Forming Connections between Theory and Real Devices in a General Statics Course

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Introduction

Most engineering instructors have witnessed their students’ struggle to connect what they are learning in their classes to the engineering profession. Comments like “I’ll never use any of this on the job” or “My uncle is an engineer, and he says he’s never once used calculus” are just a couple examples of the students expressing their struggle to see the relevance of what they are learning. Likewise, engineering faculty are often frustrated by their students’ apathy toward real learning. When a machine design student says, “You mean I have to remember Statics?” it becomes clear the student didn’t see the usefulness of free-body diagrams back in Statics class.

When students don’t see a connection between the concepts they learn in Statics and their future as engineers, they are less motivated to engage and to remember what they learn. There may be many contributing factors as to why students tend to see Statics as "series of mathematical manipulations" rather than a way to understand physical systems. Textbook problems, by necessity, are neatly condensed, and modeling decisions have already been made, but the result is that students don’t recognize them as real problems. When handed actual objects, students fail to see the forces acting on the object as the neat vectors they’ve seen drawn in their textbook figures. The leap from a real device to a mathematical model is big, and yet instructors spend very little time letting students practice that step.

The goal of this paper is to present a particular activity that has been used in Statics instruction at the University of St. Thomas to engage mechanical engineering students in modeling a real device and to answer design-related questions. The student is given a significant amount of independence in deciding how to model the geometry, connections, and forces that act on the device. Then, the students attempt to answer engineering questions by applying the theories they’ve studied in class. The activity is accompanied by a pre- and post-activity quiz, and a writing exercise. The paper will present quantitative results of the testing and also themes from the student writing that help demonstrate how foreign, but satisfying, it feels for them to apply theory (on their own) to a real device.

Background

When the activity was first designed, the author was simply looking to introduce another active-learning experience into the classroom to engage the students. Prince provides an extensive review of the research on active learning and notes that students remember more if brief activities are introduced into lectures. Felder makes broad recommendations on how engineering teaching can be improved. Felder and Silverman argue that though students all have different learning styles, and a small number of techniques can meet the needs of most students. They recommend using material that emphasizes practical problem solving and fundamental understanding. They also discuss the importance of reflective learning (along with active learning). The author’s initial vision was to bring a can crusher to class and let the students answer some questions about mechanical advantage, thus extending familiar content
from their Statics course (drawing free-body diagrams, balancing forces and moments) to an idea that was brand new to them (mechanical advantage).

What surprised the author when first introducing the can crusher activity in 2012 was that the students were truly troubled with how to represent the force from the can onto the can crusher. The vast majority of students would draw the force in the wrong direction. Steif et al.\textsuperscript{5} state “Certainly, the initial stage of surveying a physical system, the true modeling stage, can be the most difficult.” The author has found this to be true, and it relates to the students reluctance to use mathematical models later in their coursework or in their careers. If the student cannot make the first connection between the real system and the mathematical model, all the mathematical analysis tools they’ve learned become useless.

The other lesson from those initial attempts at creating a meaningful activity was that students need to face their misconceptions before they can revise their thinking. The instructor can present an example of a can crusher and state that the force onto the can is downward, therefore the force from the can onto the plunger is equal and opposite (upward). The student will nod in agreement and copy down the information. But, later when left to model a similar device on his own, he may still draw the force acting on the device in the wrong direction. His association with the force being directed onto another object by the device is so strong, that he wants to place the force in the same direction \textit{on} the device. Unless, he is confronted with why his ideas don’t make sense, he will continue to believe them, even if everything the instructor told him to the contrary made sense when he heard it. Muller\textsuperscript{6,7,8} showed that when misconceptions were not addressed students believed they were learning, but the misconceptions persisted. On the other hand, when misconceptions were addressed students reported feeling more confused, but testing revealed they also learned more. Bransford et al.\textsuperscript{9} express similar findings: “Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts” “or they may learn them for purposes of a test, but revert to their preconceptions outside the classroom”.

