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Using Utility Value Interventions to Explore Student Connections to Engineering Mechanics Topics

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Abstract

Engineering mechanics courses (e.g., statics and dynamics) are critical foundations within an engineering curriculum and a strong understanding of these topics is often important for success in the broad range of classes that leverage and build on these topics. But students often struggle in these courses for a number of reasons and this point in the curriculum can be a "bottleneck" in terms of student success and progress toward a degree. Utility Value Interventions (UVI) offer an opportunity to increase motivation and success by helping students make concrete connections between what they learn in class and how that learning is personally useful or relevant to them. And while UVIs have shown promise in STEM more broadly, less attention has been given to them in engineering in particular. Helping students see the value of engineering content can help students persist in the face of academic challenges; this is especially true for minoritized groups in STEM. The purpose of this research is to explore the ways students in introductory engineering mechanics courses make connections between their values and their learning and success in those courses. Based on previously validated work in STEM, we developed and distributed UVIs in engineering statics and dynamics courses during the 2020-2021 academic year. The UVI asked students to think about subjects discussed in class and to articulate the ways in which those subjects are personally relevant or meaningful to their lives. We conducted a qualitative thematic analysis to explore dominant themes in student responses and organized them in terms of the different ways students perceived value and relevance of engineering mechanics concepts in their lives. Analysis is ongoing, but preliminary findings suggest that UVIs can help students recognize and form rich, meaningful connections between engineering mechanics topics and their personal lives and values. Specifically, students describe connections in terms of 1) personal relevance; 2) a sense of "seeing" mechanics in everyday life; and 3) sociotechnical dimensions of engineering. These themes suggest that when given the space and time, students can form valuable personal connections to the concepts they encounter in introductory engineering mechanics courses in ways that enrich and give meaning to their learning. Such findings are noteworthy because engineering science courses often present content in ways that are removed from authentic contexts that might help students make these vital connections. We recommend that engineering faculty both leverage UVIs in other engineering science courses while also incorporating the findings from the present work to help highlight the diverse ways students might already see connections between abstract concepts and their own lived experiences and values.

Introduction and Background

Introductory engineering mechanics courses (e.g., statics and dynamics) are critical in an undergraduate engineering curriculum. These courses often serve as a foundation upon which more complex subjects build and so it is important that students develop a strong understanding of the concepts within them. But the courses are especially challenging for students, and they can create a "bottleneck" in the engineering curriculum, at least at the university where this research was conducted. Research has shown that engineering students are most likely to leave their major during the second year of school, which generally coincides with the timing of these courses (Min, Zhang, Long, Anderson, & Ohland, 2011). Further, at the present university, this bottleneck tends to disproportionately affect minoritized students, resulting in equity gaps in learning and student success. It is therefore vital that engineering educators devise educational approaches that can address these gaps and increase success and learning for all students.

Research in STEM and engineering education recognize the importance of student motivation for success, performance, and persistence in degree programs (Jones, Osborne, Paretti, & Matusovich, 2012; Jones, Epler, Mokri, Bryant, & Paretti, 2013; Jones & Skaggs, 2012; Lee, Kajfez, & Matusovich, 2013). In general, students who have higher levels of motivation and interest related to engineering are more likely to succeed and persist than their less motivated cohorts. One critical aspect of motivation and interest is utility value, or the belief that an activity will be useful in achieving personal or academic goals (Hecht, Grande, & Harackiewicz, 2020). According to expectancy value theory (Eccles & Wigfield, 2002), utility value can impact students' expectancy for success, which is often a useful predictor of performance and persistence in STEM and engineering more broadly (Andersen & Ward, 2014). By recognizing learning activities as useful in meeting short- and long-term goals, students are more likely to engage with content in ways that help develop a stronger understanding of the content and to succeed in courses that present significant challenges (e.g., statics and dynamics).

At the same time, scholars have argued that the content of these courses is often presented in ways that are, intentionally or otherwise, often disconnected from authentic or "real-world" applications (Leydens & Lucena, 2017; Stettler Kleine, Zacharias, & Ozkan, 2021). Problems are often presented free of broader contexts in which the concepts might apply, and they ask students to employ complex math and physics concepts to scenarios that might bear little, if any, resemblance to the real world or their lived experiences. Such issues can present challenges for students as they struggle to understand the relevance or application of the concepts they are learning both within their lives and the engineering profession more broadly. Without making meaningful connections between their lived experiences and the content they are learning, engineering students can lose motivation and expectations for success in their academic and professional careers (Kosovich, Hulleman, Phelps, & Lee, 2019).

