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Fun Friday: Assessing the effectiveness of weekly real-world applications in introductory dynamics lectures

Dr. Thomas Golecki, University of Illinois at Urbana - Champaign

I spent 10+ years in industry as an engineer in structural mechanics and structural health monitoring projects, earning professional licensure as PE and SE. My PhD research focused on the structural optimization of dynamic systems including random loading and vehicle-bridge interaction. Now as teaching faculty, I try to connect course concepts to real-world examples in a way that motivates and engages students.

Mikayla R Hoyle, University of Illinois at Urbana - Champaign

Mikayla R. Hoyle is a PhD student in the Dept. of Mechanical Sciences and Engineering at the University of illinois Urbana-Champaign (UofI) with interests in bone biomechanics. She holds a B.S. in Mechanical Engineering from the University of Kansas. For the past three years, she as been a part of the Strategic Instructional Innovations Program (SIIP) team in the Mechanical Science and Engineering Department at UofI, contributing to advancing undergraduate engineering education.

Melany Denise Opolz, University of Illinois at Urbana - Champaign

Melany D. Opolz is a PhD student in the Department of Chemical Engineering at the University of Illinois Urbana-Champaign, specializing in equine biomechanics and bone chemistry. She holds a bachelor's degree in Chemistry from Cameron University and a Master of Science in Chemical Engineering from the University of Illinois Urbana-Champaign. For the past two years, she has been a part of the Strategic Instructional Innovations Program (SIIP) team in the Mechanical Science and Engineering Department at the University of Illinois Urbana-Champaign, contributing to educational advancements in engineering.

Jean-Christophe Raymond-Bertrand, University of Illinois at Urbana - Champaign

Jean-Christophe Raymond-Bertrand is an undergraduate student in Industrial Engineering at the University of Illinois Urbana-Champaign, and rising doctoral student at Virginia Tech. His interests are in Operations Research, specifically optimization under uncertainty and Markov decision processes. His current research uses Network Theory and Mixed Integer-Linear Programming (MILP) to determine unintended disparities in the impact of automated traffic law-enforcement on different groups in the city of Chicago.

Nikhil Chandra Admal, University of Illinois Urbana-Champaign

Dr. Admal is a professor of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign. He holds a Ph.D. in Aerospace Engineering and Mechanics and a Master's in Mathematics from the University of Minnesota, Minneapolis. His research focuses on multiscale modeling of materials, particularly the mechanics of defects. Dr. Admal has published over 20 papers in peer-reviewed journals. He is actively involved in engineering education, especially in incorporating real-world examples into existing undergraduate courses in Solid Mechanics and in creating connections between different courses.

Wayne L Chang, University of Illinois Urbana-Champaign

Dr. Wayne Chang is an assistant teaching professor in the Aerospace Engineering Department at the University of Illinois at Urbana-Champaign. He received his BS, MS, and Ph.D. in Mechanical and Aerospace Engineering from the University of California, Irvine.

Dr. Kellie M Halloran, University of Illinois Urbana-Champaign

Kellie Halloran is a Teaching Assistant Professor in Mechanical Science and Engineering at the University of Illinois Urbana-Champaign. She holds a BS, MS, and PhD in Mechanical Engineering from the University of Illinois and is currently investigating ways to engage undergraduate students and encourage curiosity and creativity in larger engineering classes.

Callan Luetkemeyer, University of Illinois at Urbana - Champaign

Callan Luetkemeyer is an Assistant Professor of Mechanical Science and Engineering at the University of Illinois Urbana-Champaign. She received her MS and PhD in Mechanical Engineering from the University of Michigan in 2020 following a BS in Biomedical Engineering from Saint Louis University. From 2020 to 2022, she was a postdoctoral fellow at the University of Colorado Boulder. She began her tenure-track faculty appointment at UIUC in 2023, where she teaches courses on solid mechanics and conducts research combining nonlinear solid mechanics, imaging, and extracellular matrix biology. In 2020, she received several research awards, including the Schmidt Science Fellowship, the Savio LY Woo Young Researcher Award, and the Ivor K. McIvor Award for Excellence in Applied Mechanics Research. In 2024, she was included in the "List of Teachers Ranked as Excellent by Their Students" at UIUC.