Using hands-on activities is not new to engineering instruction. Feisel and Rosa\textsuperscript{10} give an extensive review of the historical role of instructional engineering laboratories. However laboratory or hands-on learning specifically for Statics instruction is a relatively modern concept developed in recent decades. Numerous authors have described hands-on instructional activities involving pulley systems, levers, cables, trusses, ladders and friction forces to demonstrate and teach basic principles of Statics.\textsuperscript{11,12,13,14,15,16,17,18,19} The focus of their work is in improving the conceptual understanding of the student and helping the student relate theory to the physical. Some of the exercises also incorporate creativity and design.\textsuperscript{14,18} There is not, however, a direct effort by these authors to connect students to real-world applications that mechanical engineering students might encountering in their future careers. Campbell\textsuperscript{20} uses an enticing approach in his use of “model making and breaking”. Students design structures to strict specifications and then build and test the structures to the point of breaking. The appeal to the student is high because it is fun to break things, and the relevance is there for structural engineers, but mechanical engineering students may still struggle to see the connection to their careers. Sophomore-level students do not yet have the experience to see that the tools used in analyzing structures will also be useful in analyzing moving parts--unless we give specific examples.
Some real-world problems have been used, without the hands-on aspect, to serve as a motivator for the student to engage with the concepts. Condoor et al., and Shih et al. and Rosser et al. devised methods that incorporate case studies, short examples, and interactive computer models from real-world problems. Steif created homework assignments based on fairly common devices (SUV hatch, cork screw, bicycle rack, exercise machine, etc.) which have more real-world relevance to mechanical engineers than trusses and beams. Steif displayed the devices digitally and students were to determine on their own which dimensions and features were critical to their analysis. Making those decisions outside of class proved challenging for the students, and Steif recommended future improvements such as offering students guidance a day or two before the assignment was due.

The work presented in this paper strives to marry hands-on learning and real-world relevance for mechanical engineers. Similar to Steif’s homework idea, the students answer engineering design questions regarding a physical device, in this case, a can crusher. The difference is, the students can hold the device in their hands, and they do the work in the classroom where the instructor can help redirect them if they get stuck or take a wrong turn as they make decisions on how to take a real object and create a mathematical model. Mariappan et al. and Hickman et al. also use a can crusher as the subject of longer open-ended design projects for sophomore engineering students. The current author is more interested in a small addition to the lecture setting.

The can-crusher activity was not designed to stand alone. The Statics course at the author’s institution includes three 65-minute lectures and one 90-minute lab session weekly. The lab sessions involve many hands-on learning activities. Still, several times throughout the semester the author brings applications into the lecture sessions for students to explore. The author feels it is important that the students see applications in the lecture as well as the lab, so they do not develop a false sense that theoretical and physical are unrelated. Recent changes have also been made to the Statics lab format at University of St Thomas to ensure that the problem solving done in the lab requires implementation of the theory taught in lecture.

The author anticipated that the can crusher activity would make the students feel uncertain about their abilities. From the very first experimentation with the activity, the students were asked to write about the experience afterward. The author responded to their writing with encouragement and reassurance that struggling and making mistakes are all part of learning. Helping students adopt a “growth mindset” is an important goal of this activity. “Instructors must inherently believe that all students have the ability to increase their intelligence.” Responding to the students’ uncertainty with the assertion that their fears and discomfort are a normal part of learning is an important part of the exercise presented in this paper. In addition to providing a mode of interaction between the student and professor, the act of writing and reflecting also helps to make the connections gained from the activities more lasting.

The remainder of this paper will present a brief overview of the activity and how it was implemented. Results of pre- and post-activity testing will be presented, and common themes in student writing will be discussed.
Method

The process for implementing the activity has evolved over time from a one-hour exercise to a series of steps over multiple days. On the first day, during a 65-minute class-period, a standard lecture is given on simple machines. The concept of mechanical advantage (the ratio of force output over force input) is also introduced to the class. A textbook example problem on the analysis of a vise grip is worked for the students, and students are encouraged to ask questions throughout. The steps presented include: identifying external forces on the simple machine; separating bodies; modeling internal forces on free-body diagrams; using equilibrium equations to solve for unknown forces; and determining the mechanical advantage of the vise grip. In the final 10 minutes of the lecture, students take a pre-activity quiz.

