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Introducing First-year Students to the Engineering Design and Communication Skills Needed in Capstone

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From the Start: A Case for Introducing a Design, Build, Test Classroom Earlier in the Curriculum

Following a recommendation of the College of Engineering Industrial Advisory Board, faculty at Embry-Riddle Aeronautical University integrated almost all upper-level engineering capstones with courses in advanced technical writing starting in 2003 and finalized the completion of this effort in 2013. The courses are co-taught by a professor of engineering and a professor of communication, working in tandem to provide comprehensive, industry-reflective design experience to students over the course of a year. In the course students work in teams to deliver progress reports and presentations on a design they formulate and build at facilities available on campus. Their progress presentations and reports are modeled after those seen in industry.

In Fall of 2021 two of this paper's authors sought to mirror this paired instruction in the students' first year. They created a "cornerstone" course by combining an early curriculum CAD design course, EGR 201, with a technical writing course, COM 221 [1]. The two courses were scheduled back to back on MWF, which created a 2 hour and 40-minute block of instruction time.

As part of the paired cornerstone courses students completed two engineering design projects that were intended to mirror what students are required to do in the capstone courses. The initial individual assignment asked students to design a 3D-printed water rocket. Students documented their particular design in a written proposal. The second project was team-based, and it involved designing a system in response to a provided RFP. The teams were tasked with refining the requirements and then developing possible design concepts, which they presented in a Concept Design Review; the presentation was accompanied by a written proposal. Subsequently, teams developed the details of their design, and they created more refined CAD models, which were presented in a Preliminary Design Review. In the last weeks of the semester, teams refined their designs further as analyses were done to show how their design met system- and subsystem-level requirements. Students presented their final designs in a Critical Design Review that was followed by a technical report documenting their design. A formal drawing package was submitted along with the report.

Through this cornerstone model, the authors were able to foster the adoption of skills and problem-solving capabilities needed to accomplish tasks in upper-level engineering courses at their southwest engineering university. Since the curriculum change last year, all new sections of EGR 201 have been offered as paired courses. Two combined courses in the fall and one in the spring, each with about 30 students gives a ninety-student impact over the course of a year. These courses have met with equal, if not greater, success. While the authors of the previous paper find value in their initial findings, the continued success of their early integration model has led them to consider a significant restructuring of the current curriculum to privilege early experience with combined project-based classes.

Problem Defined

Initial concerns with the early project-based combined course model were that students might lack significant background knowledge and communicative experience needed to make such an approach to design achievable. While students could be counted on to acquire such knowledge and experience throughout their time in the program, the early positioning of the cornerstone course in the overall curriculum meant that students entering the combined course in their first year would need significant assistance to reach even a reduced version of the design products and documents that their more experienced, senior-level peers produce.

Assertion

While students in the early-level combined courses have less technical knowledge than their counterparts in the senior capstone courses, the authors of this study discovered that first-year students are surprisingly capable of grasping and communicating advanced engineering topics when given supplemental instruction on focused engineering topics. Counterintuitively, first-year presentations and reports often describe their design solutions more clearly and trace the solution to design requirements more effectively than many senior capstone presentations and reports.

In this paper, the authors give examples of their supplemental instruction at the cornerstone level, provide illustrations of these moments of outstanding, competent performance by first-year students and make a case for a dynamic shift in engineering curricula based on their findings.

Supplemental Instruction of Focused Engineering Topics

At its core, the design process involves defining a problem and its surrounding requirements, proposing a solution to the problem, and demonstrating that the proposed solution satisfies the requirements and therefore solves the problem. With guidance, first-years can identify a problem, specify requirements, and propose reasonable solutions. What they lack are the engineering tools to demonstrate that the proposed solution satisfies the requirements.

To bridge this gap, the authors provided targeted instruction on key engineering concepts and basic formulae relevant to the individual projects. Because structural integrity is an important requirement for any mechanical design, all students were given one lecture on the strength of materials. Topics included stress and strain, stress-strain diagrams, bending stresses, beam deflection, and thin-walled pressure vessels. The concepts were introduced, and formulae were provided without derivations.