Dr. Brian Mercer, University of Illinois at Urbana - Champaign

Brian Mercer is a Lecturer in the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. He earned his Ph.D. from the University of California, Berkeley, in 2016 and subsequently worked as a research engineer at the Illinois Applied Research Institute before turning to a career in teaching and education in 2018. His technical expertise lies in computational and theoretical solid mechanics, and he teaches a range of courses in these topics, including introductory solid mechanics, machine component design, computational mechanics, and finite element analysis. Brian's pedagogical research efforts focus on developing and implementing effective teaching strategies for large lecture courses and increasing student literacy in using computational tools such as Python and to aid in performing calculations and simulations relevant to engineers.

Prof. Matthew West, University of Illinois Urbana-Champaign

Matthew West is an Associate Professor in the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. Prior to joining Illinois he was on the faculties of the Department of Aeronautics and Astronautics at Stanfo

Prof. Mariana Kersh, University of Illinois at Urbana-Champaign

Mariana Kersh is an Associate Professor in the Department of Mechanical Science and Engineering at The University of Illinois at Urbana-Champaign, Health Innovation Professor in the Carle-Illinois College of Medicine, and Director of the Tissue Biomechanics Laboratory. She also serves as co-chair of the Integrative Imaging Theme of the Beckman Institute for Advanced Science and Technology. Her research focuses on the use of experimental and computational methods to evaluate the interdependence of mechanical, compositional, structural properties of bone, ligament, and tendon to investigate the progression and treatment of musculoskeletal diseases. Her work has been funded by NSF, NIH, and industry/foundation sponsors. She has received awards from the US and Australian Orthopedic Research Societies and the Beckman Foundation in recognition of her scholarship.

Fun Friday: Assessing the effectiveness of weekly real-world applications in introductory dynamics lectures

Abstract

Given the math-intensive and computational nature of introductory dynamics, many concepts are presented with simple examples where applications have been abstracted away for the sake of clarity. While this approach achieves clarity, it lacks connection to the real world and does not communicate the true value of the content. In this work, we present the results of a study aimed at improving students' impression of the value of the course content by highlighting real-world applications of introductory dynamics topics. This study was conducted in a large 2-section course, where each lecture section consists of approximately 200 students in various engineering majors, with 50-minute lectures on Mondays, Wednesdays, and Fridays. One section received traditional instruction, while the other section spent a portion of class time (10-15 minutes) each Friday discussing real-world applications of the course content. The sections were surveyed at the beginning and end of the semester to assess their impressions of (1) their curiosity about the material, (2) the connections to real-world applications and (3) the value created by the course content. These three themes were selected around the "3C's" of the Kern Entrepreneurial Engineering Network (KEEN) entrepreneurial mindset (Curiosity, Connection, Creating Value). The survey included both quantitative responses on a Likert scale and qualitative, open-ended responses. The survey results showed that the intervention increased students' perceptions of the value of the course material while showing little change in their curiosity or recognition of connections to their fields. Qualitatively, students responded positively to the focus on applications, dubbing these days "Fun Fridays".

Introduction

The benefits of real-world context in engineering education have been established [1, 2, 3, 4]. Contextualized problems can help to enable engagement and increase student motivation. However, the time and effort of instructor preparation required to change course modalities from deductive to inductive (such as problem-based learning) can be a significant obstacle to implementing real-world examples of course content. This work offers an approach to incorporating real-world examples without overhauling a traditional course organization.

Introductory dynamics is a necessary prerequisite for many engineering disciplines. As such, it is often presented in generalized conceptual, or 'toy' examples disconnected from practical applications. As a result, the course can feel like a series of equations to remember. This feeling was expressed by a student in anonymous course feedback from a prior semester as

> *I would very much appreciate if ... we went over the main topic that we are learning and how it is used in application so that we can better understand why we are learning what we are learning.*

In a recent offering of this course, we aimed to build a sense of ownership and intuitive understanding of the relationships implied in the equations being discussed. The main idea is to take an equation used in class and show how it relates to real-world situations. We hypothesize that by relating the equation to a real-world example, the value of the course content is more readily apparent to students. Here the inclusion of multiple real-world example problems is evaluated via student surveys before and after the semester. The survey ask students to evaluate statements reflecting how well the course achieved the 3C's of the KEEN framework: Curiosity, Connections, and Creating Value [5].