One way that educators have sought to increase student motivation and success is through the use of Utility Value Interventions (UVIs) (Hecht et al., 2020; Hulleman, Kosovich, Barron, & Daniel, 2017). UVIs typically take the form of short writing assignments that prompt students to think about course content and the relationship that content might have to their own lives or goals. UVIs have been used in STEM education as well as other disciplines to increase motivation and a growing body of research has demonstrated positive student outcomes. For example, Hulleman et al. (2017) used UVIs in an introductory psychology course and demonstrated their positive impact on interest, expectancy for success, and subsequent performance. Relatedly, Kosovich, Hulleman, Phelps, & Lee (2019) used UVIs to improve algebra performance for community college students. Although they note that UVIs were more effective for improving men's scores than women's, the men in the sample were also lower performing than women, suggesting a positive impact for students most in need of help. And while research in engineering specifically remains limited, Turoski & Schell (2020) implemented UVIs in an engineering design course and their preliminary findings point to increases in student interest and motivation related to engineering. UVIs thus represent a potentially high-impact practice with a relatively low barrier to entry.

We focus on UVIs here because as researchers have noted, UVIs tend to benefit students who might be more likely to underperform or withdraw and less likely to succeed (Harackiewicz, Canning, Tibbetts, Priniski, & Hyde, 2016; Hulleman et al., 2017; Kosovich et al., 2019). For example, Harackiewicz et al. (2016) employed UVIs in an introductory biology course and focused their analyses on the differential impact across the race and social class of participants. Their findings highlight that while UVIs are beneficial in enhancing interest and performance for all students, they are "especially powerful" for first generation and minoritized students (p. 21). And given that performance and motivation are useful predictors of persistence in engineering (e.g, French, Immekus, & Oakes (2005)), we see UVIs as a potentially useful tool for mitigating equity gaps and increasing retention and persistence of students from minoritized groups. Second, scholars have shown how minoritized groups might enter engineering for different reasons than their dominant cohorts (Brawner, Lord, & Ohland, 2011). Specifically, women are more likely to enter engineering based with a desire to help others and a feeling of social responsibility (Canney & Bielefeldt, 2015). We therefore argue that UVIs offer space for students to explore these interests and make more explicit connections between engineering course content and their broader motivations, which have the potential to positively impact motivation and success of other minoritized groups (Camacho & Lord, 2013).

In the present research, we implemented a series of UVIs in statics and dynamics courses that were designed to help students make more explicit connections between the technical engineering content they learn and their own lives. While UVIs have been shown to be effective in improving student performance (Hulleman, Godes, Hendricks, & Harackiewicz, 2010) and mitigating equity gaps (Harackiewicz et al., 2016), more attention has been paid to the outcomes of the intervention with less focus on the content of student responses to the specific UVI prompts. As a result, we aim to unpack student responses to UVIs in ways that will help educators better understand engineering student interests and, importantly, inform future learning experiences that help students make richer connections between their learning experiences in class and the relevance of those experiences within their own lives. To that end, we pose the following research question:

> *How do students articulate connections between engineering mechanics concepts and the usefulness to their lives beyond the engineering classroom?*

We conducted exploratory research of student responses to UVIs. We used thematic analysis approaches to investigate and characterize student responses along three primary dimensions related to their personal impact, perceived societal relationships, and the ways they see and interact with the world. These themes suggest that students are eager to make connections between engineering science content and their own lives and point to useful avenues for engineering educators to leverage these connections to improve student success and mitigate equity gaps for minoritized students. The following sections offer a brief overview of the relevant literature; a discussion of our data collection and analysis; our findings in the form of themes and supporting student responses; and some implications and suggestions for ways that engineering educators can use these findings to improve their own pedagogy and instructional design.

As we and other scholars argue, helping students make connections between course content and the personal usefulness of that content to their own lives can help increase motivation and ultimately, achievement, retention, and other positive educational outcomes (Hecht et al., 2020; Hulleman et al., 2017; Klebanov, Burstein, Harackiewicz, Priniski, & Mulholland, 2017; Rosenzweig et al., 2019). And while research has demonstrated positive impacts on student motivation, less is understood about the specific nature of those connections or the specific parts of students' experiences that form those connections. Our work in this paper helps to address this gap by exploring, in depth, student responses to UVIs designed to facilitate connections between course content and relevant lived experiences.

Methods

This research is part of a larger project that is working to mitigate equity gaps in performance and retention for minoritized students in engineering (i.e., women, students of color, LGBTQIA+, first-generation, students with disabilities). As part of this work, we are developing adaptive learning modules that help increase student conceptual understanding, belongingness, and importantly, motivation in engineering mechanics courses (Rassouli & Ríos, 2020; Rıos et al., 2020; Ruiz, Trageser, & Lutz, 2021; Trageser & Lutz, 2021). To better tap into student interest and motivation, we are working to develop motivational course content that will help students recognize connections to their lives and develop a more sustained interest in engineering. In the present study, we leverage UVIs to achieve these goals. The following sections offer an overview of the data collection and analysis as well as relevant limitations and researcher positionality.

