Making space for curiosity, connection, and creating value by integrating real-world examples into engineering education

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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.

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Making space for curiosity, connection, and creating value by integrating real-world examples into engineering education

Abstract

Teaching methods that emphasize theory without including practical applications can make transitioning to industry challenging for students and employers. Research and design engineering has moved to smaller, entrepreneurial companies where engineers may take on business roles, and the transition to such roles is enabled by developing an entrepreneurial mindset. The entrepreneurial mindset is a framework, focusing on the social and societal components of entrepreneurship, to stimulate *curiosity*, build *connections*, and *create value* (3Cs) for students. We surveyed more than 500 students at the start and end of the semester in introductory statics, dynamics, and solid mechanics courses to evaluate the degree of integration of an entrepreneurial mindset and compare their identification of real-world applications relative to applications used in course content. The survey found that students tend to agree less that the course stimulated their curiosity compared to the other Cs. Students in dynamics identified 2-4 times more real-world applications than students in statics or solid mechanics, but this did not relate to homework and test applications used. This difference may be related to other aspects of course content that were not evaluated such as online reference pages, lectures, and discussion worksheets. These study results provide valuable insights into how students' view the entrepreneurial mindset integration depending on the structure and resources of the course.

Introduction

Engineering education that prioritizes theory and includes very few practical applications makes transitioning to industry difficult for everyone. Employers have increasingly voiced their preference for engineers who have a solid entrepreneurship education [1]. Many employers are willing to pay more for people with good business skills such as good communication, problem-solving, and complex thinking [2]. Research and design engineering has moved to smaller, entrepreneurial companies where engineers are often asked to take on more business roles along with their engineering role [3]. Even if engineers are not also in business roles, employers are placing higher value on well-rounded individuals who can apply their entrepreneurship education while in their engineering role [4].

Despite employers' emphasis on entrepreneurship, students often do not recognize their role as an engineer in business [5]. Therefore, there is an emphasis on including entrepreneurship in engineering education. The goal of integrating entrepreneurship education is not just about students starting their own business, but also encouraging students to think entrepreneurially [6].

This is called the entrepreneurial mindset. The entrepreneurial mindset is founded on metacognitive processes and the use of higher-order cognitive strategies, meaning working in uncertain environments and having adaptable decision-making [7]. Engineers are known for being methodical and analytical, so an entrepreneurial mindset allows for full use of those skills in entrepreneurial-minded ways [6]. One way to add entrepreneurship into education is by adding courses, but incorporating practical courses may be difficult with the current curriculum. Entrepreneurship can also be integrated into existing engineering courses through adding more projects, bringing real-world examples into the classroom, and lecturing less [8].

Many components of the entrepreneurial mindset have been identified through the years, but engineering educators have emphasized three main components: curiosity, connections, and creating value (3Cs) [9]. Curiosity is the desire to understand the technical, societal, and economic aspects of any problem, solution, or opportunity. Connections is the ability to take in information from many sources to gain insight and develop solutions. Creating value is broadly defined as making a positive impact on the economy, society, or oneself [6]. It is easiest and most intuitive to integrate the 3Cs into project-based courses like a semester-long design course [10]. While this is helpful, these types of courses tend to appear in the third or fourth-year curriculum. Incorporating the 3Cs earlier in a student's college career means finding ways to do this in lecture and theory-heavy courses that typically occur in the first or second year.

The aims of this study were to (1) evaluate students' baseline perceptions of the courses ability to integrate the 3Cs at the beginning and end of the semester; and (2) compare students' identification of real-world applications relative to applications used in course content. Surveys were used to gather student feedback because one of the goals for identifying the 3Cs was to create a framework that could be translated into a survey instrument [9]. These introductory courses are very large ($n = 1228$ per semester), and surveys represent an efficient method to collect data from this many students. This analysis was done in students enrolled in introductory statics, dynamics, and solid mechanics, because these courses are taken early in a student's college career and have a community of practice (CoP) centered around their maintenance and improvement [11]. This group has worked for the past 10+ years to reform these courses, and wanted to understand how the impact of these changes on students' entrepreneurial mindset before making a concerted effort to intentionally incorporate the 3Cs. Targeting courses taken early in students' college careers means they have taken little to no project-based courses, where the 3Cs are more apparent. Student answers are less likely to be subconsciously swayed by these courses designed to have students work through a real-world application using content they have learned in other courses. The majority of their learning experiences thus far have been traditional lecture and lab/discussion courses. These CoP members, some of which were also involved in our group, were motivated to aid in our study through distributing surveys and providing feedback. We also discussed the various methods previously employed by the CoP that resulted in 3C integration into these courses.

Methods

Survey data was collected from introductory level statics, dynamics, and solid mechanics courses (solids) at the University of Illinois Urbana-Champaign (UofI). All three classes were structured the same way: three 50-minute lecture sessions a week, one 50-minute discussion section, and online homework and tests. In lecture, the professor would cover relevant material, work example problems, and ask poll questions using the iClicker system. The discussion sections consisted of problems presented in the form of worksheets and solved in small groups. The online homework and tests were done on PrairieLearn where, for homework, students received real-time feedback on how to properly solve problems when they get stuck [12, 13]. The tests were proctored asynchronously through the Computer-Based Testing Facility on campus within a three-day window [14]. The course staff consisted of the instructor, graduate teaching assistants, and undergraduate course assistants so the staff-to-student ratio is approximately 1:30. This allows for online help forums to be maintained and most hours of the day covered by at least one staff member so students can receive timely answers to their questions.