The pre-activity quiz (see Appendix A) is meant to evaluate the students’ ability to apply what they have seen in lecture to another simple machine or “device”. Photographs were used to present two simple devices: 1) a nut cracker and 2) a toggle clamp. For the toggle clamp, a brief video was also shown in which a hand is seen applying a force to the handle of the toggle clamp until the clamp crushes a piece of PVC tubing. For each device, the students are given approximately 3 minutes to answer a series of questions related to modeling external forces, drawing free-body diagrams, identifying two- and three-force members, and identifying input and output forces.

On the second day the modeling activity takes place. The instructor brings common can crushers to class and invites students to bring aluminum cans to crush. Students work in pairs or small groups to model the can crusher and the forces which act on it. The instructor presents the goal as determining the mechanical advantage for various positions of the can crusher and comparing the mechanical advantage of different models. Instructor also lets the students know it’s likely they will not be able to finish the activity in the one class period, and there is no time pressure to complete all of the analysis questions.

The student groups are given a handout with a series of suggested steps and a few photographs of the can crusher in various positions (see Appendix B). To a fellow engineering professor this may seem overly prescriptive for an open-ended student-guided activity, but from the students’ perspectives it is still far from clear. They often write of not having enough instruction and not knowing how to begin, which is necessary, for they are to decide how to begin for themselves.

Students are encouraged to crush cans and manipulate the actual devices as they consider their analysis questions. Instructor and a teaching assistant (for classes over 20) circulate the room to interact with the students. Effort is made to encourage students to answer their own questions. The instructor may ask questions that challenge the students’ assumptions or encourage them to manipulate the can crusher to better feel and visualize the forces. Students are regularly asked to teach each other. A group that is struggling with a certain step will be invited to get help from another group who has that step figured out. Figure 1 shows typical interactions as students wrestle with which directions the forces act. Figure 2 shows a student trying to explain to an instructor why he drew his forces the way he did. Their hand gestures demonstrate how much interaction they need with the physical model before they can translate the physical into lines on a page.
In approximately 50 minutes of work time the average student group will complete the mechanical advantage analysis for one position. A small number of groups may not get that far. An even smaller number of more capable groups may have time to evaluate multiple positions and compare the different can crusher designs.

Figure 1: Students Interactions

Figure 2: Student-Instructor Interactions

In the final minutes of the class period, students are given a question to write about for the next class period. The question also has changed slightly over the years. The question used Fall 2015 read as follows:
Write one paragraph on your experience analyzing a real device. How did your experience compare to analyzing textbook problems? How did the exercise make you feel about your abilities to analyze real devices?

Student notes and sketches from the modeling activity are collected, but not graded. The instructor does look them over and insert comments. None of the can-crusher activities are graded, but the instructor awards small amounts of homework points for participation to ensure students are motivated to attend and engage.

On the third day, students return to class with their individual essays, and they take the same quiz that they completed on day 1. The instructor takes about ten minutes to present her own analysis of the can crusher and make some general comments about how using a force triangle allows a visual connection between the orientation of links in the can crusher and the relative size of the input and output forces. Students are reminded that it is fine if they did not complete all the questions on the previous day and that the exercise was simply meant to show them how the tools they are learning in Statics can be applied to designing a better can crusher.

After reading the student essays, the instructor returns the essays, generally with added words of encouragement—especially for those who expressed insecurity or worries about their skills. The instructor also writes an email to the class identifying common themes and encourages the students that the frustration they experienced is perfectly normal. Students are reminded that modeling real systems often requires many missteps before a useful model is generated, and like all skills, modeling real devices gets easier with practice.

Assessment of Conceptual Learning

Fall 2015 was the first year that a pre- and post-activity quiz was introduce. To ensure that the quiz was measuring the impact of the activity over and above other instructional methods, the quiz was given after a standard lecture on the same content. However, one factor that could not be controlled is how many students studied the material outside of class between the pre-activity quiz and the post-activity quiz.

Twenty four students participated in all three components of the conceptual learning assessment: pre-quiz, activity, and post-quiz. Scores for students who missed any one component were removed from the data. The numbering system in Table 1 was devised to identify concepts since some of the quiz questions had multiple steps. Figure 3 shows the number of correct responses for each of the concepts for both the pre- and post-activity quizzes.