Data Collection and Sample

Data were collected during the fall 2020 and winter 2021 academic terms in both engineering statics and dynamics courses. We adapted existing UVI tools from prior research (e.g., Canning et al., 2018; Harackiewicz et al., 2016; Hecht et al., 2020; Hulleman et al., 2010) to ask students to explore connections they were making between the content they were learning in class and their lives beyond the classroom. Over the course of the academic term, we assigned students a series of different UVIs that had different points of focus or emphasis, and the one ued in the present research centered on identifying a skill or topic from class and connecting it to some aspect of their lived experiences outside the classroom. Specifically, students were asked to respond with approximately 250 words to the following prompt:

> *Research has shown that identifying personal value in classroom content can significantly improve academic performance (Hulleman et al., 2010). Select a topic covered in class and discuss its relevance to your own life. Be sure to explain why and how the specific information is relevant and or useful to you personally. Literal applications of the content are valid, but you might also use this space to reflect on deeper utilities (e.g., fulfillment, meaningfulness) that are not directly linked to getting a good grade.*

In line with recommendations from prior research (e.g., Kosovich et al. (2019), the UVI was integrated into the course as an assignment. The assignment was distributed through the ConceptWarehouse (Koretsky et al., 2014), which allowed for the responses to be collected anonymously while still allowing instructor feedback (e.g., (Koretsky, 2020)). We also used the ConceptWarehouse because it is an existing research tool that asks students to opt in for consent to have their responses used as data for research. Prior to analysis, students who did not consent to allow us to use their responses were removed from the dataset.

Students were given full credit for completing the exercise, regardless of the nature of their specific responses. Collecting data in this way allowed students to be candid in their answers while still ensuring they would be able to receive credit for the assignment. In total, we collected 101 and 94 responses to the prompt in statics and dynamics, respectively, for a total of 195 UVI responses.

Students were prompted to enter demographic information through the ConceptWarehouse interface, though doing so was not mandatory. As a result, we have incomplete demographic information about the students in the present sample; a topic we will address further in the limitations section. For the statics sections, 44 out of 101 students entered demographic information and in dynamics, 40 out of 94. As a result, we are unable to offer a full description of the student sample in the present research, and this represents a limitation of the study. However, the research was conducted at a large, public, land grant university and the demographics of the courses are consistent with the overall demographics of most engineering programs and departments nationwide—that is, predominantly white and male. Future research should explore differences in UVI responses across relevant demographic variables such as race, ethnicity, gender, first-generation status, age, etc. in order to better understand the nuances and differences in motivation for different populations of engineering students.

Data Analysis

We followed thematic analysis procedures consistent with recommendations by Braun & Clarke (2006). Specifically, we followed the six overarching phases from reviewing the entire corpus of responses and creating analytic memos; naming and operationalizing emergent codes; extracting dominant themes; and producing the final report in the form of the present research paper. While a full discussion of the methods outlined by Braun &Clarke (2006) is beyond the scope of the present work, see Ruiz et al. (2021) for more detail regarding the analysis approaches used here.

In generating codes, we examined student responses for recurring or common themes. We focused on allowing themes to emerge from the development of initial, open codes that would eventually cluster around broader themes. For example, we noted in the following passage themes related to both safety and structural engineering.

> *[Q]uestions such as trusses that we have been working on recently are easily applicable to the real world. It has been interesting working on truss problems as there are many applications in the real world such as bridges, buildings, or other structures that use truss structures for their support. The calculations of tension, compression, and moments about hinges are what these structures rely on to keep their rigidity and the people on and below them safe. Working through these problems, it is interesting to see how professionals in the field have to look at these problems and accurately take these things into account in order to keep lives safe. [Student ID 6135, Statics]*

We used initial codes to examine relationships, similarities, and differences across codes to form themes that operated at higher levels of abstraction and were defined by groups of initial codes. We created logical groups of codes to develop themes and worked recursively through the data to draw conceptual boundaries around the themes and the codes that comprise the higher-order ideas captured within them. As a result, the codes formed the basis for the descriptions of the themes, which offer a meaningful overview of the salient aspects of student responses Returning to the above example, the codes S*afety* and S*tructural Engineering* would ultimately be grouped under themes of *Sociotechnical Dimensions* and *Personal Relevance*, respectively. (These themes are discussed in more detail in the Results section below.)