These courses have one key difference: the reference material used. Solids (classic) used reference pages, but there were little to no figures, animations, or real-world applications. While the text in these pages was closer to what one would expect for reference pages, the lack of visual components made the pages feel much closer to a textbook. Dynamics (modern) also used reference pages, but unlike solids, these pages had many figures and animations to accompany the text and equations provided. There were also several detailed real-world applications on many of the pages to foster curiosity within students. These applications included a link to the relevant course material so students could see how they connect. Applications were also widely varied to increase the potential of students seeing the value created. Statics (halfway between classic and modern) used an online open-source textbook and had partial reference pages. The statics reference pages that existed linked to the dynamics version of the content. Another difference that only affected statics was two-thirds of the students only took the first 10 weeks of the course.

These surveys were distributed in the Spring of 2024 in the 3rd (start) and 15th (end) weeks of instruction during their discussion sections. Data were collected at the start of the semester from 680 students and the end from 590 students. The survey consisted of four Likert Scale (1, “strongly disagree” to 5, “strongly agree”), one open-ended, and demographic questions (Table 1).

The Likert Scale questions were chosen to gain insight into students’ perception of the course content as it relates to the engineering mindset. Each question focused on only one of the Cs. Curiosity and connection only had one question, but creating value had two questions. This was to evaluate if students saw value in the course content for their personal life or the world around them. The questions were the following:

- Q1, curiosity: “The content in this class stimulates my curiosity about real-world problems”.
- Q2, creating value: “I see how the content in this class helps engineers and scientists tackle major world challenges”.
- Q3, creating value: “The content in this class will be helpful for my future career as an engineer”.
- Q4, connection: “Outside of class, I understand how course concepts connect to the design and engineering of everyday objects”.

Table 1: Demographics of surveyed engineering students.

Variable		**Start**		**End**		**Total**	
		N	**(%)**	**N**	**(%)**	**N**	**(%)**
Course	Total	656	100%	572	100%	1228	100%
	Statics	224	34%	78	14%	302	25%
	Dynamics	180	27%	283	49%	463	38%
	Solids	252	38%	211	37%	463	38%
Sex	Female	173	26%	145	25%	318	26%
	Male	464	71%	407	71%	871	71%
	Other	3	0%	5	1%	8	1%
	NA	16	2%	15	3%	31	3%
Race	White	293	45%	250	44%	543	44%
	Asian	267	41%	197	34%	464	38%
	Black/AA	9	1%	8	1%	17	1%
	Hisp./Latino	49	7%	39	7%	88	7%
	Other	7	1%	4	1%	11	1%
	NA	17	3%	18	3%	35	3%
Department	MechSE	235	36%	195	34%	430	35%
	CEE	125	19%	135	24%	260	21%
	ISE	124	19%	111	19%	235	19%
	AE	81	12%	69	12%	150	12%
	EU	29	4%	18	3%	47	4%
	Other	62	9%	44	8%	106	9%
Years at UofI	<1	131	20%	30	5%	161	13%
	1 - 2	454	69%	449	78%	903	74%
	2 - 3	54	8%	76	13%	130	11%
	3 - 4	12	2%	13	2%	25	2%
	>4	0	0%	1	0%	1	0%
	NA	5	1%	3	1%	8	1%
Transfer	Yes	14	2%	13	2%	27	2%
	No	635	97%	555	97%	1190	97%
	NA	7	1%	4	1%	11	1%
International	Yes	104	16%	97	17%	201	16%
	No	544	83%	471	82%	1015	83%
	NA	8	1%	4	1%	12	1%

AA, African American; Hisp., Hispanic; MechSE, Mechanical Science & Engineering; CEE, Civil & Environmental Engineering; ISE, Industrial & Enterprise Engineering; AE, Aerospace Engineering; EU, Engineering Undecided.

The open-ended (OE) question was, "Give an example of how this course's content will help you tackle a real-world problem." Student responses were categorized into five categories: (1) classic engineering components, (2) non-specific objects, (3) course content descriptions and basic definitions, (4) "it doesn't", and (5) other applications. Course content (CC; homework and quiz problems) were gathered and sorted into the same categories. Classic engineering components are commonly used engineering components, often found in homework problems, such as a simple beam, a bridge, and trusses. Non-specific objects were responses that had words like 'things', 'parts', and 'items', whereas course content was problems of random shapes, 2D abstract objects, and points. Course content descriptions and basic definitions are things like the definition of stress or a statement that could be found on a syllabus. Responses that made up the "it doesn't" category were from students that explicitly states that the course will not help them tackle a real-world problem. Other applications were anything else that did not fit into any of the other four categories.

Statistical analyses were performed to compare the distributions of beginning to end of semester responses, responses between courses, and open-ended responses to course content. Responses were collapsed into three groups; 'strongly agree' and 'agree' were combined, as well as 'strongly disagree' and 'disagree'. 'Neutral' formed the third group. Blank open-ended answers (approx. 30%) were removed. Statistical significance was analyzed using the chi-squared test. Significance was set at $p < 0.05$.