Methods

This study was conducted a large public Midwestern university. The Spring 2024 Introductory Dynamics course consists of two lecture sections of 254 and 206 students each taught by different instructors, along with 18 discussion sections of approximately 26 students each. Lectures are three 50-minute sessions on Monday, Wednesday, and Friday. Student attendance in their registered lecture section was incentivized with a small participation credit for responding to real-time lecture polls. Discussion sections meet once per week for 50 minutes, and are not separated by lecture, that is, students in a discussion section may be enrolled in either lecture section. The course has a common set of homework assignments, quizzes, and exams that are used by both sections. This arrangement provides an opportunity to implement a change in one lecture section and evaluate its impact relative to other unchanged lecture section. The test and control sections were equivalent in terms of key demographic indicators and exam performance as shown in Table 1.They had no statistically significant differences in female percentage (two-proportion z-test: $p = 0.60$) or final exam mean (t-test: $p = 0.24$). The standardized mean difference in final exam scores is $d = 0.11$ standard deviations, which is a small effect size using the standard criteria. For this study, one lecture section (the "test" section) dedicated a portion (10-15 minutes) of each Friday lecture to discuss real-world applications of the dynamics principles covered in the course. The other lecture section (the "control" section) did not include this change. To understand the impact of this change, students were surveyed to assess their impressions of the course at the beginning and end of the semester.

Table 1: Demographics of Introductory Dynamics course.

Section	Number of Students	Percentage Female	Lecture Time	Instructor	Final Exam Average	Final Exam Stdev.
Control	206	23%	3 P.M.	A	68.6	17.0
Test	254	21%	2 P.M.	B	70.5	17.4

Real World Examples

The following sections present a subset of real-world scenarios where the concepts taught in Introductory Dynamics are clearly present. Because this course is required for students in multiple engineering departments (mechanical, aerospace, civil, systems etc.), the examples selected were intended to include a variety of disciplines while also being transparent, fundamental, and/or timely. In this context, **transparent** refers to the underlying dynamics principles being readily apparent. An explanation should not require a great deal of domain-specific knowledge for students to understand the connection. For instance, Example 1 discusses the dynamics of rolling motion in cars versus trains, but no special automotive or railroad knowledge is necessary. **Fundamental** refers to examples selected because the dynamic principle being discussed is necessary for function. Example 8 discusses a ship that capsized as a result of imbalanced loading. This imbalance is computed directly from the center of mass equation presented in class. In this example, the location of the center of mass determines the stability of the ship. Finally, **timely** applications are particularly useful to highlight as students can see both the public discussion in news stories and the technical background in class. Discussion of Example 3, the Fury 325 roller coaster which suffered a structural failure in the summer of 2023, includes news stories and videos dated only a few months prior to the course. While these three ideas guided the selection of examples, they were not specifically labeled as such when presented to students. The examples below show the type of real-world applications used, actual lecture content for each varied from annotated notes, slides, videos, etc. Some of these sparked significant discussion and conversation during lectures. The descriptions below of each example explain the relevance of the specific example, but does not necessarily include everything presented to or discussed with students.

Example 1: Rotational and Translational Velocity

The introduction to rotational motion includes the relationship in Equation 1 relating translational and rotational velocities, v and ω, by the radius r.

$$v = \omega r \tag{1}$$

This relationship is highlighted by comparing the turning mechanisms in cars vs trains. While traveling around a curve, the path of the wheels will be at different radii for the inner and outer wheels. Per Equation 1, this necessitates different velocities for the wheels to make a smooth turn. For cars with a continuous rear axle, a differential allows for different rotational speeds, ω, of each wheel to achieve different wheel velocities, v, required to make a smooth turn. In a train axle, however, there is no differential. If considering a single wheelset, the beveled wheels can shift laterally on the rails in a turn resulting in slightly different radii, r, for each wheel. Note the slight bevel on a typical train car wheelset shown in Figure 1. This difference in radii achieves different wheel velocities, v, for the same rotational speed ω required to make a smoother turn with a solid axle. For these two vehicles, different translational speeds v of the inner and outer wheels are achieved by modifying either the rotational speed ω or the wheel radius r in Equation 1. This example is nice in that it uses this equation in two ways, first to show that the velocities must be different for a vehicle going around a curve where r and ω refer to the road geometry and angular speed of the vehicle around the curve respectively, and second to show how this is achieved via wheel rotational speed and radii where r and ω are the wheel radius and rotational speed. In class, this example was presented with a whiteboard sketch of vehicle turning and wheel geometry. Note that the effect of beveled wheels is reduced considerably in parallel axle configurations, but this level of detail is beyond the scope of this example.