The questions are fairly basic for students in their ninth week of a sophomore-level Statics course. For every concept, at least 54% of the students had a correct response before the activity. Students displayed significant difficulty in identifying two- and three-force members before the activity (concepts 3-5 and 12-14). Student were generally very good at drawing external forces that they thought of as “inputs”, but struggle with “outputs”. Only 54% of the students were able to correctly draw the external force from the clamped PVC tubing onto the toggle clamp.
concept 11) in the pre-activity quiz. Students fared better at drawing the force from the nut onto the nutcracker. One hypothesis is that when students watched the video of the toggle-clamp and saw the member of the toggle clamp move downward and crush the PVC tubing, they strongly associated a downward motion with the output force, making it difficult for them to imagine there was an external upward force acting on the toggle clamp itself—even though they had just seen their instructor work through a problem and explain that the force onto a vise grip is equal and opposite of the force it exerts onto clamped material.

<table>
<thead>
<tr>
<th>Concept #</th>
<th>Original Question #</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutcracker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1a</td>
<td>correctly drew force from hand</td>
</tr>
<tr>
<td>2</td>
<td>1a</td>
<td>correctly drew force from nut</td>
</tr>
<tr>
<td>3</td>
<td>1b</td>
<td>zero 2-force members</td>
</tr>
<tr>
<td>4</td>
<td>1c</td>
<td>link 1 is a 3-force member</td>
</tr>
<tr>
<td>5</td>
<td>1c</td>
<td>link 2 is a 3-force member</td>
</tr>
<tr>
<td>6</td>
<td>1d</td>
<td>3 forces on free-body diagram</td>
</tr>
<tr>
<td>7</td>
<td>1d</td>
<td>correct input</td>
</tr>
<tr>
<td>8</td>
<td>1d</td>
<td>correct output (either direction)</td>
</tr>
<tr>
<td>9</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concept #</th>
<th>Original Question #</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toggle Clamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2a</td>
<td>correctly drew force from hand</td>
</tr>
<tr>
<td>11</td>
<td>2a</td>
<td>correctly drew force from clamped material</td>
</tr>
<tr>
<td>12</td>
<td>2b</td>
<td>link 3 is a 2-force member</td>
</tr>
<tr>
<td>13</td>
<td>2c</td>
<td>link 1 is a 3-force member</td>
</tr>
<tr>
<td>14</td>
<td>2c</td>
<td>link 2 is a 3 force member</td>
</tr>
<tr>
<td>15</td>
<td>2d</td>
<td>Force on handle is input</td>
</tr>
<tr>
<td>16</td>
<td>2d</td>
<td>force on clamp end is output</td>
</tr>
</tbody>
</table>

Table 1: Numbering System for Quiz Responses
Figure 3: Results of Pre- and Post-Activity Quizzes

After the activity, the number of correct responses increased or stayed the same for every concept. Correct responses regarding the force from the nut onto the nutcracker (concept 2) increased from 75% to 92%. Correct responses regarding the force from the clamped tubing (concept 11) onto the toggle clamp also increased from 54% to 75%. Modest gains were also made in number of correct responses in identifying two- and three-force members. Overall the modeling activity seemed to have a positive effect on the students’ ability to model forces.

The less dramatic improvement in identifying three-force members (concepts 4, 5, 6, 13 and 14) could be due in part to students’ general resistance to using the concept of a three-force member during the exercise. Some students circumvent the instructions and write equilibrium equations, rather than drawing a force triangle. In which case, the students may not have consciously identified that the handle of the can crusher did indeed have three forces applied to it. The students are encouraged to draw a force triangle because it is more visual, but the method of analysis is not forced as long as their equations are correct and they are finding ways to get useful information out of them.

Common Themes in Student Essays

Essays from 99 students collected over four semesters* were studied. Common themes in essays included: 1) the students found the activity more challenging than textbook problems; 2) the students liked the activity and wish they could do more similar activities; 3) students don’t necessarily see textbook problems as relevant to their futures as engineers; 4) students lack confidence in their ability to apply what they learn in classes to real problems; 5) the students feel that more activities like this would help them connect what they are learning to their future work as engineers; 6) the activity may be particularly appealing to students for whom English is a second language (ESL students). Evidence of these themes is presented below.