Results

Statics

For all 3C categories, changes in students' perceptions of integration were not significant between the start and end of the semester in statics. There was also statistically no difference between any two questions at either survey time point (Fig. 1 top).

The types of examples that students gave for real-world applications of course content were different from beginning to end of the semester ($p = 0.005$; Figs. 2A,D). The number of students giving a classic engineering component (start: 21% versus end: 46%) as their example more than doubled. Students responding with a non-specific object (start: 35% versus end: 25%) and course or engineering description (start: 25% versus end: 19%) slightly decreased, while real-world applications (start: 18% versus end: 9%) halved. The amount of students that did not think statics would be helpful did not change (1%).

The distribution of example types that students gave in their responses was different than the examples they were exposed to in the course content (p = 0.003; Figs. 2D, 3A). Classic engineering components (OE: 46% versus CC: 43%) was mentioned at approximately the same rate as content given. Non-specific objects (OE: 25% versus CC: 13%) and course or engineering descriptions (OE: 19% versus CC: 16%) was mentioned more than what was given. Real-world problems (OE: 9% versus CC: 28%) were mentioned approximately 3X less than the course content.

Dynamics

Student impressions of the 3Cs improved throughout the course of the semester in Dynamics (Fig.

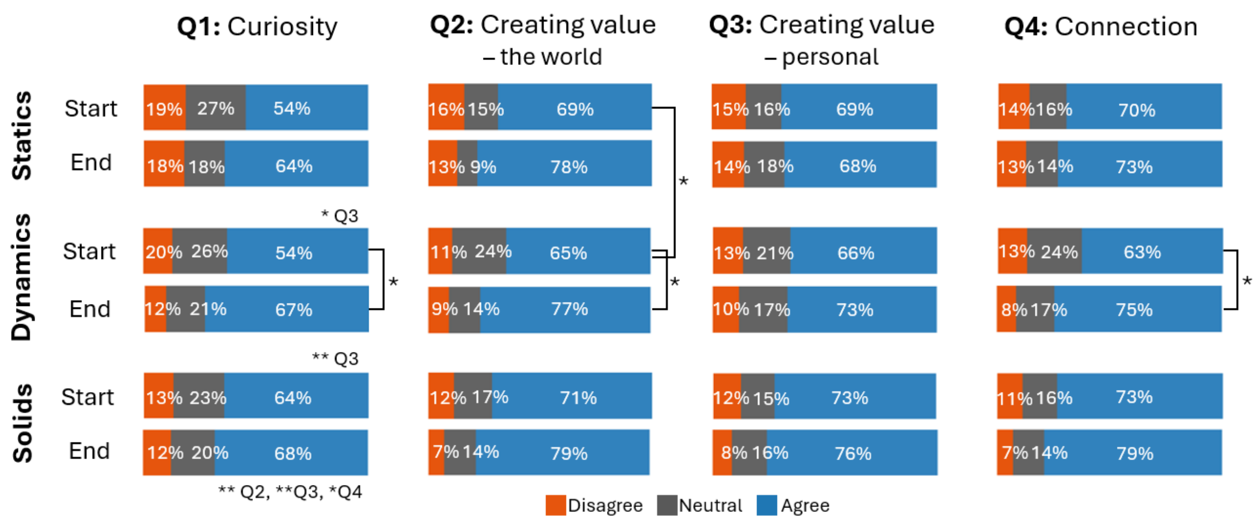

Figure 1: Student perception of 3C integration using 4 questions (columns) in each class (rows) at the beginning and end of the semester using a modified Likert-type scale (orange - disagree, gray - neutral, blue - agree).
* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$ indicates significance in distribution.

1, middle row). Students agreed more (start: 54% versus end: 67%) and disagreed less (start: 20% versus end: 12%) that dynamics stimulates their curiosity ($p = 0.031$). Students agreed more (start: 65% versus end: 77%) and were neutral less (start: 24% versus end: 14%) that dynamics created value for tackling world challenges, but their impression of dynamics creating value for their future career did not change ($p = 0.012$). Students agreed more (start: 63% versus end: 75%), were neutral less (start: 24% versus end: 17%), and disagreed less (start: 13% versus end: 8%) that dynamics helped them connect course concepts to the engineering of everyday objects ($p = 0.049$).

At the start of the semester students agreed less (Q1: 54% versus Q3: 66%) and disagreed more (Q1: 20% versus Q3: 13%) that dynamics would stimulate their curiosity when compared to creating value for their future career ($p = 0.045$). By the end of the semester, there was no difference between their perceptions of stimulating curiosity and creating value for their future career.

The distribution of examples students given for real-world application of course content changed from the start to the end of the semester ($p < 0.001$; Figs. 2B,E).

The number of students providing a course or engineering description (start: 34% versus end: 30%) and didn't think the course would be helpful (start: 5% versus end: 6%) did not change. Classic engineering components was 3.5X lower (start: 22% versus end: 6%) and non-specific objects (start: 30% versus end: 20%) slightly decreased by the end of the semester. The amount of students that provided a real-world application (start: 9% versus end: 38%) quadrupled.