Then, as teams recognized a need to verify requirements, additional instruction was provided. For example, one project involved combined torsion and bending, so they were introduced to the concept of principal stresses and provided the necessary formulae. Another project involved transient heat transfer through a plane wall. They were given a basic explanation of finite difference analysis and provided an Excel spreadsheet that performed the necessary calculations.

The students were remarkably receptive to this instruction because it directly applied to their projects. They asked perceptive questions and quickly learned to apply an approach used for one problem to similar problems. Although their depth of understanding was superficial, they proved capable of communicating the analyses. Their final reports and presentations described the analyses clearly, and when questioned about their analyses by outside reviewers, they answered competently.

Besides giving the students the tools to solve the immediate problems for their projects, this instruction will provide them with context as they dive into the concepts more thoroughly in their later courses. Because they will have seen how to apply the concepts to real-world applications, they should better see the value in the material. They should also recognize that each course does not exist in a vacuum. Rather each real-world problem requires a variety of engineering tools to be applied in new ways.

Student Performance Across a Mirrored Curriculum

To demonstrate student uptake of these concepts and supplemental lessons, we provide illustrations of student engagement with the material. One of the unique affordances of the current iteration of the combined design course was that a professor responsible for teaching a section of the combined first-year course was also teaching a section of the senior-level combined capstone course. Because the first-year students from the previous year's instruction were not yet seniors, this year's seniors had yet to receive instruction in design-focused writing or presenting strategies [1]. As such, a unique comparison was possible. Many of the instructive materials, outcomes, and handouts given to the senior-level students directly mirrored or emulated those given to the first-year students. This mirroring afforded a unique moment whereby seniors and first-years were given nearly identical instruction, allowing for a more equivalent direct comparison of their productions. The mirroring occurred in the lessons, assessment, and mentoring structures. An analysis of each is provided below.

Mirrored Lessons

As students in the upper-level course had not yet received instruction in engineering writing, their lessons were kept almost identical in theme to those received by the first-year students. The lessons and their contents have been organized in the table below for ease of comparison.

Table 1: A Comparison of Lessons Given in COM 221 to Those Given in COM 420
* Lessons taught in both the lower-level and upper-level communication courses

COM 221 Lessons	COM 420 Lessons – Propulsion Section
1. Introductions, Syllabus, and Basic Project Management	1. Introductions, Syllabus, and Logo Design
2. Learning to Learn	2. Requirement Writing
3. Creating a Positive Team Culture *	3. Writing Introductions, Using MS Styles *
4. Writing Introductions, Using MS Styles *	4. Creating a Positive Team Culture *
5. Addressing Team Conflict *	5. Addressing Team Conflict *
6. Writing Memos, Integrating Figures into Technical Writing *	6. Project Management: Gantt Charts, MS Projects
7. How to Make Decisions as a Team	7. Patents, Intellectual Property, and How to Cite Works in Engineering Writing
8. Continuing to Manage Successful Team Operations	8. Integrating Figures into Technical Writing*
9. Writing Proposals and Drafting Engineering Storyboards	9. Designing Slides *
10. How to Make Arguments in Engineering *	10. How to Organize a Presentation
11. How to Analyze an Audience	11. How to Make Arguments in Engineering *
12. How to Revise by Identifying Components of an Argument	12. How to Deliver Effective Speeches as a Team *
13. How to Revise by Organizing and Unifying Your Argument	13. Writing in a Simplified Style *
14. Designing Slides *	14. How to Design Engaging Posters
15. Writing in a Simplified Style *	
16. How to Deliver Effective Team Speeches*	

The table above provides a list of the lectures and activities given in both courses. To keep the direct instruction brief and leave more time for group design work, lectures were delivered in under twenty minutes using a PowerPoint format. Each lecture had integrated activities and discussions to embed learning throughout the semester. The mirrored lesson format above demonstrates a distinctive symmetry in the lessons between the two sections, with some days hosting directly identical instruction. As shown in Table 1, instruction differed most heavily between the beginning and end of the semester. The differentiation is due to the senior course ending in a design symposium. After their year-long project resolves, seniors are invited to speak at a design symposium with a poster presentation where they share their year-long progress and results with other students and invited professionals from various industries. The first-year students do not have a symposium to present at, so their instruction in symposium-specific criteria was bypassed.

