2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #39375

Developing a Curiosity Mindset in Engineering Undergraduates via Hands-On, Inquiry-Based Learning Activities with Hidden Discoveries

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Abstract

In a world full of rapidly developing new technologies, it is critical that engineers develop their sense of curiosity so that they are prepared - and excited - to continue to learn throughout their careers. An engineer who is curious about technology will be intrinsically motivated to engage in life-long learning. Indeed, it is an ABET requirement that engineering students *recognize* the need for life-long learning, but in addition to recognizing this need we wished to increase the likelihood for engineers to indeed *engage* in a life-long activity throughout their careers. Accordingly, to promote intrinsic motivation for life-long learning, we developed a series of inquiry-based activities promoting curiosity in an upper-division mechanical engineering senior design course. Our method includes three components. First, we explicitly introduced the value of curiosity in engineering and created assignments that prevented students from treating lab components as a "black boxes", but rather required understanding of how they work. The second method was mechanical dissection, where students took apart and discovered how a gearbox, encoder, and potentiometer worked. In the third method, students are challenged to discover a "hidden" factor that would improve their theoretical model to better match with experimental results. These activities were implemented in an upper division design class with 131 students, who were surveyed at the beginning of the class and after the curiosity focused activities in week 5. The survey showed that, after the class exercises, 83% of the students were more interested in using theory in engineering design, 79% were more interested in understanding the physics of how things work, and 76% of the students were more inclined to take things apart. Notable demographic differences were observed. Whereas 40% of Under-Represented Minorities (URMs) students had not taken anything apart prior to the class, compared to 18% for non-URM students. In terms of gender, 30% of female students compared to 20% of the male students had not taken any objects apart prior to the class. Discovering the hidden factor proved to be a challenging yet rewarding activity; only 35% of the students discovered the challenge on their own, but overall, 83% did discover the challenges with help from other students. Student comments expressed how inquiry-based activities promoting curiosity are valued by students.

Introduction

Lifelong learning is a critical component of any technical career, and its importance is evident by the ABET requirement that accreditation requires engineering programs to teach lifelong learning skills [Naimpally, 2011]. In addition, engineers must not only learn how to use new technologies but also comprehend the underlying principles and physics that govern them. This knowledge helps them make informed design decisions and evaluate the pros and cons of different technologies better. Moreover, by grasping the fundamentals of a component's operation, an engineer can more effectively interpret a manufacturer's specification sheet, as will be described later in this document.

The challenge remains: how does one effectively teach lifelong learning skills that will be used long after graduation? In this paper, we argue that fostering curiosity among students can develop a natural inclination for lifelong learning. By genuinely interesting students in understanding how engineering components work, they will be intrinsically motivated to continue learning throughout their careers. Our approach to address this challenge was to explicitly teach the value of curiosity and develop techniques to increase it.

This paper describes a senior-level mechanical engineering design class that incorporated activities to foster curiosity. One such technique was mechanical dissection, where students took components apart to gain a deeper understanding of how they function. [Sheppard, 1992]. Additionally, students were challenged to uncover hidden phenomena in the hardware they were working with. The lectures and assignments emphasized the value of curiosity. To measure the effectiveness of these techniques, student surveys were conducted at the beginning and after the completion of a key deliverable.

Background

According to Evans et al. [2022], curiosity occurs when students encounter uncertainty and seek to close a knowledge gap, which can lead to deep and meaningful learning [Jirout et al. 2018]. Curiosity supports lifelong learning, one of the most desirable outcomes of higher education, by its role as an intrinsic reward [Kang et al. 2009], which is essential if we wish students to engage in life-long learning after graduation. Curiosity and conscientiousness have been shown to be correlated with student success [Leslie 2014]. Curiosity has also been linked with workplace learning and job performance [Reio et al. 2000].