The distribution of course content students saw was different than the distribution of their responses to the open-ended question ($p < 0.001$; Figs. 2E, 3B). Classic engineering components (OE: 6% versus CC: 18%) and non-specific objects (OE: 20% versus CC: 64%) were mentioned

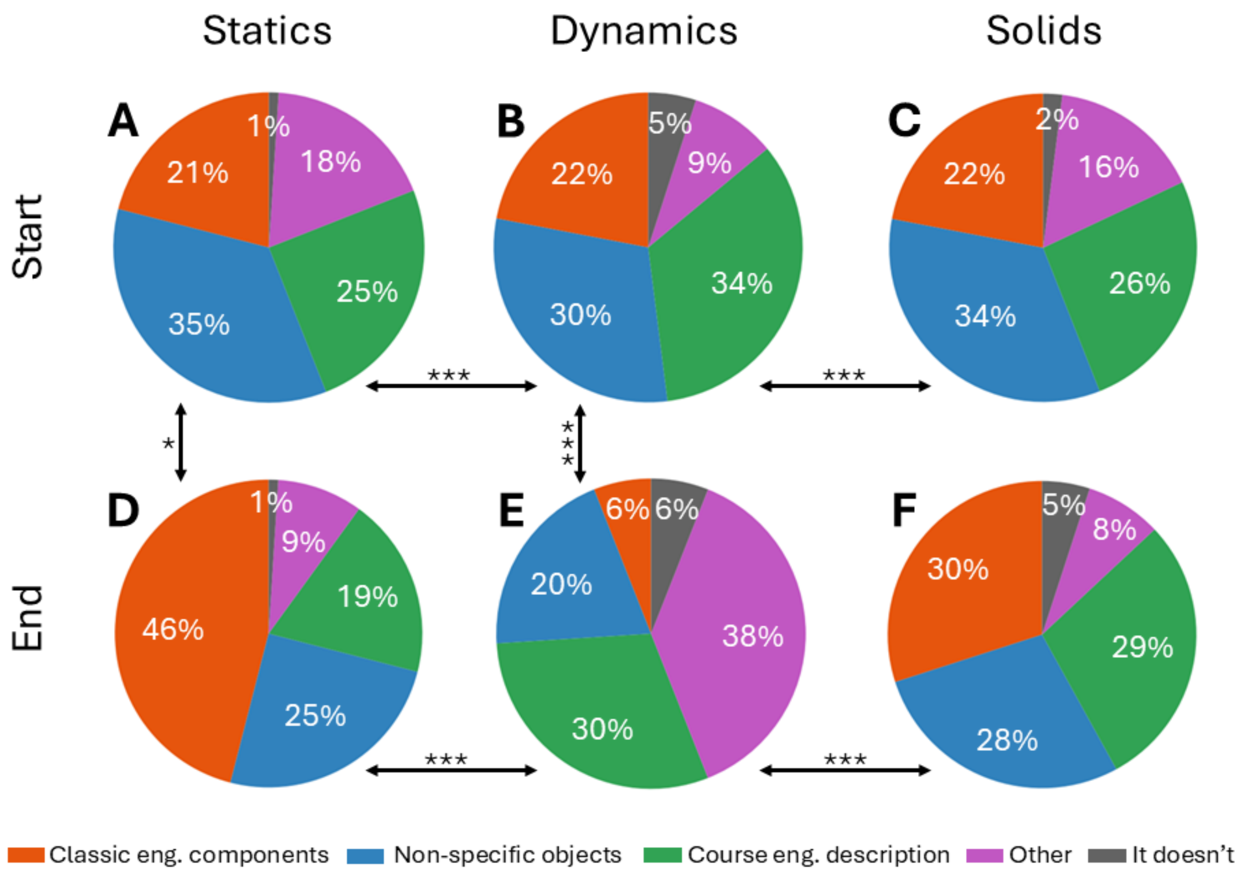

Figure 2: Student responses by category to the open-ended question "Give an example of how this course's content will help you tackle a real-world problem." by course (columns) at the start (top row) and end (bottom row) of the semester. Lines drawn between two pie charts indicate statistically significant different distributions(* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$); response distributions in charts B/E, and C/F, were not significantly different.

approximately 3X less at the end of the semester than the content seen. Students mentioned course or engineering descriptions (OE: 30% versus CC: 8%) approximately 3X more than the course content, and other applications (OE: 38% versus CC: 10%) was mentioned approximately 4X more.

Solid Mechanics

Students' view of the entrepreneurial mindset course integration did not change from the start of the semester to the end, but there was a difference between some of the questions (Fig. 1 bottom). At the beginning of the semester students agreed less (Q1: 64% versus Q3: 73%) and were more neutral (Q1: 23% versus Q3: 15%) that solids would stimulate their curiosity when compared to it creating value for their future career ($p = 0.008$). By the end of the semester this perception gap had widened to all three questions. Students agreed less (Q1: 68% versus Q2: 79%, Q3: 76%, Q4: 79%), disagreed more (Q1: 12% versus Q2: 7%, Q3: 8%, Q4: 7%), and were more neutral (Q1: 20% versus Q2: 14%, Q3: 16%, Q4: 14%) about this course stimulating their curiosity when compared to creating value for tackling world challenges, creating value for their future