Despite these differences, once the semester settled into the writing, speaking, and design tasks by the teams, the workloads and content were remarkably similar. This parity between courses allows us to understand that the lessons given at the lower level were not too advanced in content or work for the students to acquire the necessary competencies from a communication standpoint. Rather, the students at the first-year level were able to keep pace with the seniors in their lessons and outputs. While technical communication proficiency takes time and focus, this time and focus is possible at various times within the curriculum.

Mirrored Assessments

Building from the mirrored lessons, the assignments were also mirrored, demonstrating that assessment and standards were the same across both sections. The upper-level course typically follows a design structure based on writing a series of documents that frame a proposed design project and then detail discrete plans for its completion. These assignments and a brief description are as follows:

> *Request for Proposal:* A document meant to frame the need for the project. Students write as if they are an industry partner framing the request for the engineering work that needs to be completed. In COM 420, this document is occasionally drafted in collaboration with real industry partnerships to give students a direct sense of working across institutions.
>
> *Requirements:* A document that outlines the requirements for the project. These requirements are written as specific, measurable outcomes that the remainder of the project is held to.
>
> *Teamwork Agreement:* A document that outlines the agreement to work together as a team and discusses the specifics of that arrangement in a pseudo-contract format.
>
> *Trade Studies:* A document that gives a briefing on the work the students did to make design choices between the different aspects of their project. Trade studies are typically conducted in a recognized matrix format and then are followed by a written explanation of logic and constraints to arrive at these matrix-based decisions.
>
> *Concept Design Review:* A presentation of the initial design concepts developed by the students. While the design at this stage may be rough in nature, students give a range of preliminary analyses and research that shape their design decisions.
>
> *Preliminary Design Review:* A presentation of the student’s fully drafted designs. CAD models are expected at this stage, and the purpose of the review is to explain how their preliminary design fully meets the requirements of the project that were set in the earlier requirements document.

Like the course lessons, these assignments were nearly identical between the upper and lower variations of the course. While the student's projects differed (for instance, the lower-level courses were not given industry-sponsored projects), the outcomes of their work were assessed the same from a communication and design perspective. Additionally, the level of engineering detail expected was similar. In both cases, students were expected to create comprehensive models of their designs with CAD software and incorporate those models into reports and review presentations.

Furthermore, the rubrics used to assess the communication goals were identical. An example of one of the communication rubrics is provided below:

Design Concept Presentation FA2022

You've already rated students with this rubric. Any major changes could affect their assessment results.

Criteria	Ratings				Pts
Slide Title	5 pts **Meets Expectations of Professional Presenting** The slide title is in the top left of almost every slide. It is concise and directly states the purpose of that slide.	3.5 pts **Underperforms Expectations** The titles are at the top left of most slides, but they are sometimes vague or unclear.	1 pts **Fails to Meet Expectations** Titles are messy, disorganized, or absent.		5 pts
Slide Evidence	10 pts **Meets Expectations of Professional Presenting** Each slide presents direct and compelling visual evidence of what the speakers are trying to verbally explain.	9 pts **Meets Expectations of Student Presenting** Most slides contain direct and compelling visual evidence of what the speakers are verbally explaining, but some bullet points or unnecessary icons/pictures are used.	7 pts **Underperforms Expectations** The presentation is filled with evidence that does not directly explain what the speakers are verbally saying. It deviates from their purpose, or, alternatively, it is too simplistic to be of use.	3 pts **Fails to Meet Expectations** The evidence given in the presentation appears to be low-effort or lacking in substantial scientific understanding of the project.	10 pts
Running header	5 pts **Meets Expectations of Professional Presenting** There is a clear running header throughout the presentation.	0 pts **Fails to Meet Expectations** The presentation is missing a means of organizing the audience's expectations.			5 pts