* The activity has been implemented by the author 6 times, but essays were not preserved every semester.
1) Many of the students struggled with the activity. Sixty-six percent (66%) of all the students said that the activity was more challenging than textbook problems. Students described the experience as “difficult”, “more complicated”, “harder”, and “more involved”. They wrote: “forces were harder to see and the directions are difficult to determine”; “[it] forced me to think”; and “it was definitely more difficult because there is no textbook drawing telling me where the forces act.”

2) Despite the majority of students feeling the activity was harder than what they are used to, 89% of all students had something positive to say about the experience. They used words like “fun”, “exciting”, “pretty cool”. Some students said “I liked it”, or “I thoroughly enjoyed it,” or “the lecture went by quicker (sic)”. They also offered insight as to what was good about it. Examples of what they liked: “I felt as though I was able to gain understanding of how to better analyze these devices.”; “[I] was able to figure out…”; “[I] could consult with a partner”; and “[it] helped me learn the principles and ask questions, which is the main way I learn.”

3) Instructors may see the textbook problems as perfectly relevant and easily relatable to future applications because they know that the same concepts apply to more than one application, but students do not necessarily see this connection. One student writes: “Sometimes I have a hard time enjoying the textbook problems just because I don’t see where most of them can be applied to real life other than just learning how to solve them.” This student seems to be making the argument that his professor wants him to learn how to learn, but he’s not sure the specific concepts he’s learning will be ever useful to him.

Instructors may think that solving a textbook can-crusher problem is very similar to answering analysis questions about a real can crusher. Students do not necessarily see analyzing a real can crusher as same thing they’ve always done. They describe the modeling activity as a “unique experience”. One student literally uses the word “foreign” to describe his experience. Another student writes very eloquently:

“Working on this activity has demonstrated to me the disconnect between theoretical and practical knowledge. We may think that we have proper knowledge of a field with only what we learn from textbooks, but we often find that isn’t the case, and rightly so. I myself was confused about the nature of the forces associated with the machine. Perhaps this confusion arose simply because this is new material.”

4) Only 11% of all students did not have anything explicitly positive to say. Their comments were not necessarily 100% negative, but they focused on the challenge and did not express any benefits or enjoyment. Their essays often struck at the heart of their own self-doubts. A few examples are given below:

“The textbook gives us all of the information we need to solve the problem and provides you (sic) with a clear drawing of the device. We had to decide which measurements we would need to find to help us solve the problem. Although we could pull the lever arm down and see how the forces moved, it was difficult to find where the actual forces would go. This exercise made me feel very frustrated and confused.”
“As with anything new it was going to be uncomfortable. I’m sure with more practice I’d feel more confident in my abilities. For now, the challenge of finding the forces made me doubt my Statics abilities.”

“To model the device we had to look beyond the mechanics to see what exactly the device did. When we are presented with a book problem all we have to do is apply the concepts we learn in class. To model the device, we had to completely understand the concepts, and there is a huge difference between applying and understanding concepts. To be honest, this experience humbled me as it tested me in understanding the concepts. I’m sure that if the device was already modeled and I was assigned to find a force or reaction of a member of the device I could, but if I was asked to find that same force or reaction and the problem was not modeled I am not sure if I would be able to.”

“One major problem was trying to figure out all of the forces acting on the can crusher (both internal and external) on the free-body diagram. With a textbook problem, the forces are usually pretty obvious. Because of this I was pretty frustrated with analyzing the can crusher.”

It was rare that students wrote that they specifically prefer lecture-style learning, but some are quite concerned about the possibility of making mistakes. One student wrote: “Good chance of people doing it wrong before they know that they are wrong. [That’s] why I prefer class problems that teach us the steps to solving the problems before we actually analyze the object in class.”