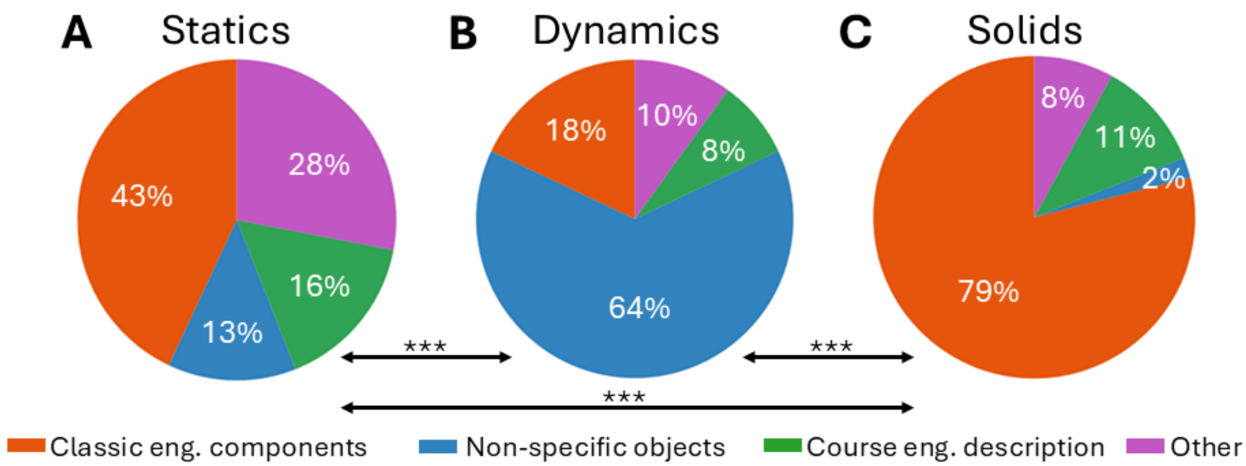

Figure 3: Homework and text question topics by category in statics (left), dynamics (middle), and solid mechanics (right). Lines drawn between two pie charts indicate statistically significant different distributions (* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$).

career, and connecting to the engineering of everyday objects ($p = 0.002$, $p = 0.003$, and $p = 0.012$).

The distribution of examples that students gave for real-world applications of course content did not differ between the start and end of the semester (Figs. 2C,F). At the end of the semester, 30% of students identified classic engineering components, 28% identified non-specific objects, 29% gave a course or engineering description, 8% were able to identify a real-world application, and 5% thought dynamics would not help them tackle challenges. Notably, the number of students that gave a real-world example (start: 16% versus end: 8%) halved, and the the number that thought the course would not be helpful (start: 2% versus end: 5%) more than doubled.

When comparing students' open-ended responses to the course content, the distributions were different ($p < 0.001$; Figs. 2F, 3C). Classic engineering components (OE: 30% versus CC: 79%) were mentioned 2.5X more than the course content. Non-specific objects (OE: 28% versus CC: 2%) were mentioned >10X more than what was given. Students answered with a course or engineering description (OE: 29% versus CC: 11%) 3X more than what they saw in class. Real-world examples (OE: 8% versus CC: 8%) were mentioned at the same rate as those that they saw in class.

Course Comparison

There were very few differences in the 3C questions when comparing between courses. The only difference found was students at the start of the semester in statics agreed more (statics: 69% versus dynamics: 65%), disagreed more (statics: 16% versus dynamics: 11%), and were less neutral (statics: 15% versus dynamics: 24%) about the course creating value for tackling major world problems than the students in dynamics ($p = 0.04$; Fig. 1 Q2).

Statics and solids had no difference in open-ended responses, but both courses were different from dynamics ($p < 0.001$; Fig. 2). Dynamics had less classic engineering components (dynamics: 5% versus statics: 21% and solids: 22%), less non-specific objects (dynamics: 22% versus statics:

35% and solids: 34%), more course engineering descriptions (dynamics: 30% versus statics: 25% and solids: 26%), more other applications (dynamics: 34% versus statics: 18% and solids: 16%), and more it doesn't (dynamics: 9% versus statics: 1% and solids: 2%) responses.

All three courses were different in the course content used in homework and tests ($p < 0.001$; Fig. 2). Solids had the most classic engineering components (solids: 79% versus statics: 43% versus dynamics: 18%). Dynamics had the most non-specific objects (dynamics: 64% versus statics: 13% versus solids: 2%). Statics had the most course engineering descriptions (statics: 16% versus solids: 11% versus dynamics: 8%) and other applications (statics: 28% versus dynamics: 10% versus solids: 8%).

Discussion

Solid Mechanics - classic style course

The results for the solid mechanics course show student curiosity was not being stimulated. This could be a result of a few different things. Not only was solids the classic style course where the reference pages had no applications, over 3/4 of the content students were exposed to were classic engineering components, the majority of them being beam problems. The lack of diverse (other) applications in solid mechanics content could explain the lack of curiosity and why the percentage of students able to provide a real-world application for content halved. Students were not regularly exposed to a variety of homework and quiz problems with applications throughout the semester.

Dynamics - modern style course

The dynamics results showed student perception of the 3Cs integration can be improved within a semester, specifically curiosity, creating value (for the world), and connection. Also, students more easily provided an example for how the course content can be used in the real-world than students in statics or solids. Despite the homework and tests having very few application problems, these outcomes could have been due to the exposure of applications through the reference pages. Many of the homework and quiz problems were 2D abstract object and point problems. This abstractness could have allowed students to come up with their own ideas as to where the material could be used.