Credibility and Trustworthiness

To establish credibility and trustworthiness, we followed recommendations by Barber & Walczak (2009) for peer debriefing as well as Carcary (2009) for the use of audit trails. The final author conducted the primary analysis and developed initial codes through open coding and first cycle methods (Saldaña, 2015). The first two authors then conducted an independent review of the data set and composed analytic memos following recommendations by Saldaña (2015). Following the memo process, the first two authors met with the final author to discuss thoughts, feelings, and impressions of the data and to arrive at preliminary themes and codes. After a codebook was agreed upon, the first two authors independently coded subsets of the data and those codes were compared to those applied by the final author. Where there was disagreement, the research team argued to consensus to revise the operational definitions of the codes. While we present these steps in a linear fashion, it is important to note that the entire process was iterative, and the research team engaged in several rounds of coding, negotiation, and revision to develop the final codebook. Throughout this process, the research team kept detailed audit trails and memos related to the development of the themes and codes.

Context, Positionality, and Limitations

Also important to note is the context in which student responses were collected. Both the third and fourth authors have experience integrating issues of equity and inclusion into engineering courses. Specifically, the third author works to integrate content concerning folks with disabilities and teaches an upper-division course on design for disability. In dynamics, the third author incorporates modified versions of this content and helps emphasize the ways in which engineering solutions can contribute to equity and access. In addition, the fourth author has experience with issues of engineering and social justice and teaches an upper division class on engineering design theory and social justice. Similarly, the fourth author works to incorporate sociotechnical topics into all their courses, including engineering statics. We note our positionality because the topics we teach likely influenced student responses to the UVI prompts. That is, not all engineering instructors work to integrate social or non-technical topics into what are primarily technical courses, and this integration probably influenced the kinds of connections students made between the course and their lives. Nonetheless, as noted in the Results and Discussion sections below, we argue that integrating sociotechnical topics can help engineering educators tap into a broader range of student interests and motivation, which can ultimately increase persistence and retention of a more diverse student body.

The findings below should also be interpreted considering existing limitations. First, though we do note that prior research has demonstrated that UVIs can be especially helpful for minoritized students, we do not have complete demographic data from our sample. The ConceptWarehouse does not require that students disclose this information to access the content on the site, and so some students decline to enter their demographic information. Future research will work to collect this information more systematically. Second, because the UVIs were implemented in all sections of the courses taught by the third and fourth authors, we do not have data on whether these students who completed the UVIs did better than students who did not. Future research will compare the performance of students who completed UVIs to those who did not in the form of concept inventories, exam scores, and final grades. However, the purpose of this research was not necessarily to test the impact of UVIs but to more deeply examine the content of student responses. We sought to better understand the nature of the UVI responses themselves in ways that might help us build off them and create meaningful educational content. Thus, while literature would suggest that the use of the UVIs was likely to have had a positive impact on their performance, the focus of this research is driven by different goals.

Results

Three dominant themes emerged in student responses. First, students described the *Personal Relevance* of mechanics concepts in terms of how it might help them advance within their own engineering discipline and how their influence on problem solving and thinking about their lives more broadly. Second, students came to "see" the application of mechanics concepts and applied this new lens both in diverse ways outside their formal engineering curriculum (i.e., *"Seeing" Mechanics*). Finally, UVIs gave students space to explore the *Sociotechnical Dimensions* of engineering in ways that emphasize broader social impact and public safety. An overview of the themes, definitions, and supporting codes are provided below in Table 1. We elaborate on these themes and codes in the following sections and support them with student UVI responses that illustrate the ways they emerged from our data.

Table 1: Emergent themes, operational definitions, and supporting codes.

Themes	Operational Definition	Supporting Codes
Personal Relevance	Discussing the value that learning mechanics has on their personal life and endeavors (present and future) and how this learning better develops their ways of thinking.	- Disciplinary Connections - Engineering Thinking/Reasoning -Symbolic Connections
"Seeing" Mechanics	Describing how thinking about mechanics has offered a new lens to view and better understand the physical principles that govern interactions with the world.	- Mechanics in the World - Hobbies
Sociotechnical Dimensions	Discussing social aspects and implications of engineering concepts and developing an awareness of engineers' responsibilities in the context of these issues.	- Safety - Social Justice/Societal Impact

Personal Relevance

Personal Relevance captures the different ways that students made connections between mechanics concepts and their personal lives. Some noted the usefulness of mechanics concepts for their major or chosen discipline, and others described how their learning has impacted the way they break down and solve problems outside of the classroom. In addition, students also noted how particular concepts they learned might be useful in abstract ways that made symbolic connections to their lives.

Disciplinary Connections

Students in this study used UVIs to make connections between mechanics concepts and their use in various engineering disciplines. We defined *Disciplinary Connections* to note instances where students reflected on how specific mechanics topics might be useful or important for success in their area of study or eventual career. The following excerpt shows a student reflecting on how their knowledge of rigid body rotation and angular momentum will be pertinent to their future work as an aerospace engineer.