While it’s disheartening to read that even a small number of students are still frustrated at the end of the activity, the essays reveal that students are aware that they need additional skills to solve real problems, and it worries them. However, ending the activity feeling frustrated or less confident is not the goal. Therefore, the instructor responds to these comments by looking for additional ways to make the student feel safe during the activity, and follows up with words of encouragement directly to the student. Initial confusion may not be avoidable, but the goal is that the student moves beyond frustration to discovery and a sense of accomplishment.

A few students had legitimate complaints when teaching assistants in the room gave them poor advice and left them feeling very unsure. The instructor responded to that feedback and took more steps in the future semester to ensure that anyone brought in to help with the activity had very clear understanding of both the concepts and the intent of the activity†.

5) When the students do make the connection between theory and application, they often feel more motivated to engage in the textbook learning as well. One student writes, “The exercise made me feel good about what we’ve been learning because I can see how we can apply it. [It] got me thinking about where I can use Statics in other applications.” Other students write: “[The activity] helped me to see the real life situations that could come out of these textbook problems and why they are important.”; “I have learned a lot more in Statics than I thought.”; “[It was]† Former students are often far better teaching assistants than colleagues because they are less intimidating and they follow instructions well.
nice to be able to take principles used in [textbook] problems and see them in action using a real world model.”; and “examination of the actual can crusher gave a tangible use to our skills.”

When students see that the concepts they are learning in class connect to real devices and real questions that they imagine engineers in their field address, they gain excitement for their futures and motivation to keep learning. Students know engineers don’t sit around solving problems from textbooks with neat diagrams, but they aren’t sure what they do. One student writes: “book problems are easier, but doing these types of activities are (sic) more beneficial to our learning. I felt like a real engineer.” Others write: “[It] makes me excited for future engineering problems and seeing real world applications as well as the mathematical analysis”; and “I felt way better about engineering as a whole. If this is what engineers do, I want it!”

6) It wasn’t until essays from multiple semesters had been compiled that the author noticed the activity could be particularly beneficial to ESL students. Of the 99 students participating in the activity, 14 were ESL Students—mostly foreign students who have come to the United States for an engineering education. Ninety three percent (93%) of ESL students used positive expressions in describing the activity. Two ESL students specifically noted that doing the activity was easier than doing textbook problems. (None of the native English speakers said this.) One explained, “pictures in the [text] book get a little confusing with all the descriptions written on it. This exercise made me feel more confident on the way I approach a problem because I could visualize the way the forces act on a part.”

It’s unclear from this small sampling of data if ESL students uniquely benefit from the activity, but with a growing percentage of Saudi students in the engineering program at the University of St Thomas, more effective tools for reaching the ESL populations could be a worthy topic of future exploration.

Refining the process

Over six semesters of implementing the activity, several lessons were learned. 1.) Letting the students know that you anticipate that they may feel uncertain or frustrated during the exercise seems to help them to see it as part of the learning process rather than an injustice imposed upon them. As a consequence, their essays become less about how fair or clear the instructions were and more about their learning experience. 2.) The more opportunity the students have to handle the actual device they are analyzing, the better. Photographs are helpful, but not an equal substitute. One device per four students works pretty well. 3.) Language matters. “Output force” can mean many things, but, the “external reaction force from the can onto the can crusher” is descriptive and clear. It took the author a long time to realize that the language presented to the student could be causing part of their confusion about force directions. Once students are clear on reaction forces, the instructor can go on to explain that the output force from the device onto the can is of equal magnitude and opposite direction to the reaction from the can back onto the device. 4.) Students will write authentically about their experience if they think their instructor’s interest in their experience is authentic. It may be coincidental, but the one semester that the author mentioned that the essays would be helpful in formulating a paper on the subject, was the only semester that sarcasm and silliness appeared in the essays.
Conclusions

Deficiencies in basic conceptual knowledge sometimes go unnoticed when students are solving textbook problems. Students can be mostly successful in much of their coursework by learning procedures even if their true understanding of the foundational concepts is weak. Asking students to model real systems (on their own) stretches them to understand on a deeper level, particularly if it requires that they confront their misconceptions. The can-crusher activity was effective at bringing students face to face with their misconceptions about the direction of external forces and improved their performance on a conceptual test.