The Kern Entrepreneurial Engineering Network (KEEN) has developed a framework for promoting an entrepreneurial mindset, which includes three core factors: curiosity, connections, and creating value [KEEN 2015]. Many KEEN-affiliated programs have implemented courses to promote an entrepreneurial mindset [Caplan et al. 2017; Estell et al., 2016; Gorlewicz 2020, LeMasney et al. 2020; Prince 2016; Vigeant et al.]. These courses value curiosity as one of the components of an entrepreneurial mindset, but the primary emphasis is not on increasing curiosity are it relates to engineering. The KEEN-affiliated programs typically teach in the context of working on real-world design projects, which is resources intensive and often limited to 1 or 2 such course in an undergraduate engineering curriculum.

In this paper, the authors aim to develop methods for teaching curiosity in more traditional lab setting, where all students can work on the same prescribed assignments. These curiosity building activities are implemented before student tackle their 15 week real-world capstone design project. Accordingly, the ultimate objectives of the KEEN affiliated programs of developing curiosity and an entrepreneurial mindset are similar to the objectives of the authors of this paper. However, the approach presented here is to explicitly develop curiosity before more open-ended real-world projects, in a “walk before you run” paradigm. Furthermore, the approach presented in this paper, in which all students work on the same lab and design assignments, is efficient to teach to a large number of students.

Methods

<u>Course and Project Structure</u>

The Mechanical Engineering senior design course, MAE 156A&B, at University of California at San Diego (UCSD) is taught in a 2-quarter sequence. During the first six weeks of the sequence, students work in pairs (with some groups of 3) on a mechatronic project that emphasizes applying dynamics modeling to predict hardware performance. Afterwards students work in teams of 4 or 5 on a capstone design project with sponsors from industry, the medical school, engineering faculty, and the community. This study was conducted during the mechatronics project in the first five weeks of the sequence, where emphasis was placed on curiosity in lecture and lab activities. The study took place during the winter quarter of 2023 with 131 students enrolled in the course. A survey was conducted at the beginning of the class and at week 5, which will be discussed in the Results section.

The first 5 weeks of the class were based on a mechatronics project where students connected an Arduino to a motor driver which was used to spin an acrylic flywheel as shown in Figure 1. The motor had a 4.4:1 gearbox and an encoder on its shaft. The flywheel had holes near its outer edge where bolts and nuts could be placed to increase the weight and inertia of the flywheel. A series of assignments and labs were conducted where students developed a theoretical model of the system dynamics including motor dynamics, the effect of the gearbox, and Coulomb friction in the gearbox which increased as a function of the weight of the flywheel. Students plotted motor velocity as a function of time and identified the rise-time and terminal velocity of the system.

A culminating assignment was the Modeling Challenge, where students used theory and prior experimental results to predict performance of a new configuration. Each student group was given a random number of bolts and nuts (all symmetrically arranged) to place on the outer edge of their flywheel, and a random Pulse Width Modulation (PWM) level between 50%-100%. The students had to turn in their predicted rise time and terminal velocity, and then conduct a test run to measure their hardware performance with this configuration. The assignment grade was based 50% on a written report, and 50% on a metric of how closely the students predicted the rise time and terminal velocity. Accordingly, students were highly motivated to predict the performance of their setup as closely as possible.

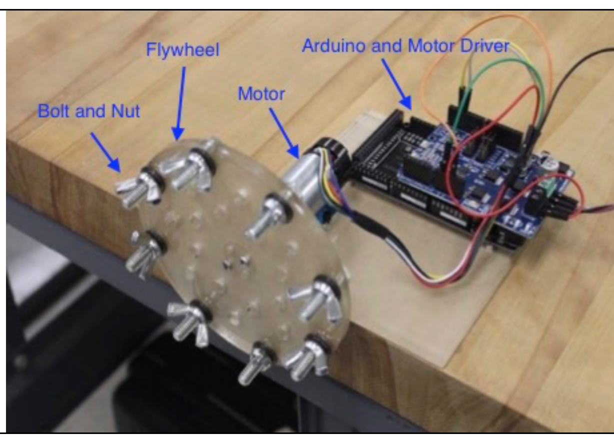
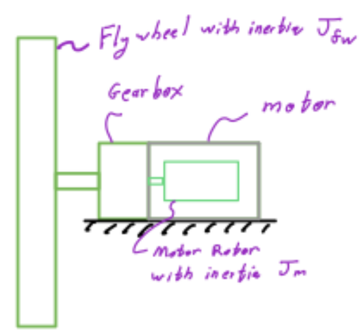