> *… I also am enjoying dynamics more - especially what we're doing right now, rotation and angular momentum - because I know it will be applicable in my career. I'm an aerospace major and my ultimate goal is to work for NASA, Lockheed Martin, Rocketdyne, etc and work on space exploration satellites. One of my favorite things to study in that specific field is deep space exploration and gravitational assist. That maneuver is obviously more complicated than just rigid body rotation, but the concepts I'm learning in this class are helping me better understand what I will hopefully be doing professionally one day. [Student ID 897, Dynamics]*

By recognizing how concepts they were learning might be useful for them as professionals in the future, students made connections that helped them enjoy the material and potentially take a more active interest in their engineering major.

Engineering Thinking/Reasoning

Students also saw value in the systematic problem solving mindset taught in mechanics more broadly. *Engineering Thinking/Reasoning* describes students who connect problem solving strategies to other areas of their lives that require systematic or logical processes. They noted how they can transfer the problem solving approach used in class to make sense of problems both inside and outside of an engineering context. In the excerpt below, a student demonstrates how "zooming in" on each aspect of a complicated problem can help it seem less difficult.

> *These ways of solving big and seemingly complicated problems are very helpful if we can understand what it is teaching us at the very basic level. It is teaching us that as long as a problem is large and seems too difficult, we can zoom in and calmly analyze how everything is related. We then can come to see that the relationships between parts can be fairly easy to understand and solve. [Student ID 8376, Statics]*

Essentially, the student is describing a systems thinking approach to complex interactions in a problem. With many challenging "threshold concepts" in mechanics (Baillie, Goodhew, & Skryabina, 2006; Prusty & Russell, 2011), students can often feel overwhelmed by complex problems. For some students, "calmly analyzing" problems can help make them more comprehensible and easier to solve.

Symbolic Connections

In describing the usefulness of mechanics for their own lives, students also made what we termed *Symbolic Connections* to the content. These connections were related to the ways mechanics concepts might have served as metaphors for other aspects of their lives, such as the way equilibrium (i.e., equal and opposite forces) highlights the need for balance in one's personal and academic life. The following student response illustrates this point.

> *...The concept of equilibrium can be applied to my personal value of living my life in balance. I try to have contrast between working hard and rewarding myself. I have never believed that the fast-paced, achievement-based lifestyle in the US was healthy. It creates excessive competition and is too future-focused. Hard work is very important if one wants to be successful, but too much work takes away from developing a strong sense of self, forming relationships, and discovering hobbies. I have always found it difficult to find this balance in my life with the constant pressure to go to a good college, perform well, get a good job, and on top of all that, be the person who I want to be. I think that our culture places too many expectations on young adults when we are at such a critical point in our lives for self-development and forming healthy living habits. [...] To tie it back to static equilibrium, I like to look at my daily commitments as forces pulling my life in different directions. I need to work hard enough in order for me to achieve my goals, and I also need to give myself breaks to restore my energy, but most importantly, I need to fill my life with people and hobbies that bring me joy and help me continue to become the balanced individual that I strive to be. [Student ID 8333, Statics]*

Another student recalled the concept of impulse momentum and impact as a way to think about the impact they have on the world around them as well as how the world might impact them.

> *When we were learning about impulse and momentum of particles in class, I remember writing notes down about impacts. After reviewing my notes the day after, I began to think about the meaning of the word impact. In Dynamics, impact is referred to as a collision between two bodies that occurs in a very small interval of time that exert large forces on each other. Then I began to think more deeply about the world outside of Dynamics. How does this material impact me? How do I impact others? Will this impact be good or bad? In Dynamics, an impact can either be negative or positive which corresponds to the direction of the particle. Real-life activities and actions can also have positive and negative impacts. What will be the impact on my grade if I choose to study or not for my Dynamics final? It is important to recognize how we are human beings and act as external forces to other people. It is necessary to be aware that, even without knowing it, we can make huge impacts on other peoples lives because we are such large forces in life. Then I began to think of Newtons Third Law that states that for every action (force) in nature there is an equal and opposite reaction. So if we are external forces in life, we have direct impacts on other peoples lives, but since there is always an equal and opposite force acted on us, its important to have positive impacts on other people, so that we can then be treated in the same positive way and other people can be positive forces in our lives. I think of Newtons third law in dynamics, as Karma in real life, it can either be positive or negative, so lets always treat people positively. :) [Student ID 9259, Dynamics]*

It is interesting to note how students made choices to take a relatively abstract view on the connections between mechanics concepts and their lives and such findings highlight how the terms we use for scientific concepts can influence student beliefs and interpretations of events outside of their engineering classroom experiences.

“Seeing” Mechanics

This second theme captures student discussions of a new lens in which to apply mechanics concepts to how they view and interact with the mechanical world. We see this theme in two distinct ways. One is its applications to the world in structures and objects students see around them, such as trusses in a bridge in their town (*Mechanics in the World*). The other is students applying this new lens to the activities and projects they participate in during their time outside of engineering classes (*Hobbies*).

