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Guiding First-year Students through the Design Process in Linked Computer Aided Design and Technical Writing Courses

Dr. Matthew J Haslam, Embry-Riddle Aeronautical University - Prescott

Department Chair, Humanities and Communication

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At the recommendation of the College of Engineering Industrial Advisory Board, faculty at Embry-Riddle Aeronautical University began integrating communication instruction with the senior capstone design classes in 2003. This effort was formalized in 2013 when a one-semester Speech class was replaced with a two-semester Advanced Technical Communication class that is co-taught with the capstone classes.

For these co-taught courses, a communication instructor and an engineering instructor work in tandem to guide student teams through the year-long design process. Teams report on their progress and results through technical reports and presentations modeled after those used in industry.

Problem Defined

The authors, who co-teach a mechanical engineering senior capstone design class, have observed that students come to their capstone classes unprepared for the open-ended, team-based work expected. While students have learned to solve a variety of engineering problems within specific disciplines, they have not learned to follow an engineering process to identify and formulate a real-world problem and to apply their disparate problem-solving skills to that problem.

The engineering process comprises six well-established steps:

1. Define the problem to be solved to ensure a common understanding and to avoid later scope creep.
2. Specify system-level requirements following the SMART model: specific, measurable, achievable, relevant, and time-constrained.
3. Conduct trade studies to identify the concept that best meets the requirements. Brainstorm a range of potential solutions and quantitatively rank them against the requirements.
4. Develop the selected design concept into a preliminary design typically including CAD models and a system performance model; this step often involves lower-level trade studies.
5. Develop a detailed design ready for prototype manufacturing; formal engineering drawings document the design, and detailed analyses show compliance to requirements.
6. Validate the design through prototype testing carefully planned to confirm that the design meets the specified requirements and solves the defined problem.

Capstone students struggle with each of these steps because they lack experience with the process. They resist documenting a clear problem statement as they assume everyone involved shares a common understanding. Unless directed otherwise, they find it difficult to compare concepts on a rational basis. As they develop their design, they fail to recognize how their past coursework applies to their designs. They see each course in isolation, and because the courses focus on solving well-defined problems, they have little experience transforming a real-world situation, through appropriate assumptions, into a solvable engineering problem. As few students have manufacturing experience, they often give little consideration to the manufacturability of their designs. Finally, because they failed to establish clear and measurable requirements, they struggle to design an experiment to validate that their design meets those requirements.

The authors have also noted how students in the capstone courses struggle with the required teamwork. These difficulties stem, in part, from the fact that team projects in pre-capstone courses do not prepare students for what is required in capstone. Table 1 documents how team projects differ in courses that lead up to capstone and the projects expected in capstone courses.

Table 1: Pre-capstone Projects Compared with Capstone Projects

	Pre-capstone Projects	**Capstone Projects**
Team Size	2 – 5	5 – 14
Team Duration	Varies from 1 week to the full semester	2 semesters
Team Structure	Informal, often comprised of friends	Formal team w/ team lead and assigned roles
Scope	Distinct projects that last 2 – 5 weeks 1 – 5 hours a week 5- to 25-page reports Only 2 required EGR courses include presentations	Requires 28 weeks to attempt to complete 10 – 18 hours per week 30- to 100-page reports 5 – 8 presentations over 2 semesters

Previous research documented that students develop teamwork habits in pre-capstone courses that do not serve them well subsequently. Due to the short duration of the team projects, students describe developing a "get the project done" mentality in which they do not acknowledge, address, or resolve conflicts they face in completing the project. They also explain how nearly all of the pre-capstone teams involved working with friends or acquaintances. In these settings there was no need for a formal team lead nor the need to organize a team, identify team rules, or develop team processes for ensuring balanced participation and ensuring the quality of team-authored documents. Far too often, given the limited scope and lack of complexity, the projects require only limited interaction between teammates. It is common for teams to produce "combined individual work" where each person completes his or her tasks separately with the work being compiled just before a deadline.[1]

In none of the pre-capstone courses did students receive instruction on how to work in teams. In this regard, these students are not unique. The literature on teamwork in academic classroom settings acknowledges that students are expected to complete team-based assignments without any explicit instruction on teamwork.[2]

To address this deficiency, one author developed a series of research-based teamwork presentations that are given in the first semester of capstone. Despite the formal instruction, all too often teams fall back on old habits; the result is that too many teams experience "unhealthy team dynamics that inhibit the progress of the students' projects." In some cases, "the team dynamic is so unhealthy that despite repeated conflict mediation, the team project is jeopardized."[3] In an extreme case one student chose to depict his capstone experience in the form of a World War II map.