Statics - halfway between classic and modern style course

The statics results show that course content alone was not the answer for improving students' perception of the 3Cs integration. Statics students saw the most application problems through their homework and tests, yet the number of answers to how the course can be used in the real world halved over the duration of the semester. The problems in this type of course content are generally standard problems that have been tweaked to look like a specific application. For example, instead of a problem being a weight attached to the bottom of a string, the problem is changed to a lamp hanging from the ceiling. Functionally, it is the same problem, but the lamp looks a bit more interesting than a non-specific weight. Changing classic problems to look like other applications is not the best way to improve 3C integration.

Ideal application content

Homework and tests are an important part of the content in any course, but it may not be where the 3Cs can be most impacted. While working on these problems, students' main concerns are likely getting the right answer and solving the problem quickly, not always thinking about the application being used. The ideal format for the 3Cs to be improved is one where the problem facilitates discussion and the application is fully fleshed out.

The reference pages provide a good at-home format for these applications. There is plenty of space to add as much detail as needed to lay out the application and how it connects to the content. These applications have external links to additional content when relevant and links to the course concepts that apply. This allows students to see the connection laid out clearly for them and explore parts of the application that pique their interest. In the application example from dynamics particle kinematics shown (Fig. 4) there is an animation showing how time is quantified by the Earth rotating around the sun as well as the accompanying math [15]. This application links to angular velocity and acceleration. This application also has a historical breakdown of how the ancient Greeks estimated the radius of the Earth and distance to the Sun (not shown) to further expand on this application in a way that likely would not be possible in another setting.

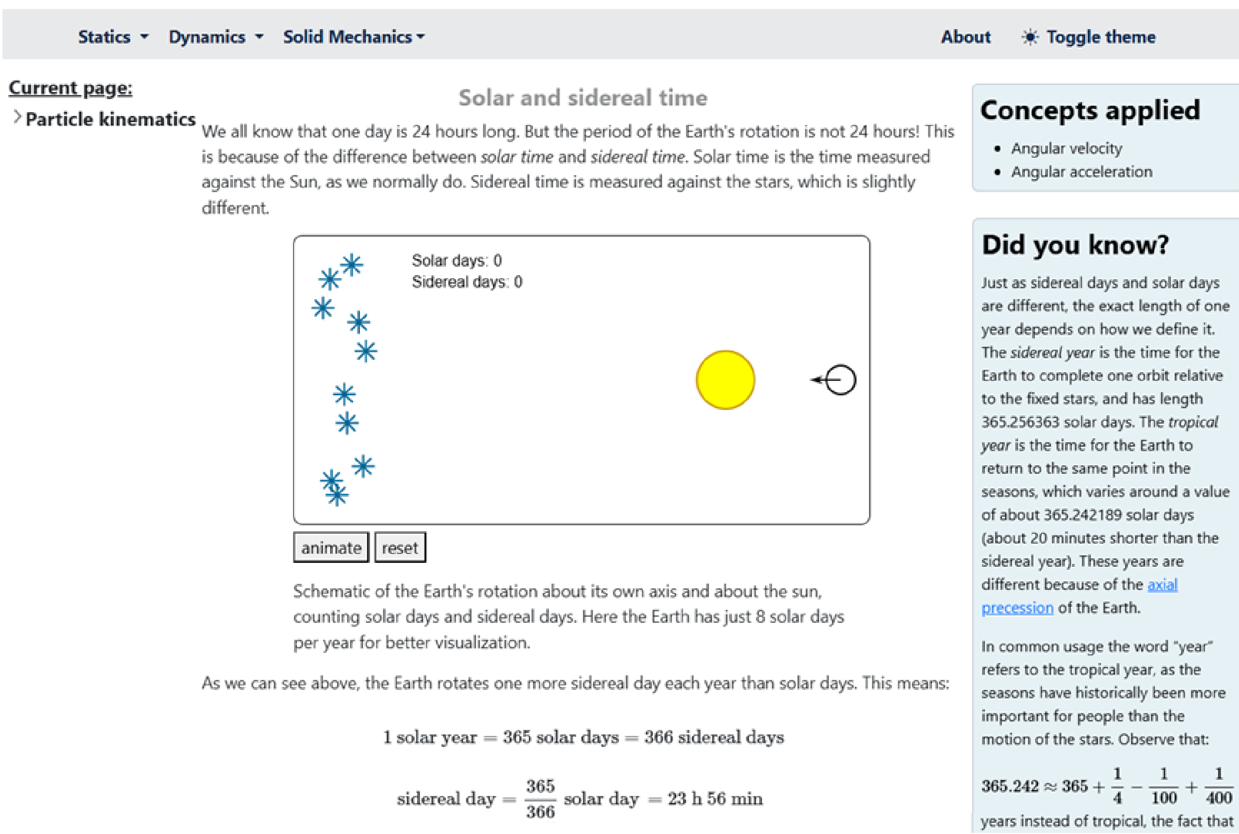

Figure 4: Example reference pages application. Particle kinematics (angular velocity and acceleration) applied to the Earth's rotation around the sun.