Mechanics in the World

Students often described how mechanics concepts gave them a new ability to understand the world around them. *Mechanics in the World* therefore refers to student discussions related to observing how statics and dynamics concepts apply to the existing physical systems students witness in their lives. One student noted that while taking statics, they have been able “to develop a mindset that allows [them] to analyze and imagine the forces that will be acting on the structures” [Student ID 8307, Statics]. Students note this lens when viewing different systems around them (e.g., reaction forces in the hinges of cabinets, moment arms of wrenches, two force members in trusses of bridges). In one example, this student notes how this lens helps them see the concept of moments in the structures around them both around campus and in other built environments.

> *I think moments are a particularly impactful part of what we have covered in class. A lot of what we encounter in structures, especially in more modern architectural fixtures and such, involve single support systems like beams, sign outposts, etc. This class has given me more context which I can use to make observations around me. I have noticed even around campus, more systems than I thought will create moments and because they are stationary, must have something to counteract this moment. Technically, even the swim diving board creates a moment. Just having a deeper mathematical understanding of the working of things around me to layer on top of my other experiences provides a unique outlook that I hadn’t achieved before this course. [...] Especially when I go to bigger metropolized [sic] areas [...] I am able to have a more contextualized view of the infrastructure and mental energy put into making something operational, or in the instance of moments, utilize the forces and sum of moments to get desired rotational moment, or stop natural rotational movement that is unwanted. [Student ID 6598, Statics]*

Students noted literally being able to “see” the concepts in play in different physical and mechanical systems around them, which helped give them a better understanding of the way those aspects of the world works.

Applications to Hobbies

Students also applied this new lens to the activities, projects, and structures they work on in extra- and co-curricular spaces. More specifically, students described how learning about mechanics helped them make more informed decisions about the physical aspects of different hobbies or activities that move beyond typical classroom examples (e.g., bridges, systems of pulleys). Often these activities are sports, or other physical activities that students describe seeing in ways they have never done before by analyzing or incorporating mechanics concepts like moments, rigid body, work energy, etc. In the following excerpt a student describes how mechanics concepts have helped them improve their form when lifting weights.

> *Another application of statics in my life currently is applying my knowledge of statics to when I work out. I lift weights most days of the week, and working out is an important part of my life. Now when I lift, I think about the different forces and moments that the weights place on my body, which my muscles must respond to. For example, I noticed that during the pec fly (laying down with straight arms moving from side to straight up) there would be larger moment when my arms are fully extended versus partially bent. Now if I struggle to finish a set, I bend my arms slightly more to reduce the moment and reduce the strain on my muscles. Applying my statics knowledge to different exercises helps me think about which variations have which effects on my muscles. Thinking about statics in the real world has helped my understanding in the class and given the class more meaning in my life. Statics has been my favorite class this quarter, and I am excited to see what else we will learn in the remaining weeks. [Student ID 5935, Statics]*

This student highlights how they now look at their hobby in a completely different way because of the new perspective gained from their mechanics class. This connection can help students see the application of concepts to aspects of their lives that are important to them and that can help spark more sustained interest in mechanics.

Sociotechnical Dimensions

Our third theme focuses on students who connect mechanics topics to the impacts engineering work has on the people and world around them. We defined *Sociotechnical Dimensions* as instances where students recognize engineers' responsibilities beyond technical competence, such as keeping people safe, promoting social justice, or positively impacting society.

Safety

Our first code within this theme is *Safety*, which describes students who connect mechanics concepts to the professional and ethical responsibilities of keeping people safe through good practice of engineering. These excerpts highlight how mechanics can provide the foundation for meaningful engineering calculations, like finding the allowable stresses in bridges, factors of safety in buildings, or impact forces in airbag design. The following student describes how important static equilibrium is for designing safe homes for people.

> *During my studies and working career, I will be able to apply the concepts I have learned in this class to help design and analyze structures in static equilibrium. Obviously, a residential home must be in static equilibrium in order to properly stand and function on its own. Therefore, this topic is very important in*

determining whether or not a built structure is safe for people to use. As an engineer, it is my responsibility to help people by ensuring their safety and efficiency when using complex structures, especially their homes. By ensuring that a structure is in static equilibrium with balanced forces, I can build something safe for people to use. This topic within the course will provide me with a foundational understanding of systems in static equilibrium, which will be crucial when designing structures on a larger scale and combining smaller systems to make a safe and sturdy structure. [Student ID 8492, Statics]

This student views their understanding of static equilibrium as a tool they can use to keep people safe. Students see value in improving people's wellbeing through engineering, and these reflections give students the space to connect that value to a specific course topic.