Photo of Flywheel Setup



Sideview of Flywheel Setup

Figure 1: Modeling Challenge Configuration for First Preparatory Project

A key educational objective of the Modeling Challenge was to emphasize to students the benefit of applying engineering theory to machine design. Accordingly, we wanted the hardware objective to be formulated to reward effective use of theory, and that a significant portion of the project grade to be based on hardware performance. In a prior iteration of this lab [Delson et al. 2012] students were given an optimization challenge where they competed to achieve a specific performance metric on a given task. However, using the optimization results for grading purposes became problematic, since there are manufacturing variations between motors resulting in differences in no load speed and stall torque, and coming up with a well formulated optimization challenge each quarter was difficult. To address these issues a switch was made to the Modeling Challenge where all students were on equal playing field since their objective was to predict the performance of their setup as accurately as possible which does not penalize a group even if their specific motor was slightly slower due to manufacturing variations. Many mechatronic projects in the classroom encourage students to utilize a wide range of moving parts, but these can be difficult to theoretically model precisely in the class time given. Accordingly, we selected a single Degree OF Freedom (DOF) that we could model form fundamentals. We covered the physics of DC motors, and had the students derive the effect of a gear ratio on the effective inertia and effective friction of the system. Student generated theoretical plots of the motor speed for a step response at various PWM levels. We used both a closed-form solution that showed the exponential rise of motor velocity, and a numerical solution to the system Ordinary Differential Equation (ODE) which allowed for non-linear effects to be modeled.

During the summer before the first time this assignment was offered, the authors of this paper ran the setup to prepare for the class. During this preparation, they noticed that there was an error of up to a 10% between theoretical predication and hardware performance in the terminal velocity of the motor. While a 10% error may seem small, it bothered the authors to the point where we delved into its cause for close to a week. We found that the error in terminal velocity correlated to velocity squared of the flywheel. We hypothesized that the reason was aerodynamic drag, and then confirmed this by operating the system with a flywheel of similar mass properties but a streamlined shape. Upon reflection, we realized that a key educational goal was for to elicit a similar level of curiosity and for them to engage in inquisitive discovery. In winter 2023 we identified curiosity as an explicit educational objective of the class and structured the course material accordingly. We felt that imparting a sense of curiosity and investigation would be of more benefit to the students than developing an additional mechatronic skills, as they embark on their capstone projects and ultimately their career.

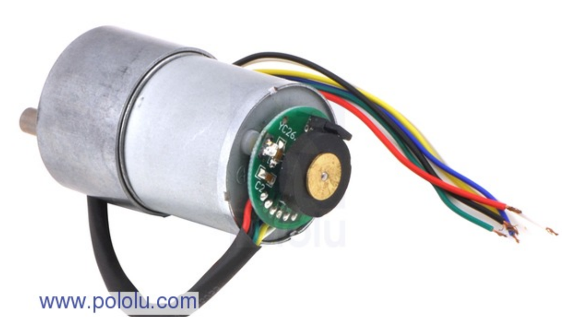
Developing Curiosity

Curiosity was encouraged in the class in lectures, mechanical dissection exercises, and curiosity challenges. In the first lecture of the class the example of the discovery of Teflon by Roy J. Plunket [Roberts 1989] was discussed in which Plunket inquisitively cut open a gas cylinder that did not release gas to find out the reason why. To emphasize the importance of understating underlying operational principles of devices, the example of piezoelectric pumps was presented as an example of technological innovation in one area, piezoelectric membranes, impacted technology in other areas, pumps. Then students were assigned a task where they had to identify an area of technological advancement which impacted technology in another area and describe the fundamental physics behind the advancement. This exercise was meant to reinforce the message that staying abreast of technology development was key regardless of the area one works in.