Lectures are another good place to incorporate detailed applications. If reference pages, such as the ones in dynamics, are in place, the applications in the pages can be discussed in class. Other examples that the instructor knows about or videos of the topics being applied can also be incorporated to facilitate discussion around the 3Cs. Lecture can also be a good place for simpler examples where classic problems have been tweaked to look like a real-world example (Fig. 5). This example from solid mechanics shows how a cylindrical pressure vessel was changed to be the crew lock on the ISS. It is functionally the same problem, but it looks different. In a homework or test problem, there would be no discussion around this problem, but in lecture time can be taken to talk about how the crew lock shape can be approximated by a hollow cylinder and worked in the same way a classic-looking problem would be worked.

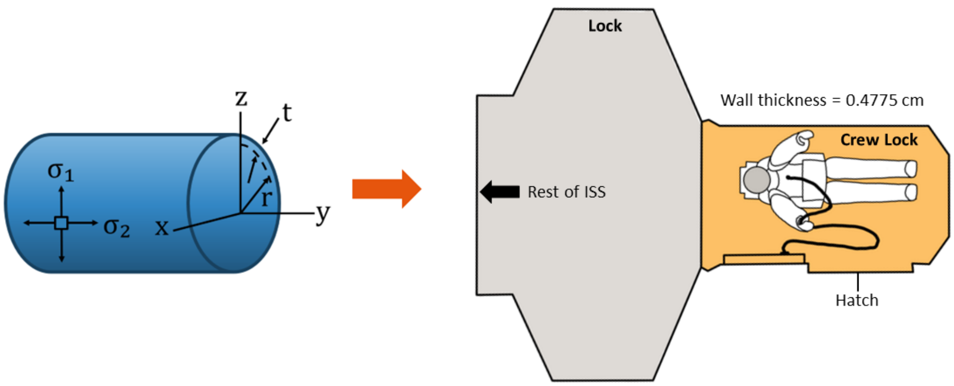

Figure 5: Lecture example change in solid mechanics. Pressure vessels - hollow cylinder changed to crew lock on ISS.

Discussion section worksheets are the perfect time to incorporate real-world applications. The goal of these worksheets is not to finish them in the allotted time, but rather to deepen the students' understanding of the material and how it connects to the real world. This course content was not included in the study as it is a separate goal of our group to upgrade this content. Two of the worksheets we have converted so far are free body diagrams and moments [16]. The free body diagram worksheet used to be a box held up by springs and students were asked to find angles and replicate the problem using a peg-board setup. This was changed to an astronaut strapped to a treadmill in space, preparing for a workout (Fig 6 A). The moments worksheet used to be a series of problems of different classic engineering components with moment-inducing forces applied (force applied to an arbitrarily bent pipe shown here). This problem was changed to the muscle forces applied to the knee at a single time point during running (Fig 6 B). The biggest piece of feedback from these worksheets was to incorporate classic problems before the more complicated application problem as a warm-up problem. Since the material was still so new, students struggled immediately jumping into complex application problems without reviewing a simpler problem first.

This study had several limitations. First, lectures were not included in the course content data. For these courses, the core lecture slides are the same between professors, but how a professor introduces them and incorporates real-world applications is not standardized. Different sections of a course within a semester are not exactly the same. Future research could include the lecture content. Another limitation is that only one semester was included. Future studies should include more semesters. Only about a third of the statics students take the whole course, so the end of the statics course only reflects these students. Including the students that are only required to take the first part of the course would provide a more holistic representation of this course.

Future work could explore how the material covered in each course is a factor in the integration of

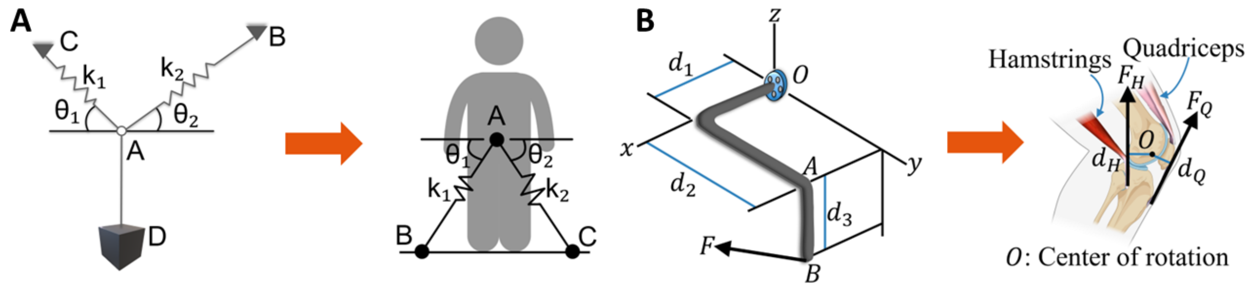

Figure 6: Worksheet changes in statics. (A) free body diagram - box and spring assembly changed to an astronaut about to workout on a treadmill on the ISS. (B) Moments - bent pipe with an applied load to a snapshot of a knee during running.

the 3Cs. The order of courses could also be a factor. Statics is taken first, and then dynamics and solid mechanics are either taken concurrently or sequentially after that. Other demographics analysis was not examined in this work. Lastly, the presence of 'it doesn't' answers when asked to give an example for how the course will help tackle real-world problems should be further explored. Understanding why students feel this way could help identify the gaps in these courses as it pertains to the 3Cs.

