.2 2016	57	8.04	7.31	8.38	7.98	4.3%	9.2%
GenPhys total 2015	55	5.99	6.00	6.22	6.47	3.8%	7.8%
GenPhys sec.1 2016	25	6.28	6.52	7.02	7.18	11.8%	10.1%
GenPhys sec.2 2016	17	5.65	5.65	6.45	6.82	14.3%	20.7%
Impact module for Sophomore/Juniors:							
Mechimat 2016	50	8.42	8.06	8.51	8.07	1.1%	0.1%
Strengths 2016	13	8.54	8.15	8.46	7.62	-0.9%	-6.6%
Weighted average		7.44	7.08	7.57	7.39	1.9%	4.4%

Results of the surveys overall showed improvement in the mean scores to both questions: a 1.9% improvement in question one and 4.4% improvement in question two. Due to high variation in the responses, this increase does not meet 95% confidence levels to be statistically significant. However, in certain classes, the responses were markedly improved. It seems students in the engineering-specific courses like Dynamics and Mechanics of Materials understand the relevance of course material more than students in freshman-level Physics courses. In comparing only the pre-test scores, the first-year physics courses averaged a full point lower in both questions than the pre-tests of students in sophomore and junior level engineering courses. Furthermore the Physics classes also showed a bigger gain on the post test. These freshman-level courses showed a 3% gain on question one and a 7.2% gain in question two after the demonstration (a half-point higher on the 10 point scale).

Of course, such an improvement in the general freshman classes is key to motivating students to continue their studies and to reach the courses that are more specific to their interests. With respect to question one on career impact, it makes sense that the metric did not improve significantly. The provided modules did not relate as much to career relevance as to world impact.

In some surveys the students were also asked to comment on the wheelchair demonstration after providing numerical ratings. Students wrote:

- "…a first hand example of how the calculations and material covered in class is used to help design and use a product."
- "It was a cool applicable demonstration of how strengths analysis is needed in any industry...."
- "It was very informative and very neat."
- "Showed a real life application...showed software and Excel integration well."
- [It showed…] "how complex impact loading is and how it can be measured in the real world."
- "Safe design should plan also for possible mis-use and stress, not just intended use."
- "Real world example of testing."

As shown, most comments recognized the value of a "real world" example of how theory is applied. In addition, side benefits were mentioned such as learning about testing and instrumentation techniques.

Overall, the modules demonstrated measurable improvement in student perception of the relevance of coursework in impacting the world. Since the improvement due to this short demonstration appears to be most influential in the freshman physics courses, it is intended to continue those modules. In the upper level courses, the effectiveness of a short module was not demonstrated and will be discontinued.

While this project was focused on changing student attitude, there was an attempt made to quantify technical learning of the topic in one module. In University Physics, a baseline was determined in 2014 before the modules were implemented (Table 3). There was a question on the third test of the semester and another on the final exam that related directly to the impulse-momentum principle. In the baseline year, 22% of the students answered the question correctly on test 3 and 53% answered a similar problem correctly on the final exam. Because tests during the semester are returned to the students, the problem on test 3 was changed each year. After the module was presented in 2015, the score on the test 3 problem rose to 41% correctly answered. However the related question on the final exam which was identical to the 2014 final exam dropped slightly to 52%. The lack of improvement led to modifying this module to use load cells instead of the SmartWheel™ to make the impulse more obvious. In 2016, the new module was presented. Unfortunately, the physics professor neglected to analyze test 3 results before returning the exams. Also, the professor decided to change the problem on the final exam in 2016 in striving for continuous improvement. The score on the new problem took a dramatic downturn with 31% correct answers. Because there was a difference in difficulty of the related problems, numerical comparisons year to year were of no use. Apparent improvement on test 3 in 2015 is similarly questionable, due to a change in the test problem.

Table 3. Comparing scores on relevant test problem before and after modules

Year	# Students	% Correct on Test 3	% Correct on Final Exam	Notes
2014	76	22%	53%	Baseline - no module performed this year
2015	83	41%	52%	Problem changed on test 3 from 2014
2016	113	Not gathered	31%	Problem changed on Final Exam from 2015

Lessons learned:

Developing short demonstrations involving research methods and instruments are time consuming. Equipment must be selected and purchased. Methods are tested and revised. Many interdepartmental discussions are necessary to schedule and participate in another professor's lecture. Gathering pre-test and post-test data subsequently requires faculty cooperation and detail tracking. This effort is compounded if requesting the lecturing professor to analyze test problem performance. The effort is also multiplied greatly to convert to video format: procuring related clips, voice overs, lecture re-takes, video editing, arranging acting subjects, and so on. With such a time demand, one key to success was hiring an upper level engineering student to work 10 hours/week for approximately a semester per module, plus another semester for the video production.

Interdisciplinary projects can produce unique solutions and foster cross-campus unity, but it takes extra time and effort. Working with busy people who do not report to the same department requires fostering ownership and friendship. One just can't send an email across campus and expect results to show up in the inbox. In this project, some grant money was available to share with collaborating lecturers. It helped to be able to offer $500-$1000 to a lecturer to collaborate, especially if she were asked to collect test score statistics. That said, it is recommended not to ask other faculty to analyze test statistics. A major recommendation is to make it as easy as possible for collaborating faculty. This means not expecting them to create, dispense, or analyze pre-tests and post-tests. Rather than ask them to analyze test problem success rates, it may be more successful to ask for copies of student tests and do that analysis oneself.

Finally, thorough project management is even more necessary in interdisciplinary efforts: Remind people often of their commitments, identify potential pitfalls, and keep everyone's interest in the higher purpose of the project.

Conclusion:

The focus in this project was to engage a large number of students with a short, human empathy demonstration to increase their motivation. 435 students were exposed to a 15 minute demonstration showing how human mobility can be improved with the topic of the class. In most classes where the students already believed the material was very relevant, the impact was negligible. Interestingly, the modules appeared to have a bigger impact in courses that needed a bigger impact. In freshman physics courses, students may think, "I'm never going to use this." Showing them one example of how the theory they are learning could be used to reduce rolling resistance of a wheel chair proves the doubter wrong. In 15 minutes it is possible to show an unmotivated student that he can change the world and he might even need engineering to do it.

Acknowledgement:
The author thanks the W.M.Keck Foundation and LeTourneau University for the support that made this work possible.

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