Social Justice/Societal Impact

Some students used the space afforded by the UVI to discuss connections to societal issues that they feel engineers might be able to/responsible for addressing. One student demonstrated this point as they connect principles in dynamics to helping other people and serving communities that have been historically overlooked.

Principles in dynamics can be used in engineering to ultimately improve the quality of peoples life in all areas of the world. While working out these problems is difficult, I like that they are training me to be a better engineer, which is ultimately what I want to gain from this class. As engineers, it is important to realize that we can play a role in issues that seem to have nothing to do with engineering. We can look at overarching problems in our society, and look at specific causes, then think of how we can engineer solutions. Problems like this make me more excited to pursue a career in engineering because it opens my eyes to all the possibilities that come along with it. Engineers can solve problems and find solutions for communities in third-world countries and in low-income communities, not only design and create expensive new technology for the upper-class. I love that the core of engineering is solving problems, and I love that through engineering I will be able to make all peoples lives better. [Student ID 7927, Dynamics]

Students described how making these connections between engineering and societal issues/impact has helped them stay more motivated because they can recognize their ability to use technical skills to change people’s lives.

In general, understanding how physics affects 3D objects has been necessary for me as I am working on a prosthetic project for one of my clubs right now and need to have the necessary tools to figure out how to make that work for the patient. I am excited, as in general this class has expanded my mindset on how things work and allow me to remember why I wanted to be an engineer in the first place. I was looking forward to being able to fight for social justice, and this is the first class that really takes into account the real world applications of the technical skills that we learn. I don't want to just go into industry for the sake of it, I want to change people's lives. And often in these types of classes, I begin to lose motivation because they are difficult, until I remember why I'm doing this in the first place. It makes me excited to see what I'll be able to do in the future. [Student ID 8602, Statics]

Students noted how thinking about the relationship between engineering and social justice made them more excited about engineering and the positive impact they can have on society through their work in the profession.

Summary of Results

Students utilized the spaces provided to them via UVIs to discuss the value of mechanics in three main ways: 1) relate concepts to their present and future ventures (*Personal Relevance*), 2) discuss the impact on how they see and interact with the world around them (*"Seeing" Mechanics*), and 3) reflect on a variety of societal implications and impacts of engineering work (*Sociotechnical Dimensions*). Taken together, our findings suggest that students can make diverse connections to engineering mechanics concepts and their personal lives in ways that can generate motivation and interest. While it is perhaps unsurprising that students were able to make connections between engineering in general and personal usefulness, it is noteworthy that students made these connections with technical mechanics concepts in particular (e.g., impulse momentum, work-energy, equilibrium). That is, prior motivational research has examined why students see value engineering more broadly, but less attention has been paid to specific concepts or courses. We recommend that engineering educators use UVIs to improve student motivation, success, and persistence in foundational courses such as introductory mechanics--courses that influence subsequent decisions related to pursuing engineering majors and careers.

Discussion and Implications

Our findings suggest that students are able to make connections to technical concepts and other important aspects of their lives; we argue that these connections can be leveraged to improve student outcomes within engineering programs. Students are aware that mechanics courses such as statics and dynamics are critical for success in subsequent courses, but their relevance often ends there. For students who do not see a clear path to or application of engineering in their lives, simply recognizing these courses as important for later courses might not necessarily motivate students to succeed. By helping students focus on the relevance of mechanics beyond the importance of prerequisite courses, students can be more engaged with these concepts and make more meaningful, personal connections to the content, thereby increasing motivation and success. Moreover, given the noted impact of UVIs on students who are most likely to need help or withdraw from engineering, these activities show potential for broadening participation in engineering and achieving a more diverse student body and profession.

Utility Value Interventions and Student Motivation

Our findings show that students can find utility value in mechanics topics in ways that increase their motivation and expectancy to succeed. And while other research has focused on the positive educational outcomes UVIs create (e.g., (Hecht et al., 2020; Hulleman et al., 2017), our work focuses on *how* students make connections that lead to increased motivation, performance, etc. By investigating the "black box" of UVIs in our qualitative analysis, we can unpack and identify specifically what motivates students about mechanics both in an engineering context and in their personal lives.

Previous research has shown students' motivation and expectation to succeed can increase if they have tangible connections to their course subject matter (Hulleman et al., 2017; Kosovich et al., 2019). Our data show students making these connections, such as *Seeing Mechanics,* where students find utility value in how mechanics can “explain the world around them.” When students can articulate how they can visualize mechanics concepts at work in a skyscraper or in a diving board during their swim meet, they can find relevance in topics that are not typically situated in authentic contexts (Leydens & Lucena, 2017; Stettler Kleine et al., 2021). In turn, these UVIs can also help students visualize themselves as engineers when they reflect on a mechanics topic’s use in a future career. As noted in *Disciplinary Connections*, thinking about how concepts apply to their future profession help students begin to see themselves as engineers, which can increase motivation.