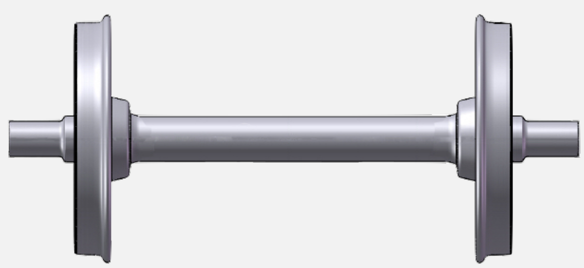


Figure 1: Typical Wheelset of rail car, note the beveled wheels result in different radii if the rail contact point shifts laterally. ('Rail vehicle wheelset' by *SCHolar44* is in the Public Domain, CC0.)

Example 2: Changing Between Basis Systems

The discussion of different basis systems (Cartesian, cylindrical, and spherical) includes Equation 2 which identifies the cylindrical basis vectors $\hat{e}_r, \hat{e}_\theta, \hat{e}_k$ in terms of the Cartesian basis vectors, $\hat{i}, \hat{j}, \hat{k}$ and a rotation angle θ.

$$
\begin{aligned}
\hat{e}_r &= \cos(\theta)\hat{i} + \sin(\theta)\hat{j} \\
\hat{e}_\theta &= -\sin(\theta)\hat{i} + \cos(\theta)\hat{j} \\
\hat{e}_k &= \hat{k}
\end{aligned} \tag{2}
$$

This relationship is used in the design and analysis of structures which utilize both cartesian and cylindrical coordinate systems. For example, the radio telescope shown in Figure 2 consists of two very different components. The primary reflector's function is dependent on its parabolic shape and is most easily determined using a cylindrical coordinate system that aligns with the pointing direction. However, a design or analysis of the base structure is most likely performed in Cartesian coordinates. For structures like this, it is essential to be able to transform coordinates into different basis systems. In many software analysis programs, multiple coordinate systems are available within an individual model, so when dealing with inputs or outputs it is important to know which system those values are provided in. In class, students were asked which coordinate system they would choose when designing these different components. Their different answers solidified the need for conversion between systems.

Figure 2: The Sardinia Radio Telescope in Sardinia, Italy ('At Sardinia Radio Telescope 2019 059' by *Mike Peel* is licensed under CC BY-SA 4.0.)

Example 3: Centripetal Acceleration in Polar Coordintes

The acceleration of a point in 2D space in the polar coordinate system is given by Equation 3. This relationship can be challenging as the centripetal and Coriolis acceleration terms can be difficult to conceptualize.

$$\vec{a} = (\ddot{r} - r\dot{\theta}^2)\hat{e}_r + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\hat{e}_\theta \tag{3}$$

Centripetal acceleration is the radially inward component resulting from rotational motion, this is the $-r\dot{\theta}^2$ term of Equation 3. Note that this acceleration is radially inward for any direction of $\dot{\theta}$. This acceleration is experienced by riders on a roller coaster, such as shown in Figure 3. This roller coaster made headlines in June 2023 after a park guest noticed a crack in one of the support columns. A video of this is available in an online article from the New York Times [6]. This video makes a dramatic introduction to this example in class. As the coaster travels around a curve in the track, this centripetal acceleration must be resisted by some reaction force. The support columns designed to resist the lateral reaction associated with the centripetal acceleration of the coaster failed. This allows for some questions to the students such as, 'Does that centripetal acceleration still exist if there is no longer a support column providing a reaction?' In this case, there was enough structural redundancy for that reaction to be carried by alternate load paths, i.e. the track structure and other support columns.

Figure 3: The roller coaster Fury 325, pictured here before a crack shut down operations. ('Fury 325' by *Martin Lewison* is licensed under CC BY-SA 2.0.)

Example 4: Coriolis Acceleration in Polar Coordinates

Coriolis acceleration, the $2\dot{r}\dot{\theta}$ term from Equation 3 is somewhat difficult to interpret as it requires both rotational and radial motion. Common explanations of Coriolis acceleration point out that this is why hurricanes in the northern hemisphere rotate counterclockwise and cyclones in the southern hemisphere rotate clockwise. In this class, a more mechanical application was desired. Students were shown two examples of components with both of these motions: the variable inertia flywheel by Zhang et al. [7] and the flywheel integrated into a turbine rotor by Hippel et. al. [8]. The first of these examples does not consider the Coriolis acceleration in their analysis. The second specifically considers the Coriolis acceleration due to a fluid moving along the length of wind turbine blades. They compute a tangential force in their equation 2 as fluid mass multiplied by two times the rotational and the radial velocities. This direct connection between the acceleration derived in class and its real-world implications is intended to help students see the use cases of this acceleration that they may not have been familiar with previously.