University-required Writing Courses

Senior engineering students also struggle with the written communications tasks they are assigned in capstone. In previously conducted research, one senior capstone student who was interviewed commented that "the team I am on is full of intelligent people who know what they are doing from a technical perspective. Unfortunately, at the start of the first semester, we were unsure of how to work together on technical reports because everyone had had different experiences in other courses. If other courses gave insight into how reports and groups work in capstone courses, the initial shock of capstone could have been avoided."[4]

Current capstone students have also identified the deficiencies in the writing instruction they have received. To graduate, all students are required to take two writing courses: a first-year composition course (FYC) and a 200-level writing course. At each level the courses are taught as stand-alone writing courses, and they include students whose majors differ widely. Students are taught general writing principles and general writing strategies by instructors who are unfamiliar with the writing demands of each students' major. For the 200-level course, engineering students almost exclusively take Technical Report Writing, which introduces students, as explained in the course catalogue, "to the preparation of formal and informal technical reports, abstracts, proposals, instructions, professional correspondence and other forms of technical communication."[3]

At no point in either of these courses do students receive explicit instruction on how to write engineering documents. Current capstone students expressed frustration they have taken the required courses at the university and yet they were not taught the engineering-specific standards they are expected to meet in capstone.

Another deficiency in the writing curriculum is that the writing instruction predominantly focuses on each student improving individual skills. In the first-year writing courses all assignments are completed individually. There are no opportunities to write with others as part of a team project. This changes somewhat when students take Technical Report Writing course. A curricular review of the nine sections offered in Fall 2021 revealed inconsistencies across the sections with regards the amount of teamwork and team writing that is completed. Table 2 documents the percentage of the final grade that is allotted to team projects and team writing.

Table 2: Teamwork and Team-based Writing in Technical Report Writing

Instructor	Sections Taught by Instructor	% of Grade Allotted to Team-based Assignments	% of Grade Allotted to Team Writing
A	1	20%	10%
B	2	0%	0%
C	3	40%*	20%*
D	2	25%	14%
E	1	0%	0%

* Instructor C allows students to work in groups of two to three on two of the three primary class projects.

A total of 66 students (34%) enrolled in these nine sections did not have the opportunity to work in a team or complete a team document.

What happens too often is that students are assigned team projects and required to write in small groups or teams, but they are not taught team-writing strategies. As a result they struggle to adapt what they have learned about individual writing processes to group settings. Steps for which they have become proficient at as an individual now become unfamiliar as they involve six to nine other students. The authors have also noticed that important steps in the writing process, like revision, can be easily skipped when teams rush to complete documents by the deadlines.

<u>Lack of Oral Presentations</u>

The senior engineering students also struggle with the oral communication tasks they are assigned in capstone. Students who are currently in the second-semester capstone course noted they are only assigned oral presentations in two engineering courses: EGR 101 and EGR 200 CATIA / EGR 201: SolidWorks. These courses are often taken in a student's first year, and they can be taken in a student's first semester. Given the introductory nature of the courses, the presentations are limited in scope. In two sections of the Spring 2022 EGR 200 course, students give a short, 5-minute individual presentation. Then, in groups of two to three students, they describe a manufacturing process they recently researched in a 7- to 10-minute presentation. Notably absent from these courses is instruction on giving audience-focused presentations, preparing well designed PowerPoint slides, and delivering information effectively.

The one additional course where engineering students are assigned an oral presentation is in the Technical Report Writing course. The aforementioned curricular review revealed that all instructors of Technical Report Writing require at least one oral presentation, although there is no consensus as to whether these presentations are done individually or in small groups.

Table 3: Oral Presentation Assignments in Technical Report Writing

Instructor	Sections Taught by Instructor	# and Type of presentations
A	1	One 10-minute team presentation
B	2	Two individual presentations totaling 15-20 minutes
C	3	Two presentations totaling 20 minutes*
D	2	One 3-minute individual presentation One 8-minute team presentation
E	1	One 10-minute individual presentation

* Students in Instructor C's course have the option of completing the presentation with one or two fellow students.

Solution

The mechanical engineering curriculum at Embry-Riddle Aeronautical University requires students to take a freshman design course (EGR 201) based on the SolidWorks CAD software. This semester-long class meets three days per week for two hours each day. Traditionally, the class has emphasized the capabilities of the software, especially as they relate to generating part models and assemblies. Students are introduced to formal engineering drawings and tolerancing, but these are not emphasized. Students work in teams to identify a need and design a solution for that need. Although each team delivers a formal presentation of their design at the end of the semester, they do not follow the established engineering process.

Having witnessed the struggles that capstone students experience, when one of authors began teaching EGR 201 in the Fall of 2020, he attempted to model the class after the capstone class. While still teaching the capabilities of the SolidWorks software and basic design principles, he emphasized a semester-long project and structured it around the six-step engineering process.