Mechanical dissection is an educational technique where students take apart devices to learn how they work [Sheppard, 1992]. Students were tasked with dissecting the gearbox attached to the motor. They had to determine the gear ratio, and also identify the contact points that contributed to friction within the gearbox. They were able to see that a radial load on the gearbox output shaft created contact at a bronze bushing, and they used this information to draw the Free Body Diagrams of the output shaft under radial load. Note that students worked in pairs, so that at least one gearbox was intact for flywheel operation in the case that one of the gearboxes was not reassembled correctly.

In a mechatronics lab session students used both a rotary potentiometer and an encoder to measure rotational position. Students were tasked with identifying the pros and cons of these 2 sensors from observation. The potentiometer was also dissected, and students could see how a wiper rubbed on a resistive element during rotation (Figure 2A). The general operation of an optical incremental encoder was presented in a slide to the students, but the encoder the students had happened to be magnetic. We used this fact to create a curiosity challenge. The housing was removed from one of the encoders (Figure 2B), and the output was connected to an oscilloscope. Students were challenged to figure out how the encoder worked, since they could see that there was no slotted disk for optical operation in the encoder. We had given the students small permanent magnetics in their parts kits but did not let them know that they were associated with this lab, and students were challenged to use their resources to discover how the encoder worked. Indeed, some students did figure out that swiping a magnet by the encoder pickup led to blips on the oscilloscope.

2A: Dissected Potentiometer



2B: Encoder With Housing Removed

Figure 2: Potentiometer and Encoder Components

We asked the students to write up their perceived pros and cons of potentiometers vs encoders. Later in the lab session, we disclosed that a key advantage of the encoder is that it is a non-contact sensor, so that no wear occurs and there is very little friction in the encoder. We had the students review specification (spec.) sheets of the sensors. In prior implementations of this class, we have found that students often have difficulty in properly interpreting values from spec. sheets. Common student mistakes in interpreting spec. sheets were due to lack of understanding of the fundamental way the component worked and could manifest itself in not understanding the significance of the value being a maximum or minimum specification. For example, a portion of a spec. sheet from a potentiometer is shown in Figure 3. There are 2 values with units of oz-on, Torque and Stop Strength. Some observant students may notice that Torque is listed as "max" and Stop Strength as "min," but when we asked students why this is the case they typically do not know. However, once the students dissected the potentiometer and saw the wiper pressed against the resistive element when sliding, and then seeing a rotating part hit a stop, they could better interpret the specs. The students understood that minimum Stop Strength is an indication of how strong the stop is to prevent over rotation, the higher the better. On the other hand, the maximum torque is the mechanical resistance to rotation, the lower the better. Another example of understanding spec sheets can be seen in that there is a Rotational Life spec. for the potentiometer, while there is no life rating on the encoder sheet because there is essentially no wear. A student could be baffled why the encoder life rating is not on its spec. sheet if they do not understand the physics of encoder operation. As educators, it is important to remember that encouraging students to use spec. sheets, but not requiring that they learn how a component works, can lead to poor level of understanding of component operation and poor decision making. Overall, by seeing the dissected potentiometer, students were better able to interpret the specification sheet.

Physical Characteristics

Mechanical Angle .... 310 ° nom.
Torque.............................. 5.0 oz-in. max.
Stop Strength................ 15.0 oz -in. min.