Example 5: Pendulum as a Simple Harmonic Oscillator

The discussion of particle kinetics includes an introduction to differential equations of motion. Students are presented with Equation 4 which shows the equation of motion of a simple pendulum linearized about its stable equilibrium point, $\theta = 0$ which corresponds to vertically downward.

$$\ddot{\theta} + c\dot{\theta} + \frac{g}{l}\theta = 0 \tag{4}$$

Here, $\dot{\theta}$ and $\ddot{\theta}$ are the rotational velocity and acceleration respectively, g is the gravitational constant, l is the pendulum length, and c is a viscous damping coefficient. Since students are likely familiar with a pendulum, the example selected here is meant to broaden their perspective of how dynamics can be used outside of mechanical engineering. This simple harmonic oscillator model has been used to quantify the severity of spasticity, a motor disorder that has been historically difficult to evaluate. In practice however, discrepancies in how measurements are taken led to confusion of results [9]. This example emphasizes the need for clear communication of fundamental decisions, such as the orientation of the angular reference frame.

Example 6: Rigid Body Velocity

After kinematics and kinetics of particles, the course transitions to rigid body dynamics. The combination of translational and rotational motion means that each point on a moving rigid body can experience a different total velocity as shown in Equation 5.

$$\vec{v}_Q = \vec{v}_P + \vec{\omega} \times \vec{r}_{PQ} \tag{5}$$

Here, the velocity vector at point Q, $\vec{v}_Q$, is defined as the sum of the velocity vector at point P, $\vec{v}_P$, and the cross product of the rotational speed, $\vec{\omega}$, and the vector from P to Q, $\vec{r}_{PQ}$. This relationship is particularly important to the flight of a boomerang, or a three-sided boomerang, sold commercially as an Aerobie Orbiter, shown in Figure 4, and passed around the classroom during this conversation. Each corner of this triangle has an airfoil profile. When it is thrown correctly, the combination of translation and rotation results in the leading edge experiencing high velocity, while the trailing edge experiences a relatively low velocity. This difference is what generates an eccentric lift force, which results in the gyroscopic precession that causes the orbiter to travel in a circular path, possibly even back to the location it was thrown from.

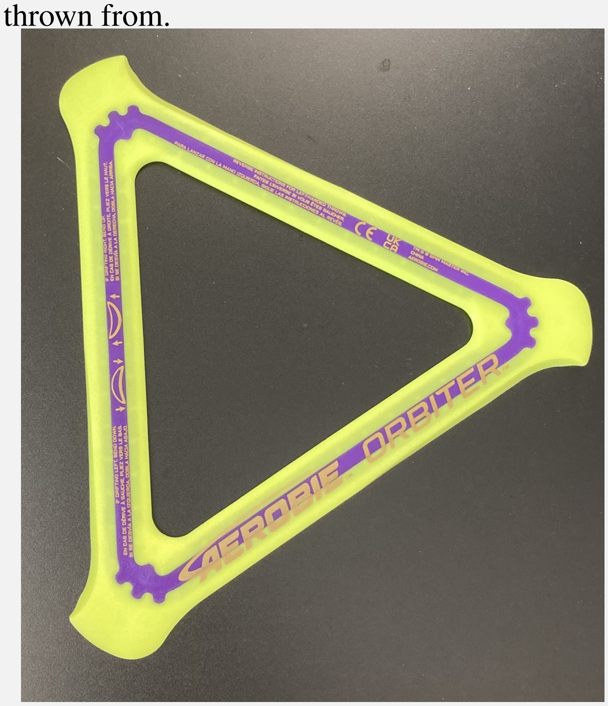


Figure 4: Aerobie Orbiter

Example 7: Rigid Body Acceleration

When discussing the kinetics of rigid bodies, the acceleration of some point Q on a rigid body is derived, and shown in Equation 6. Here the linear acceleration of point Q with respect to a known point P includes three components: the acceleration of point $\vec{a}_P$, the linear acceleration of Q resulting from the angular acceleration $\vec{\alpha}$, and the centripetal acceleration resulting from rotational velocity $\vec{\omega}$.

$$\vec{a}_Q = \vec{a}_P + \vec{\alpha} \times \vec{r}_{PQ} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{PQ}) \tag{6}$$