Visual Design	**10 pts** **Meets Expectations of Professional Presenting** The visual component of the presentation is compelling and actively engaging on its own. It adheres to all of the principles of design and is of professional quality. There is a running theme with matching colors throughout the presentation.	**9 pts** **Meets Expectations of Student Presenting** The visual component of the presentation is well crafted. It adheres to all of the principles of design but may be simple or underdeveloped.	**7 pts** **Underperforms Expectations** The visual component of the presentation is acceptable. It adheres to many of the principles of design, but there may be noticeable design issues.	**5 pts** **Fails to Meet Expectations** The visual component of the presentation is sloppy or difficult to comprehend. It may impact the understandability of the presentation.	10 pts
Page Numbers	**5 pts** **Meets Expectations of Professional Presenting** There are page numbers throughout the presentation.	**0 pts** **Fails to Meet Expectations** The presentation is missing a means of referring to specific slides.			5 pts
Organizational Slides	**5 pts** **Meets Expectations of Professional Presenting** There is a title slide, an agenda slide (or equivalent), a team introduction slide, and a slide prompting questions.	**0 pts** **Fails to Meet Expectations** The presentation is missing a means of organizing the audience's expectations.			5 pts
					Total Points: 40

Figure 1: Design Concept Review Sample Rubric Fall 2022

The rubric above is written generally enough to apply across multiple contexts, and so it was applied both at the first-year level and senior-level courses where the communication skills being worked on were largely in parity with one another. Several of the components are binary in nature: slide title, running header, page number, organizational slides. These binary assessment components serve as low stakes completion activities to allow students to set a reasonable baseline for their grade with adequate adherence to assignment criteria. Because this assignment is given as a formative assessment, these low-steaks criteria help the students receive honest feedback on the important criteria (e.g. argument and slide evidence) without it severely impacting their overall grade and growth in the course. The larger point categorizations are left for more contextual factors and thus are more subject to direct criticism. The rubric above inspires growth while setting the bar high for achievement at a professional level. As such, the rubric is geared for students who are expected to perform at a higher level than may typically be asked of a first-year course. In order to prevent these high expectations from feeling unfair to the students in the course, a direct mentoring structure similar to what the senior-level students receive was put into place in the first-year courses.

Mirrored Mentoring Structures

Beyond the teaching and assessment practices, students in both courses were mentored under a similar structure. After the lectures and activities were finished each day, the professors would approach each student group and hold individual group conferences with them to go over their design ideas, questions, and document drafts. On most days the communication professor and the engineering professor worked in tandem, though when separate expertise was needed, the mentoring was split to accommodate more groups. Often, these reviews involved the students presenting in-progress drafts of their work and the professors suggesting modifications and asking questions about their metacognitive design process. The purpose of these sessions was not to give the students the answers but to start them on the path of thinking and communicating like professional engineers.

Additionally, the dual mentoring model mirrored the mentor-seeking approaches in the upper-level classes. Often, students were required to seek out additional help and resources from outside the class. Most teams researched industry practices for their specific projects, and drew heavily on the resources in the McMaster-Carr website to identify component parts. Most teams also sought the advice of the university machinist personnel to ensure the manufacturability of their designs, and some queried student organizations to better understand their project requirements. These skills of seeking independent assistance and research are taught at the freshman level in other courses, but they are not typically taken up by students in a manner that they internalize. In typical unlinked first-year sections of communication, students have little incentive to see the value that these research and mentor-seeking practices have in the field of engineering. Though the students are told they should seek such help, they often do so at a bare minimum. However, in the group settings of the lower-level “cornerstone” course, the mentoring workshops actively encouraged students to take a more work-like inquiry process whereby students might seek out resources to help them without direct requirement to do so. Seeing this work-like inquiry valued in their professional spaces led to deeper engagement with the practice. These engagements are not typically seen until the senior-level course.

Student Outcomes

While the initial expectation was that students in the first-year course would perform to a equitable but lesser degree than their counterparts, our expectations were subverted when seeing the outcomes and productions of students at both levels. Overall, students at the lower level showed competency in writing and presenting equal to or surpassing their senior-level peers in the first semester. Examples are given and explained regarding the differences in both writing and presenting outcomes.