A fundamental challenge for all faculty is to motivate their students to do the hard work of learning. It seems that the can-crusher activity succeeded in that realm. The majority of students admitted that the exercise was harder than what they are accustomed to, and yet, an even larger majority liked it and expressed a desire to do more similar activities in the future.

Exercises like the one presented in this paper are incredibly time consuming, yet, asking students broader questions forces them to create their own models and dig deeper in their understanding of concepts being taught. Students participating in the can-crusher activity had to ask themselves:

- Can I model a three-dimensional device in two dimensions?
- How much detail is necessary?
- How do I represent this connection?
- Which forces can I ignore?
- Which principles that I have learned can be applied to help me answer this question?

The experience with the can crusher showed the students that there is another step in engineering that perhaps they had not previously thought about. For some it was intimidating because it was new and difficult. For some it was empowering because it showed them a path to connecting their course work to the world around them.

Simply creating a hands-on experiences for students is not necessarily sufficient in connecting the theory to their future careers. Hands-on activities that focus on demonstrating physical principles, but don’t necessarily incorporate the kind of problems that students envision themselves solving in their careers, may not create the same connections. One of the students who participated in the can-crusher activity said it was “nice to finally work on something very relatable to real life instead of just trusses and towers pinned down with cables which seem to be more of civil engineering topics.” Real life examples of bridges and towers from the Statics textbook and lab seem irrelevant to this Mechanical Engineering major. The student lacks the experience to know that many of the concepts learned in studying stationary objects will apply to the analysis of moving parts on the job as a Mechanical Engineer. It’s important that at least some of the activities students participate in are directly connected to something they can see themselves doing in the future.
Students’ narratives reveal that they are uncertain, and even worried, about their ability to make connections between what they learn in class and real applications. Written communication between instructor and student (and often follow up in-person conversations) were in part aimed at helping the student develop a growth mindset so that they would be more accepting of their own lack of experience and missteps. While it’s fairly easy to see that students struggle internally, it’s hard to measure if the exercise and the encouraging words from the instructor relieved their worries. Developing a way of measuring the impact of the exercise on the student mindset and confidence is a possible direction for further study.


Appendix A: Pre- and Post-Activity Quiz and Figures

1. Nutcracker
   a) Draw all the external forces acting on the nutcracker. Please approximate any distributed loads as a single point load.
   b) Identify any two-force members (circle all that apply)
      Member 1  Member 2
   c) Identify any three-force members (circle all that apply)
      Member 1  Member 2
   d) Draw a free-body diagram of member 1 only. Label the input and output force on your free-body diagram.
1. **Toggle Clamp**
   
a) Draw all the external forces acting on the toggle clamp. Please approximate any distributed loads as a single point load.

b) Identify any two-force members (circle all that apply)

   - Member 1
   - Member 2
   - Member 3

c) Identify any three-force members (circle all that apply)

   - Member 1
   - Member 2
   - Member 3

d) If you were to compute the mechanical advantage of the toggle clamp, which of the forces that you drew in part a) would you call the input and the output forces?

\[ F_{in} = \quad \quad \quad \quad F_{out} = \]
Appendix B: Activity Questions and Figures

- Draw a 2-D diagram of the machine in the first position.
- Draw the forces that act on the machine.
- Label the input and output forces.
- Draw 2-D free-body diagrams of each link.
- Use 2-force, 3-force members, and force triangle to evaluate relative size of input and output force. (You don’t have a value for $F_{in}$, but you can solve for $F_{in}$ in terms of $F_{out}$)
- What is the mechanical advantage, $F_{out}/F_{in}$ in this position?
- Consider your input force, is there a better way to apply the input force to increase your mechanical advantage? (Adjust your free-body diagrams and force triangle accordingly)
- Repeat your analysis for other positions of the can crusher. Does the mechanical advantage change for different positions of the machine? (Using drawings to back up your answers)
- Are there any positions where mechanical advantage seems to be optimal?
- Where in the range of motion would you want the best mechanical advantage? (Think about the forces you need to crush the can.)
- Look at some of the other designs. Is one design better than the others?

Can Crusher

Slightly Modified Design