Conclusion

This study summarizes data related to engineering student perceptions of how well the entrepreneurial mindset (via the 3Cs) is integrated into the courses and the identification of real-world applications. Student perception of integration and identification depended on the course. In general, there is a perceived lack of curiosity within these courses. Students' ability to identify a real-world application for the course topics was more dependent on the course being taken and less on when in the semester the students were asked. Identification was not related to the homework and test questions used, but may be related to other, harder-to-quantify, aspects of the course. The results of this study provide valuable baseline data for students' perceptions of how well the entrepreneurial mindset was integrated throughout the semester for three introductory courses. Additional research is necessary to explore the impact of changes to course content on the 3C integration in introductory engineering education through the use of a controlled trial.

Resources

A "Card" - *i.e.,* an information repository - has been created for this paper on the engineering unleashed website [16]. This card contains detailed information on how to convert classic course problems to applied problems. Examples mentioned in this paper can be freely downloaded, reviewed, adopted, and if desired modified, by anyone for use in their courses under the Creative Commons CC BY-NC license [17].

"Reference pages" - *i.e.,* course content - has been created for this project on our own website [15]. These pages contain online educational materials that enhance student curiosity, connection and creates value for both student and instructor. These pages can be freely used, adopted, and if desired modified, by anyone for use in their courses under the Creative Commons CC BY-NC license [17].

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References

[1] S. O'Leary, "Impact of Entrepreneurship Teaching in Higher Education on the Employability of Scientists and Engineers," vol. 26, no. 6, pp. 431–442. [Online]. Available: https://doi.org/10.5367/ihe.2012.0128

[2] A. P. Carnevale, M. L. Fasules, and K. Peltier Campbell, "Workplace Basic: The Competencies Employers Want." [Online]. Available: https://repository.library.georgetown.edu/handle/10822/1062942

[3] N. Duval-Couetil, T. Reed, and S. Haghighi, "Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes," vol. 28, pp. 425–435.

[4] A. Finley, "How College Contributes "to" Workforce Success: Employer Views on What Matters Most." [Online]. Available: https://eric.ed.gov/?id=ED616977

[5] C. A. Bodnar and C. Hixson, "Capturing Students' Perception of Entrepreneurial Mindset: Tools for What and Why," vol. 7, no. 1. [Online]. Available: https://eric.ed.gov/?id=EJ1199669

[6] D. Rae and D. E. Melton, "Developing an entrepreneurial mindset in US engineering education: An international view of the KEEN project," vol. 7, no. 3. [Online]. Available: http://www.jeenonline.org/Jeen_Vol7_Num3.html

[7] J. M. Haynie, D. Shepherd, E. Mosakowski, and P. C. Earley, "A situated metacognitive model of the entrepreneurial mindset," vol. 25, no. 2, pp. 217–229. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0883902608001031

[8] L. Bosman and S. Fernhaber, *Teaching the Entrepreneurial Mindset to Engineers*. Springer International Publishing. [Online]. Available: http://link.springer.com/10.1007/978-3-319-61412-0

[9] J. S. London, J. M. Bekki, S. R. Brunhaver, A. R. Carberry, and A. F. McKenna, "A Framework for Entrepreneurial Mindsets and Behaviors in Undergraduate Engineering Students: Operationalizing the Kern Family Foundation's "3Cs"," vol. 7, no. 1. [Online]. Available: https://eric.ed.gov/?id=EJ1199586

[10] J. A. Gargac, "Building Entrepreneurial Mindset: Motivating Curiosity, Connections, and Creating Value in an Assistive-Device Design Project," vol. 146, no. 054501. [Online]. Available: https://doi.org/10.1115/1.4064520

[11] M. West, M. Silva Sohn, and G. L. Herman, "Sustainable Reform of an Introductory Mechanics Course Sequence Driven by a Community of Practice," in *International Mechanical Engineering Congress and Exposition*, vol. 15. ASME, p. 11. [Online]. Available: https://dx.doi.org/10.1115/IMECE2015-51493

[12] M. West, N. Walters, M. Silva, T. Bretl, and C. Zilles, "Integrating Diverse Learning Tools using the PrairieLearn Platform," in *The 52nd ACM Technical Symposium on Computer Science Education*. ACM, Jul. 2009, pp. 161–165.

[13] M. West, G. Herman, and C. Zilles, "PrairieLearn: Mastery-based Online Problem Solving with Adaptive Scoring and Recommendations Driven by Machine Learning," in *2015 ASEE Annual Conference and Exposition Proceedings*. Seattle, Washington: ASEE Conferences, Jun. 2015, pp. 26.1238.1–26.1238.14.

[14] C. Zilles, M. West, G. Herman, and T. Bretl, "Every University Should Have a Computer-Based Testing Facility:," in *Proceedings of the 11th International Conference on Computer Supported Education*. Heraklion, Crete, Greece: SCITEPRESS - Science and Technology Publications, 2019, pp. 414–420.

[15] Mechse reference pages. [Online]. Available: https://www.mechref.org/

[16] M. Opolz and M. Hoyle. (2024) Making space for curiosity, connection, and creating value. [Online]. Available: https://engineeringunleashed.com/card/4144

[17] C. Commons. Attribution-noncommercial 4.0 international (cc by-nc 4.0). [Online]. Available: https://creativecommons.org/licenses/by-nc/4.0/