Figure 3. Portion of Potentiometer Spec. Sheet from the Borns Website

The largest curiosity challenge was the discovery of aerodynamic drag being a factor in predicting terminal velocity of the flywheel. We covered motor dynamics in lecture and derived how the expediential curve of the motor velocity asymptotically approaches the terminal velocity. The students modeled the motor velocity rise using the closed-form exponential equation and also coded a numerical solution of the motor's ODE so that they were prepared to incorporate non-linear effects. We had the students measure the terminal velocity for a configuration with bolts and regular nuts, and then a second configuration with bolts and wingnuts. In both configurations the weight and rotational inertia of the flywheels were the same. The only difference was the drag which depended on the orientation of the wingnuts (which the students were not told). Students were challenged to discover why the terminal velocity for the 2 configurations was different, and some figured out that if they aligned their wingnuts tangential to the flywheel circumference then the terminal velocity was about 10% faster at peak PWM levels than if the wingnuts were aligned normal to the circumference.

Results

At the beginning of the class, a pre-survey was conducted. Then again in week 5, which was after the Modeling Challenge, a post survey was conducted. Of the 131 students in the class, 2 choose not to have their data used as part of this study. Another 9 students did not complete either the pre or post survey, leaving 120 students with data to analyze. The data was deidentified by the Jacobs School of Engineering Data Analytics and Reporting group, and demographic and GPA information was added. Some of this added data was incomplete, so in some tables the total number of students are slightly less than 120.

The pre-survey included a question asking about prior experience with mechanical dissection in the form of "Have you ever taken something (mechanical or electronic device, appliance, clock, etc.) apart to fix it or learn how it works?" The result of this pre-survey question is shown in Table 1, along with the 4 answer options ranging from 0 to over 10. Table 1 also shows the midterm grade and the cumulative GPA of the students. The midterm focused on questions related to the theory used in the labs and assignments. As seen in Table 1, the percentage of students in the class was mostly uniformly split in terms of mechanical dissection experience (group size ranging from 21% to 29%) and many students had experience with taking devices apart, but 22% had no experience with this activity. The first 3 groups showed a steadily increasing midterm grade as the experience with mechanical dissection increased (midterm grade increasing from 69% to 84%). Interestingly the group that took apart more than 10 items had a dip in midterm grade and GPA. One interpretation may be that this group of students preferred hands-on work to the exclusion of theory, but this is pure speculation.

Table 1: Pre-Survey and Student Performance

Pre-Survey: How many items taken apart?	Percentage in Class (n=112)	Midterm Grade	GPA
0	22%	69%	3.37
1 to 3	28%	77%	3.57
4 to 10	21%	84%	3.53
Greater than 10	29%	75%	3.30
	Average	76%	3.44

Table 2 shows the demographic breakdown as a function of mechanical dissection experience. As a pre-survey question, this data is not a reflection of any educational gains in the class, but it does show interesting data. More than twice as many students from Under-Represented Minorities (URMs), 40%, had not taken anything apart prior to the class compared to non-URMs, 18%. In terms of gender, 30% of female students compared to 20% of the male students had not taken any objects apart prior to the class. The difference in gender is even more pronounced in the group that dissected more than 10 items, with only 10% of the females in this group and 36% of the males in this group. There were no large differences based upon First Generation status. Since there is a positive educational benefit associated with mechanical dissection experience [[Sheppard, 1992], the lower level of experience of URM and female students should be noted.

Table 2. Demographic Breakdown of Mechanical Dissection Experience in Pre-Survey

Categorized by Pre-Survey Question: How many items taken apart?	Gender		Minority Status		First Generation	
	Male (80)	Female (30)	Non-URM (92)	URM (20)	Not 1st Gen. (73)	First Gen. (34)
0	20%	30%	18%	40%	21%	29%
1 to 3	20%	50%	30%	15%	33%	21%
4 to 10	24%	10%	18%	30%	19%	26%
Greater than 10	36%	10%	33%	15%	27%	24%

The post-survey included 3 multiple choice questions about interest and inclination due to the mechatronics project. These questions with a 5-point Likert scale were:

- How inclined are you to take things apart, since completing the Mechatronics Project?
- How interested are you in the physics of how things work, since completing the Mechatronics Project?
- Did the modeling challenge to predict the rise time and terminal velocity increase your interest in using theory in engineering design?