This combination of acceleration components can be applied to the motion of a train car. An idealized representation of a train car consists of a rigid car body connected to a spring and damper representing the suspension system between the car and each bogie (the rail truck which consists of two wheelsets), then another set of suspensions between each bogie and each wheel. This representation is used in Golecki et. al. [10] to represent the dynamics of a train car crossing a flexible bridge. In that work, the passenger comfort is evaluated using the vertical acceleration at the ends of the train car. Because the idealized train car is a rigid component, the accelerations experienced by a passenger can be represented with Equation 6. Passenger comfort when the passenger is located at the location of the center of mass of the train car can be estimated using vertical acceleration. However, the vertical acceleration experienced by a passenger seated away from the center needs to consider both vertical acceleration and rotational acceleration terms. The centripetal acceleration is radial, horizontal in this case, and is not considered in this evaluation of passenger comfort.

Example 8: Center of Mass

When moving from rigid body kinematics to rigid body kinetics, one topic discussed is the location of the center of mass. The center of mass location, $\vec{r}_C$ for a rigid body, $\mathcal{B}$, with density ρ is computed using Equation 7.

$$\vec{r}_C = \frac{1}{m}\int_{\mathcal{B}} \rho \vec{r} dV \tag{7}$$

The location of the center of mass has profound consequences for the stability of cargo ships. A cargo ship's stability is dependent on the height of the center of gravity of the ship including its cargo relative to the center of buoyancy. The buoyancy force can be idealized as a vertical force toward the center of the volume of water displaced by the hull of the ship. Under normal circumstances, stability is maintained by adjusting cargo distribution as well as ballast. However, in September 2019, an imbalance of loading and buoyancy contributed to the capsizing of the cargo ship MV Golden Ray in St. Simons Sound off the coast of Georgia, shown in Figure 5. An investigation on the cause pointed to inadequate ballast, i.e. the center of gravity of the ship was too high, leading to its instability [11]. The concept of center of mass can feel mundane, but this example shows how it can be a complicated and critical element of dynamics.

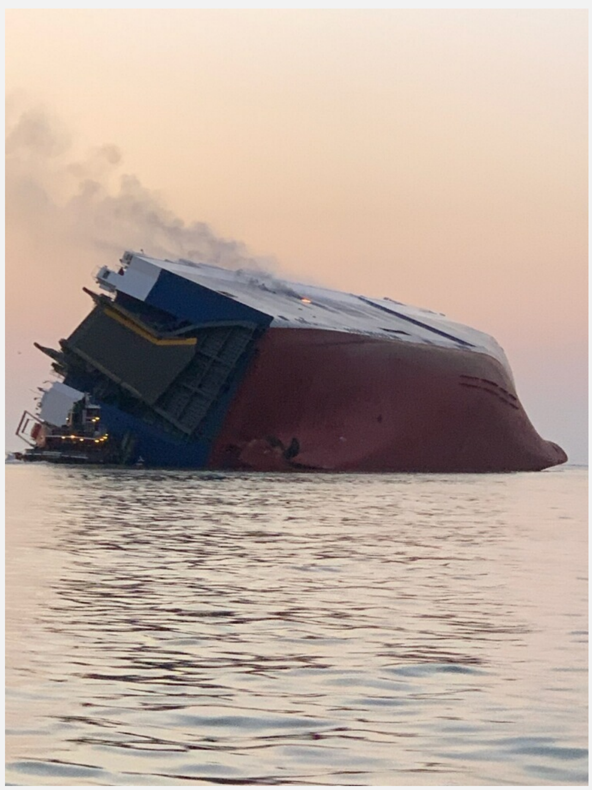


Figure 5: The capsized cargo ship MV Golden Ray (*'Golden Ray St. Simons Sound 2019'* by *U.S. Coast Guard* is in the Public Domain.)

Example 9: Kinetic Energy

One of the final topics of the semester is a discussion of kinetic energy, shown in Equation 8. This topic uses a wind turbine as a real-world example. To extract energy from the wind, the turbine must change its velocity, v. This requires the air on the downwind side of the turbine to be moving slower than on the upwind side. This also implies that not all of the kinetic energy can be extracted, since that would imply that the wind reduces to speed of zero. The actual amount of energy that can be extracted is limited to about 60% [12] as a result of considering the conservation of momentum. Actually achieving this is challenging, as the efficiency of the turbine is dependent on a number of design decisions. One attempt at improving turbine efficiency is shown in Figure 6, this turbine incorporates a shroud, which is intended to increase the amount of energy the turbine can extract from the wind.

$$T = \frac{1}{2}mv^2 \tag{8}$$

Figure 6: Shrouded wind turbine (*"New wind-lens turbine (2012 version)"* by *Tomon7* is licensed under CC BY-SA 3.0.)