Writing

One of the areas of frequent struggle and focus in the senior-level capstone sections is the writing and explaining of equations and mathematical calculations undertaken in the process of engineering. While upper-level students are typically more than able to calculate a given mathematical process, explaining the work that they have done and applying it back to their current project requirements within a piece of writing can present a significant challenge. Multiple revisions and conferences are needed to get seniors writing their equations in an understandable and unified format. Typically, after about half a semester of instruction, we will receive sections like the one from our senior-level course shown on the following page:

Euler Column Formula: Calculates the critical force (P_cr) for the legs of the A-frame under load.

$$P_{cr} = \frac{C*\pi^2*E*I}{L^2} \qquad (5)$$

Von Mises Stress: Calculates the maximum stress for a cross beam for use in F.O.S.

$$\sigma' = \left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} \qquad (6)$$

$$\sigma' = \frac{S_y}{n} \qquad (7)$$

Max velocity after free fall: Using an energy balance we can find the velocity after a known distance of free fall.

$$velocity_{MAX}(^{m}/_{s}) = \sqrt{2*Weight*\left(\frac{Height_{initial}-Height_{final}}{mass}\right)} \qquad (8)$$

Impulse: Impulse is calculated by the difference in momentums before and after impact.

Figure 2: Senior-Level Equation Writing Example

Aside from a general misalignment of fonts and inconsistency of formatting, the equations above are displayed and discussed as if the reader is already aware of the project. This is poor communicative practice by most standards. This style of equation presentation is a significant barrier to any reader who might not be working with identical equations in their own work. Furthermore, the equations are provided back to back without any context or application within the project. This rapid-fire equation notation leaves the reader to connect the calculations back to the project haphazardly, increasing the chance of reader error or misunderstanding of the design as a whole.

We place this example in comparison with one of the equation explanations from the first-year course, which is found on the following page:

3.2 Forming Calculations

Calculations are necessary to confirm that the operator can form a blank without additional assistance and that the assembly will not break under loads.

3.2.1 Forming Force

The force that is needed to form the sheet metal is important towards knowing that the device will not fail under loads. The equation below represents the force needed at the roller wheel [4]:

$$F = \frac{kLS_t t^2}{d} \qquad (1)$$

Where:

F = bending force (lbs.)
k = constant = 1.33 (for v shaped dies)
L = length of bend = 1 in.
St = tensile yield strength of stainless steel = 31200 lb./sq. in.
t = material thickness = 0.125 in.
d = unsupported material, 8 times the material thickness = 1 in.

The force equation yields a force of 648 lbs., which is relevant to calculating the stress on the part in the below sections. It is important to note that this equation is not directly related to spin forming and is rather used for a punch and die. This equation was found to be the most relatable option to get a calculation. The math was done with characteristics of a stainless steel, 8th inch blank, since that is the strongest material desired to be formed [2.2.1].

Figure 3: First-year-level Equation Writing Example

While still not perfect, this example from the lower-level course shows an exceptional grasp of both the technical communication and engineering concepts in question. Not only are technical engineering concepts being conveyed, but they are being conveyed with a clear formatting structure and a standardized notation method for the equations. Citations are clearly marked and the equations are numbered for easy reference. More importantly, the calculations are put into context with the project, making it clear for the reader where and how this engineering impacts the final design concepts. Even though this student was given this equation directly for this project instead of finding it through their own research, they are able to talk about the equation with some authority while presenting it in a way that gives context to the reader.

Examples like this are numerous and varied within our courses. While this paper does not allow for time to run through them all individually, this brief example convinces us that first-year students are capable of being taught the writing and technical skills needed to enumerate highly technical concepts.

Presenting

Similar examples exist in student presentations. Complex technical information can often get lost in the complexity or lack thereof in the slides, and the ability to present technical information quickly and efficiently in a visual format is an essential component of the senior-level capstone course.

While students in these senior-level courses are given direct instruction on how to create effective slides for presentations, these lessons may take more than one presentation for uptake. As such, the following serves as an example of slide creation at the upper level:

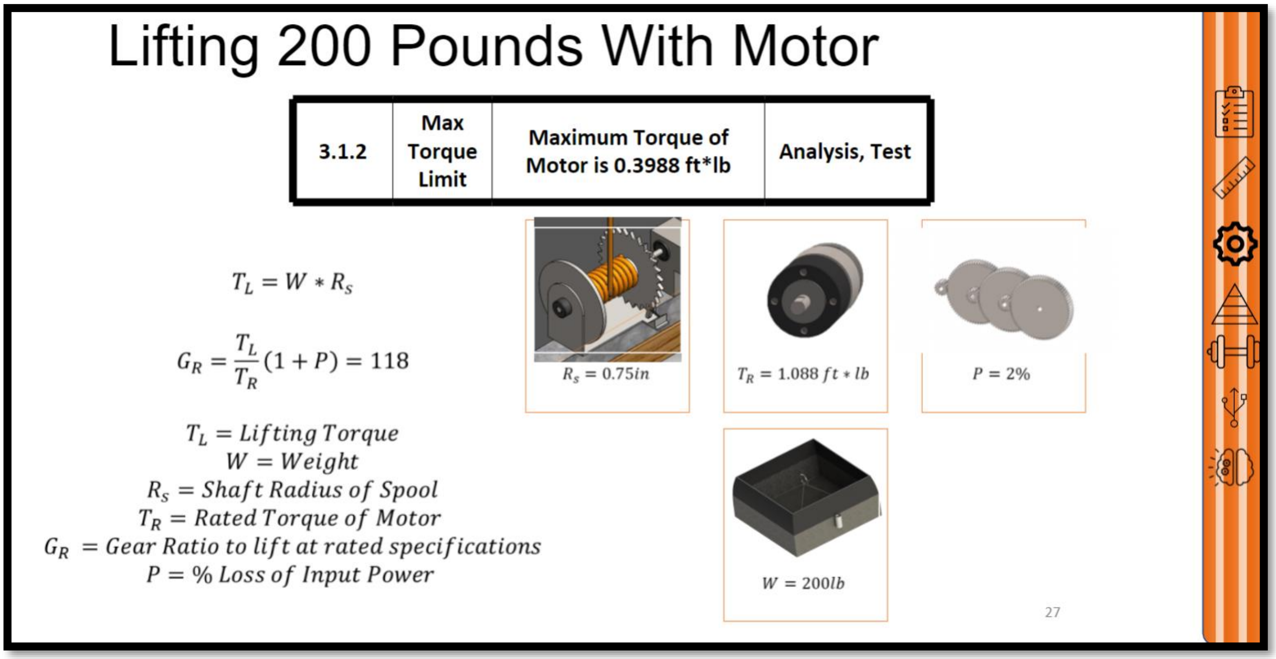

Figure 4: Senior-level Presentation Slide Example

As seen with the writing, the presentations at the senior level are expected to convey complex technical information in a simplified format. However, the visual components of these conveyances can lead to issues with clarity and visual design. In this example, we see a series of calculations to ensure that the motor the students have selected will be able to lift the 200 pounds required by their machine. While the variables involved in these calculations are laid out, they are arranged in such a way that the reader has to search to see how one equation builds into the next. The boxed design around the individual components makes the total machine operation difficult to understand and breaks up the logic of the spoken argument of the presenter. Furthermore, the visual choices made by the students, such as the light grey slide numbering and the orange running header make the slide difficult to parse from the back of the presentation space. The title of the slide, while clear on a basic level, does not convey purpose. We know that the motor will lift 200 lbs., but we are left to wonder how or why this lifting might occur.

These critiques are not meant as a criticism of the above student's work. To the contrary, this slide demonstrates learning in action that produces significantly improved results with each draft that is reviewed by the course professors and re-worked by the students. Rather, we present this slide with all of its positive and negative attributes to allow for a clear understanding of where the students are at this stage in their design process. It provides a relative measurement for student performance as we look to the first-year examples.

We now compare the previous slide to a similar one from a presentation in the first-year course.