The results of these post-survey are shown in Table 3. For each of the questions the left column shows the highest level of effect ("Much more inclined" or "Very much increased"), and the right column shows the total percentage of students that had a positive effect, i.e. includes that that indicated a "Somewhat more inclined" and "Somewhat increased" in addition to the students who indicated "Much more" or "Very much increased".

Table 3. Post Survey Multiple-Choice Results

Categorized by Pre-Survey Question: How many items taken apart?	Post-Survey: How inclined are you to take things apart?		Post-Survey: How interested are you in the physics of how things work?		Post Survey: Interest in using theory in engineering design?	
	Much more inclined	Somewhat OR Much more inclined	Much more inclined	Somewhat OR Much more inclined	Very much increased	Somewhat OR Very much increased
0	16%	76%	24%	80%	44%	76%
1 to 3	35%	87%	45%	90%	61%	90%
4 to 10	30%	74%	26%	78%	35%	83%
Greater than 10 times	27%	67%	30%	67%	33%	82%
Average	27%	76%	31%	79%	43%	83%

As seen in Table 3, the students indicated a significant effect of the mechatronics project with the curiosity building activities. The survey showed that after the class exercises, on average 83% of the students were somewhat or much more interested in using theory in engineering design, 79% were somewhat or much more interested in understanding the physics of how things work, and 76% of the students were somewhat or much more inclined to take things apart. Of especially high impact was interest in using theory in engineering design among the group that had dissection experience with 1 to 3 items; 61% of this group indicated that their interest "Very much increased" and combined with "Somewhat increased" raised this group to 90%.

There were 2 hidden factors in the mechatronic project. One was that the encoder was magnetic rather than the typical optical type, and the other was that aerodynamic drag is a factor in flywheel velocity. It should be noted that aerodynamics is typically neglected in robotic projects. Even “high speed” pick and place robots never truly reach high sustained speeds even though they have high acceleration, start-and-stop motion. Accordingly, this factor was truly hidden even to students with prior experience in mechatronics. Table 4 shows the percentage of students who discovered the hidden challenge of the encoder being magnetic, and when this discovery occurred.

Table 4. Discovery of the Hidden with Magnetic Encoder Challenge

Where you able to figure out that the encoder was triggered by a magnet, either during Lab 1 or afterwards?	**Students**	**Percentage**
No, I was not aware of this until this survey	1	0.8%
I only became aware when it was announced in lecture	20	16.7%
Yes, I figured it out with help of others	17	14.2%
Yes, I figured it out with my help from my lab partner	41	34.2%
Yes, I figured it out by myself	42	35.0%

As seen in Table 4, 35% of the students discovered the magnetic encoder challenge on their own, and an additional 48% discovered the challenge with the help from their lab partner or other students. In total 83% of the students figured out the hidden challenge by themselves or with the help of a classmate. This is an indication that the challenge was difficult enough to promote engagement to figure it out, but also that most students were able to do so.

Table 5 shows selected students’ comments regarding the “Comment on the educational experience and value of the magnetic encoder discovery exercise.” As seen, students valued the educational experience and especially the self-discovery process.

Table 5. Student Comments on the Magnetic Encoder Discovery Exercise

- The experience was very [educational] and it helped me to understand encoders significantly more than I had previously
- It [was] interesting and fun to fiddle with the components and make discoveries on my own.
- Pretty cool when you find it yourself.
- It was very interesting. I looked at the deconstructed motor and noticed that there were no holes in the encoder and that the reader was not in contact with the encoder disk, this helped make it pretty clear that something invisible was going on, and magnets were a quick guess.
- I was able to understand how the mechanism properly works and how clever engineers can be, inspiring me.
- It was a good exercise in being allowed to be creative and explorative in the MAE curriculum, something that isn't really fostered in other classes.
- Great critical thinking skills
- Very valuable! It was enjoyable to discover that on my own. The fact that I went through the motions of moving the magnet around the motor housing and actively saw the output on the serial monitor fluctuate was an experience that I will likely remember down the line. Much better than reading said outcome on a lab worksheet.
- We learned how it works by trying it out ourselves, not just by being told
- it was really fun, it makes us think and use the tools around us to find out the mechanisms of certain components. not a lot of people do that nowadays because of how easily we have access to the internet.