Connections between Social Justice and Engineering

In our data, students reflected on how mechanics concepts relate to societal issues and articulated how engineers have a responsibility to consider how their work will impact society and the world around them. At the same time, students also noted how their engineering coursework feels disconnected from the ‘real world’ because of content coming from a purely technical perspective. UVIs seemed to promote or encourage some of these connections between engineering societal/social implications of engineering work. We see this demonstrated in student discussions of *Safety,* as they connect the consequences and effects of engineering projects and policies on the public. Students discuss the responsibilities of engineers in different capacities by thinking about preventing injury, improving lives, or deliberating the extent of existing policies in keeping people safe. When reflecting in this way, students can develop a more nuanced perspective concerning engineering mechanics and complex social issues. While safety is often noted as a paramount concern in engineering (e.g., in design practices, factors of safety, codes of ethics), it nonetheless seems useful that students make *personal* connections to their knowledge and its impact on society.

With the sociotechnical connections made in these UVIs, students derive value from their understanding in ways that move beyond simply getting a good grade and into concrete ways that this understanding will help them as engineers. Previous research has demonstrated that students’ interest in safety and public welfare tends to decrease as they continue their collegiate engineering students (Cech, 2014), which makes these discussions regarding sociotechnical reflections that are developed through the use of UVIs even more notable. That is, UVIs might be a means by which engineering students can become *more* engaged over time with issues of public welfare and safety.

Engineering educators have noted the relevance of engineering and social justice (e.g., (Baillie, Pawley, & Riley, 2012; Cech, 2013; Leydens & Lucena, 2017; Leydens, Lucena, & Nieusma, 2014; Riley, 2008)) and have called for efforts to integrate such topics in engineering. However, to date, these efforts remain limited or relegated to the margins of the curricula. In this UVI, students were afforded a space to explore and voice considerations of social justice in a decidedly technical engineering context, which resulted in students connecting issues of justice and equity to science concepts. Codes such as *Social Justice/Societal Impact* demonstrate the ways in which students see mechanics concepts as relevant to understand the interrelations between engineers and society. This is important because minoritized students may enter engineering to affect social change more often than majority students (Brawner et al., 2011; Canney & Bielefeldt, 2015; Lakin, Wittig, Davis, & Davis, 2020). However, most of this work has been conducted with a specific focus on gender and less attention has been paid to other axes of oppression or marginalization. By offering a space where students can recognize engineering as a social justice effort, UVIs seem to offer potential to improve motivation for minoritized students in courses that contain significant equity gaps.

Implications for Practitioners

As noted, our research has shown that UVIs can help engineering students make more meaningful connections between their personal values/experiences and technical engineering science concepts. We therefore recommend that instructors can leverage our findings in two ways. First, instructors can draw on the themes presented here to help more students make these connections between concepts and their lives. For example, one could develop pedagogies and learning activities that encourage students to "see" the mechanics concepts in their everyday lives. Such an assignment might ask students to draw a free body diagram of something they interact with often and to think about how mechanics concepts relate to that part of their lives. By encouraging all students to make these connections in personal ways, instructors can potentially increase motivation and interest for students.

Second, instructors should consider implementing UVIs in their own classrooms. Doing so can be both an opportunity for students to develop useful connections to content and provide instructors with a better understanding of what motivates a particular class. The UVI is an intervention in itself and so by assigning UVIs in courses, instructors can communicate that it is important for students to see the personal relevance of engineering concepts. Instructors can also adapt their instruction and content based on UVI responses in a given class. Further, implementing UVIs in engineering courses beyond statics and dynamics seems useful. Indeed, future research should explore the nature of student connections to content as they progress through their technical curriculum. Given the relatively low barrier to entry and the potential impact, we argue that UVIs represent a particularly useful tool for engineering educators who want to better understand their students and improve motivation and success for all students, especially those who might be most at risk of failing or withdrawing.

Conclusion

Engineering mechanics courses represent a pivotal point in an engineering curriculum and a space in which promoting motivation, interest, and success are critical to helping students persist in an engineering degree. We used UVIs to help students make connections between specific engineering mechanics concepts and their relevance to their personal lives. And while UVIs have been successfully employed in a range of educational context, their use in engineering remains limited. To explore the content of UVIs and better understand how students made connections between mechanics and their lives, we conducted a thematic analysis of 195 student responses to a prompt asking students to articulate the relevance of what they were learning on their lives. Our analysis suggests that students see connections to mechanics concepts in ways that 1) will be useful in present and future goals; 2) help them "see" relevant topics in their lives; and 3) recognize the sociotechnical nature of engineering and the ways they can impact society. These findings highlight the potential for UVIs in engineering as both a research tool for better understanding the sources student interest and as a mechanism for increasing student motivation and success in different technical courses.

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