Survey

Students in both lecture sections, referred to here as the control section and the test section, were surveyed at the beginning and end of the semester to assess their impressions of the course content. The beginning of the semester survey received 180 responses from 460 students. The end of semester survey received 283 responses, 124 from the control section and 159 from the test section. Quantitative responses were recorded on the Likert scale (from 1 - strongly disagree to 5 - strongly agree) in addition to qualitative, open-ended responses. The quantitative questions were designed to target the 3C's of the KEEN framework: **Curiosity**, **Connections**, and **Creating Value** [5]. Students were asked how strongly they agreed with the following statements and given options of strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

- Statement 1 - Creating Value: "I see how the content in this class helps engineers and scientists tackle major world challenges".
- Statement 2 - Connections: "Outside of class, I understand how course concepts connect to the design and engineering of everyday objects".
- Statement 3 - Curiosity: "The content in this class stimulates my curiosity about real-world problems".
- Statement 4 - Creating Future Value: "The content in this class will be helpful for my future career as an engineer".

The end-of-semester surveys included the open-ended questions:

- "What are the major strengths of the instructor/course?"
- "What do you suggest to improve the course?"

Results

The Likert scale survey results are summarized in Table 2. This table shows the percentage of agreement and disagreement with the four statements listed above. Results were compared using the t-test for the means of two independent samples. These samples are the responses at the beginning of the semester, and at the end of the semester for the control and test lecture sections. A statistically significant difference was observed for the test section and not the control section for the questions related to the value of the course content. These responses are shown in Figure 7 (a) and (b) for the two questions related to course value. Figure 7 (a) shows an increase in agreement of 15.5% for the test lecture compared to only 8% for the control lecture and a decrease in disagreement of 4.3% in the test section compared to an increase of 2.3% in the control section. Figure 7 (b) shows an increase in agreement of 9.9% for the test lecture compared to only 4.6% for the control lecture and a decrease in disagreement of 5.2% in the test section compared to 2.0% in the control section. Note that in both of these figures, the 'Agree' data is relatively high and the 'Disagree' data is relatively low at the beginning of the semester. This shows that a majority of students acknowledge the importance of the topic before taking the course. At the end of the semester, more students in the test section agree and fewer students in the test section disagree with these statements than in the control section. The responses to the other survey questions showed a similar trend from the beginning to the end of the semester in both sections.

Qualitative responses from students in the test section indicated that the weekly focus on real world examples was a significant benefit of the course. A selection of student responses about the application examples are shown below:

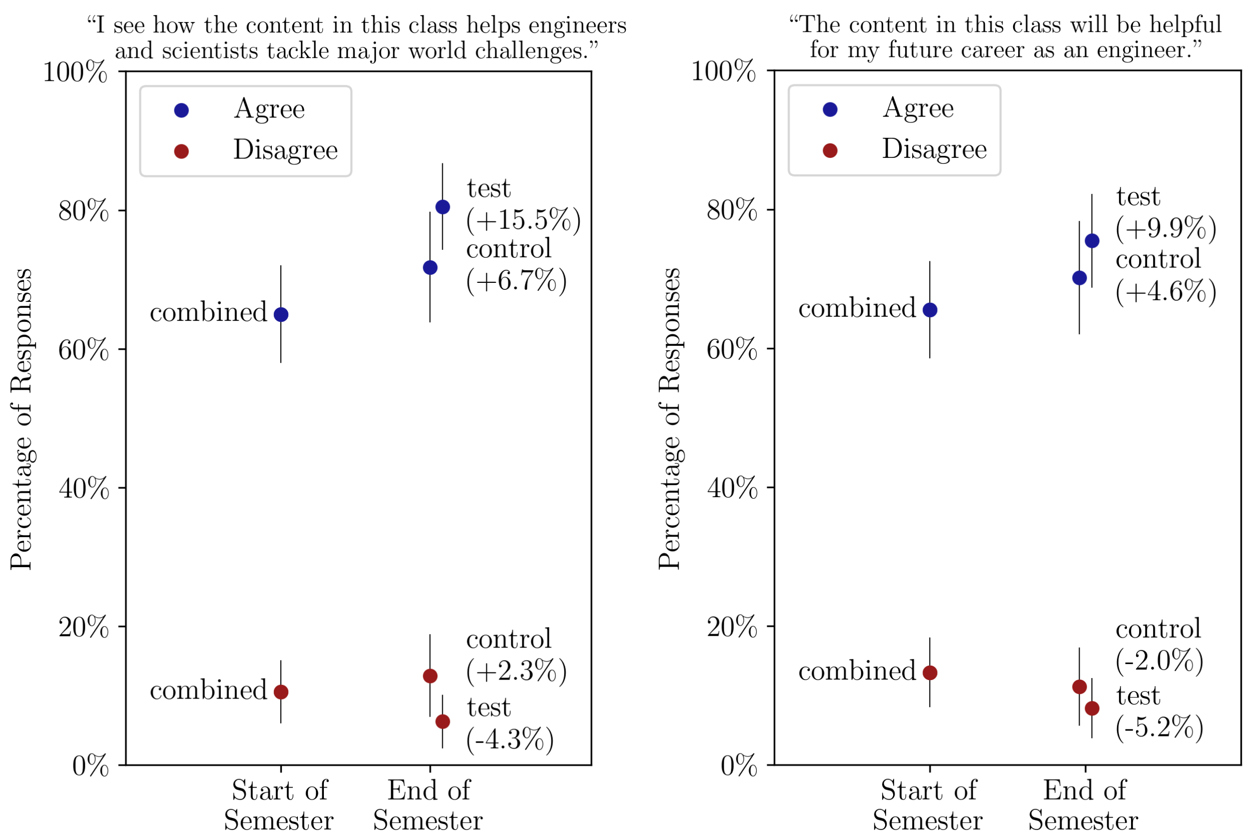
> *The applications presented were very engaging and useful. It was nice to see how the content related to the real world instead of just doing a few conceptual examples.*
>
> *I also appreciate the applications presented with almost every unit. It is nice to know that what we are learning actually means something more than algorithms and a grade.*
>
> *I really enjoy the fun Fridays, I think it helps relating the material back to real world situations.*

Discussion and Conclusions

In this work, we present the results of a study aimed at improving students' impression of the value of the course content by highlighting real-world applications of introductory dynamics topics. The Introduction to Dynamics course consisted of two lecture sections, one of which dedicated a portion of each Friday's lecture to real-world applications. Applications were selected across a range of engineering disciplines with the primary goal of demonstrating the value of topics covered in the course. Applications were selected where the course topic is readily apparent, necessary for function, or recently appearing in news media. Some examples of each of these were provided herein, along with a brief description of how the application relates to dynamics and how it was presented in class. Given that students in both the control and test lecture sections had the same course experiences outside of lectures (discussion sections, office hours, homework, quizzes, exams, reference web pages, online forum, etc.), the differences in survey results between the two sections are attributed to the differences in lectures. The only substantial difference in lectures other than the instructor was the inclusion of real-world examples about once a week. Given that the course has three lectures per week, this amounts to a relatively small percentage of the total lecture time (10–15%). This small change did not require removing any content from the course. Evaluating the students' impressions of the course at the beginning of the semester indicated that many already acknowledged the value of the course content to their future careers. However, at the end of the semester, students in the test section indicated a higher value of the course content than those in the control section. Qualitative survey data indicated the weekly applications discussed in lectures were among the student's favorite parts of the course. These applications also offer opportunities to discuss other aspects of engineering outside of introductory dynamics such as design or engineering ethics. Future work being considered in this course is to expand the use of these real world applications beyond lectures and into homework assignments and student discussion activities.

Table 2: Summary of Quantitative Survey Responses

Response		**Statement 1 Creating Value**	**Statement 2 Connections**	**Statement 3 Curiosity**	**Statement 4 Creating Future Value**
Agree	Start: Combined	65.0%	62.8%	54.4%	65.6%
	End: Control	71.8%	75.0%	68.5%	70.2%
	End: Test	80.5%	74.2%	65.4%	75.5%
Disagree	Start: Combined	10.6%	12.8%	20.0%	13.3%
	End: Control	12.9%	8.9%	12.1%	11.3%
	End: Test	6.3%	8.2%	11.3%	8.2%



(a) Statement 1 - Creating Value **(b) Statement 4 - Creating Future Value**

Figure 7: Survey responses assessing students' impression of the value of course content, bars represent 95% confidence intervals.

Acknowledgments

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