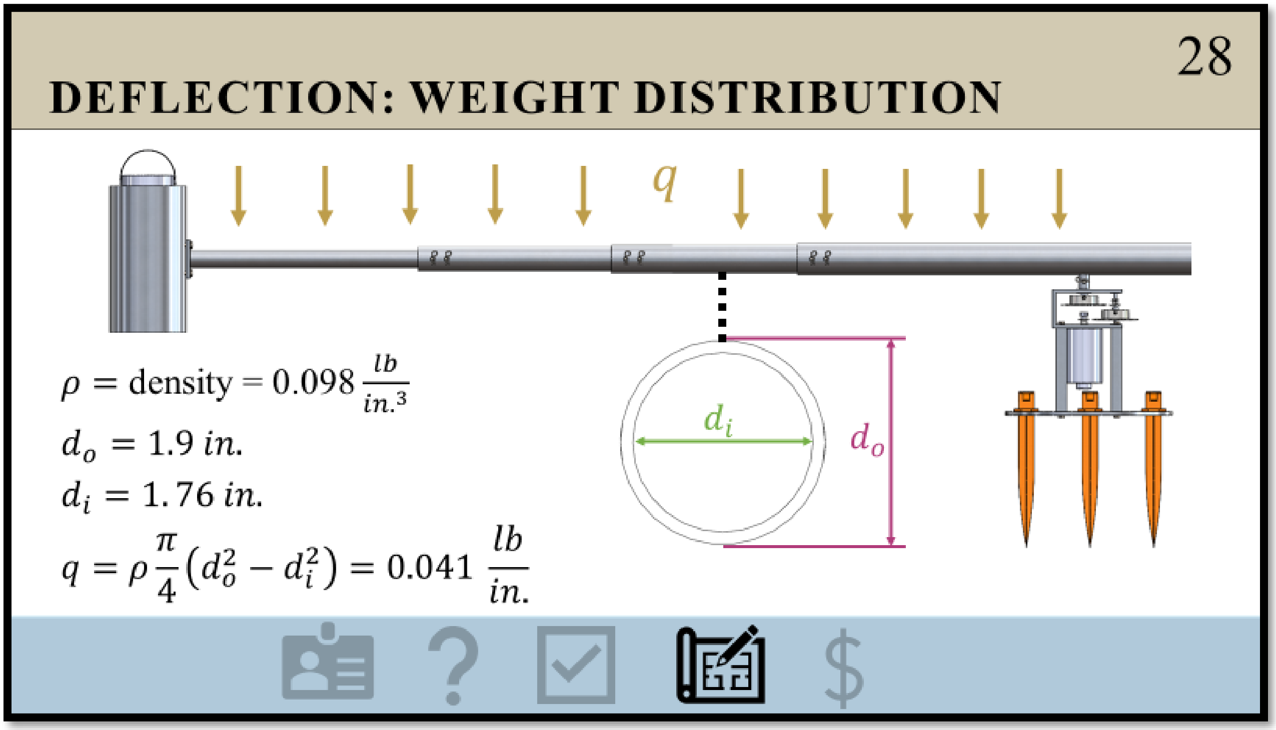

Figure 5: First-year Student Presentation Slide Example

Like the previous slide, this first-year slide sets out to convey technical calculations around a single object. In this case, the team demonstrated that they had successfully calculated the strength of material needed to avoid deflection in an apparatus meant to test the G-force loads placed on a series of electronics designed to later go into space. While suffering from some of the same problems as the first example, this slide stands out with its use of a clearly assembled component and color-coded integrated variable definitions in the images. Furthermore, the title is concise, but clarifies both the content of the slide and its purpose. This visually responsive slide design allows the audience to better follow along with the complex information provided and see how it enacts itself both mathematically and on the applied contexts at work. Simply put, it is a better representation of technical data at the first-year level than the senior slide achieved.

These examples are indicative of larger trends observed by the authors. Both the writing and presentations across sections showed equal if not superior qualities at the introductory levels. While this does not discount the learning that the seniors did, nor the hard work they have put into their projects, it leaves the authors with a difficult series of findings to reconcile. Namely, that it may be necessary to shift the engineering curriculum to reflect the consequences of understanding that not only are first-year students capable of learning these engineering and technical communication models within a design, build, test classroom, but that they may actually have a higher aptitude for learning these models at an earlier stage in their academic career. In the next section we posit reasoning for why this may be the case.

Shifting the Engineering Curriculum to Respond to Our Findings

In response to the findings above, the authors have advocated for a revised engineering curriculum that aims to accomplish the following:

1. It continues the paired EGR and COM instruction in the first year.
2. It adds coordinated EGR and COM instruction in the students' second year and paired instruction in the third year.
3. It modifies the paired instruction at the senior level so that students only have paired instruction in the first semester of the engineering capstone course.

To date, the first-year cornerstone class has been a merger of a computer aided design class, EGR 201, and a sophomore-level technical communication class, COM 221. The current university curriculum includes a first-year composition course, COM 122, but roughly half of the incoming students receive advanced placement credit for this course. It is proposed to replace this course with an engineering communication course for which students cannot receive advanced placement credit. The new COM course will replace COM 221 as the course being merged with EGR 201.