Table 6 shows the percentage of students who discovered that aerodynamic drag cannot be neglected in modeling the flywheel motion.

Table 6. Success with Aerodynamic Drag Challenge

Where you able to figure out that the bolts on the flywheel generated aerodynamic drag , either during Lab 2 or afterwards?	Students	Percentage
No, I was not aware of this until this survey	0	0.0%
I only became aware when it was announced in lecture	21	17.5%
Yes, I figured it out with help of others	15	12.5%
Yes, I figured it out with my help from my lab partner	28	23.3%
Yes, I figured it out by myself	56	46.7%

As seen in Table 6, 47% of the students discovered the aerodynamic drag factor on their own, and an additional 36% completed the challenge with the help from their lab partner or other students. Below in Table 7 are selected students' comments regarding the "Comment of the educational experience and value of the aerodynamic discovery exercise." Again, it is seen that students valued the self-discovery process. Interestingly, even those students that did not discover the aerodynamic drag factor until it was presented in lecture still seemed to learn and committed to be more investigative in the future.

Table 7. Student Comments on the Aerodynamic Discovery Exercise

- Very interesting, it was surprised that aero drag can have such a big effect on the fly wheel when we found out conducting a test
- Not noticing this until lecture made me realize I need to slow down and take in everything when working on a project
- I noticed that the velocity of the flywheel was lower with the wingnuts than the bolts but I did not take the time to mull over the possible reason why like I had with the encoder challenge. I think it takes time to think about the reasons for why something works a certain way.
- I always understood causes of aerodynamic drag, but finally being able to visualize it is what made the biggest difference for me because online learning took that from most students. Being able to see the data and visualize the effects bolts and nuts had on its overall velocity and rise time was very interesting.
- Like the magnet discovery, this was another point where it was nice that we were given time to figure it out ourselves and that creativity was encouraged. Asking that question "design a test to validate this" really helped us contextualize the question.
- Good exercise in making simplified aerodynamic load models. Also helped that it made the system non-linear and made analysis more in-depth
- This was beneficial educationally. It required critical thinking as well as practical experimentation to test our own hypothesis. I thought it was beneficial not to just give the answer away here, because in the discovery, I was also able to come up with a test method almost immediately.

Discussion

Recognizing the need for lifelong learning is an explicit goal of ABET. However, to motivate students to engage in lifelong learning years after graduation, it is postulated that internal motivation is required. The paper introduces an approach that leverages curiosity to inspire lifelong learning, and specifically focuses on implementing this approach in a senior design course. The curriculum includes lectures that highlight the benefits of curiosity, laboratory activities that involve discovering hidden factors, and mechanical dissection exercises.

Following the course, a post-survey showed that a large majority of the students indicated an increased interest in applying engineering theory (83%), understanding the physics of how components work (79%), and in taking them apart in the future (76%). The student comments depict meaningful engagement and value of the challenges and discovery that occurred.

The pre-survey measured student experience prior to the class, and thus is not a measure unto itself of the impact of the course. However, it does identify useful datapoints especially on demographic differences, which could be used to address gaps in experience, especially among URMs and female students. More than twice as many students from Under-Represented Minorities (URMs) had not taken anything apart prior to the class; 40% for URM students vs 18% for non-URM students. In terms of gender, 30% of female students compared to 20% of the male students had not taken any objects apart prior to the class.

The hidden discovery challenges showed that the activity had an appropriate level of difficulty where only 35% of the students discovered the hidden phenomenon on their own, but overall, 83% did discover the phenomenon with help from other students. Survey comments and survey results indicated that in the course, students developed an increased interest in taking components apart and learning how they work, which indicates an increased intrinsic motivation for lifelong learning. Overall, the findings suggest that the approach used in the course was effective in promoting intrinsic motivation for lifelong learning.

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