While starting this instruction early in the students' career is vital, the authors acknowledge that it is insufficient to address students' needs. Students need additional opportunities to practice what they have learned, to reflect on their learning, and to develop the necessary habits. To these ends, it is essential that quality learning environments be created in the courses students take in their second and third years.

To accomplish this objective, the technical writing course, COM 221, will be coordinated with a second-year course, likely ES 202 Solid Mechanics. It is anticipated that these courses will not be co-taught like the cornerstone class, but they will be co-requisites with each other. Students will be assigned technical writing tasks in the engineering course, and these same assignments will be assessed in their COM 221 class. Much of the focus will be on professional communication of engineering analyses.

In the current curriculum, the senior capstone classes are co-taught with advanced technical communication courses, COM 420 (1 credit) in the first capstone semester and COM430 (2 credits) in the second semester. We propose removing COM 430 from the senior capstone sequence and embed it into a third-year engineering course. By the third year students have begun to specialize within their chosen track (Robotics, Energy or Propulsion), so it will be embedded into track-specific courses. The goal is to find a project-oriented course in each track where the design, teamwork, and communication skills learned in the cornerstone class can be reinforced.

Key to this curricular development is that it is grounded in the learning outcomes of the Mechanical Engineering Department. The faculty involved have identified the skills that students need post-graduation as well as those needed to succeed in the two-semester capstone course. They have articulated an effective way to introduce those skills to first-year students, providing them with meaningful learning opportunities that are steeped in the practices they will encounter throughout their academic career.

Benefits

With the focus on developing an outcomes-based engineering communication curriculum, each assignment is created and valued as an opportunity to develop the skills requisite to perform effectively in capstone. In this regard, the engineering faculty are not asked to teach writing; they are asked to ensure their students have multiple opportunities to develop the skills the department values.

Often engineering faculty are reluctant to include writing and oral communication assignments in their classes and provide the needed instruction because these tasks reduce the class time for engineering topics [2]. With the combined approach we have demonstrated that this need not be the case. In fact, the engineering faculty member has more time to cover required material than if he taught the course separately. The COM portion of the course is organized such the writing professor forefronts all of his instruction in the first two thirds of the semester. The last third of the semester is used for one-on-one instruction and group mentoring. When this individual and group instruction is not needed, the engineering professor takes over some of the time that was initially allotted to the communication portion of the class.

This approach also acknowledges the ways that stand-alone writing courses taught as part of the general education program do not and cannot provide engineering students with the instruction they need and the assignments they require to communicate effectively as an engineer [3]. The students, right from the beginning of their academic careers, need to be exposed to the genres that engineers write and the ways of thinking requisite to write effectively in these genres. To be successful at the senior level they need multiple opportunities to engage in designed-focused projects and practice making engineering arguments.

This combined approach identifies both the teamwork and engineering design skills students need to develop prior to entering the capstone courses. Too often in academic settings students are assigned to work in teams and they are assessed based on how well their team functions, but they are not taught the skills and knowledge needed to perform intentionally [4]. The paired instruction addresses this deficiency by highlighting for students the skills they need to develop and providing both the instruction they need and the team-based opportunities to develop these skills. The same is done for the instruction on engineering design. The curriculum makes explicit what students need to learn about engineering design. With these beliefs and practices articulated for students in the first year, faculty in subsequent courses can create designed-focused assignments that seek to develop students' abilities.

Conclusion

The examples above allow the authors to conclude that the success of the first-year students compared to their senior counterparts is a consequence of the seniors not being exposed to the full design process, long-term teamwork, and rigorous technical communication standards until they reach their capstone senior design sequence. By that point, they seem to be less receptive to such elementary ideas. They become absorbed in the technical details of their projects and too often ignore the primary objective of the project and dismiss the importance of communicating their work effectively. Although seniors are fully capable of outperforming their first-year counterparts in these areas, they seem to lack the motivation. Conversely, first-year students are eager to engage in real-world engineering challenges and are more receptive to elementary ideas.

The first-year cornerstone class thus lays a foundation that should make the students better prepared when they reach their senior year. Just as we expect seniors to apply calculus and statics to their capstone projects without instruction on these topics, we can expect these students to likewise follow the design process, function effectively in teams, and communicate clearly.

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