Because of the social distancing mandated by the pandemic, students worked individually. Each student was tasked with identifying a problem or need amenable to a mechanical design solution. They submitted a short essay describing the problem and ending with a clear, concise problem statement. They then wrote a brief requirements specification listing the top-level requirements. Next, they conducted trade studies comparing candidate solutions. Because first-year students lack engineering tools, these trade studies were qualitative in nature. The trade studies and the selected concept were described in a Concept Design Review submitted as a PowerPoint presentation with voice-over annotation. Students then created SolidWorks models of their designs. They described their design in a Preliminary Design Review submitted as an annotated PowerPoint presentation. Finally, at the end of the semester, students submitted a Critical Design Review presentation describing their final design along with a formal drawing of the design.

By structuring the first-year design class similarly to the senior capstone class, the professor was able to introduce students to the engineering process. However, they did not work in teams, and technical writing and presentation instruction was limited. The authors saw an opportunity to enhance the freshman experience by combining a Technical Report Writing course with the freshman design class (EGR 201). The goal was to more closely mimic the senior capstone experience and highlight the work environment they will see throughout their careers.

Requirements

Four key requirements for the combined course were identified. It needs to be a first-year course; students need to work in teams; the teams need to identify a problem and apply the engineering process to solve it; and they need to defend their designs through formal in-person presentations and formal technical reports.

By exposing students to the engineering process in their first year, they will gain context for their future engineering courses. They will be able to relate the concepts learned in later courses to the project in this course and recognize that each new concept is just one of the many tools needed to solve a complex engineering problem. The teamwork skills learned will prepare them for later team projects, and they will learn early on the importance of communication in engineering.

Combined Courses

In the fall of 2021 the two courses were scheduled back to back on MWF, which created a 2 hour and 40 minute block of instruction time. The professors planned their instruction without strictly adhering to the assigned time for their specific course. For example, it was decided that the writing professor would frontload his instruction early in the semester. This meant that in the opening six weeks of the semester he regularly exceeded the 50 minutes allotted for his course. This arrangement allowed him to cover the needed communication instruction ahead of the main communication assignments. Later in the semester the engineering professor was able to make up the time lost in the opening weeks.

Enrollment in this one section of the Technical Report Writing course was limited to the 19 students enrolled in EGR 201. Eighteen of these students had not previously taken COM 221; one student who needed to repeat EGR 201 had taken the 200-level writing course. Thirteen students were first-semester freshmen, and six students were in their second year. Of the 13 incoming students, four had to have the FYC prerequisite waived so they could enroll in the 200-level writing course. One of the four students elected to take FYC concurrently with the paired courses.

Assignments

Students applied the engineering process through two projects. The first was an individual project that involved designing a 3D printed water rocket, and the second was a team project to solve a student-identified problem.

For the water rocket project, students were given a Request For Proposal (RFP) for a 3D printed water rocket to deliver a penny 150 ft down-range. They were given an Excel-based trajectory model that students used to performed trade studies on material choice, water fill level, nozzle diameter, launch angle as well as other design parameters. The goal was to deliver the penny at the lowest possible cost based on a prescribed cost model.

Once they determined the optimum configuration, students modeled their rockets in SolidWorks. They were given drawings of the launcher that they would use to launch the rockets. They used these drawings to ensure their designs would interface properly with the launch rail and pressurization system.

Once they completed their models, they each wrote a proposal in response to the RFP that argued that their design was the lowest cost design that would reliably deliver the penny 150 ft down range. They needed to show that their design satisfied all the RFP requirements and offered the lowest cost.

After the models were printed in the university's Rapid Prototyping Lab, a flight test competition was held. None of the rockets performed to expectations, but students learned the limitations of 3D printing and the importance of clearances and tolerancing. Afterwards, students brainstormed lessons learned for future classes.

Team Project

For the team project, each student was first tasked with identifying a problem or need and writing an RFP that described the problem and specified the top level requirements. The water rocket RFP served as a model. From the RFP's submitted, the instructors selected four problems to be solved:

1. Mountain bike wheels break and spokes go out of true too easily, and it is too difficult to replace a broken spoke and re-true the wheel.
2. A standard vise requires at least one hand to tighten the jaws making it difficult to manipulate a bulky piece into place.
3. Soccer players need a way to practice receiving a crossed ball when practicing alone.
4. Loft style dorm room beds do not provide students sufficient headroom when they sit on the bed or when sitting at a desk underneath the bed.

Teams were formed based on their interest in the four projects. There were three teams of five students and one team of four. These teams were selected in week three, and they worked together for the rest of the semester during which time they completed three oral presentations and two written reports. Each team selected a formal team lead, and they were required to complete a team contract that identified team roles, documented rules of conduct, and described team processes.

With the problems selected, the teams began by brainstorming possible solutions to the problem. They then identified the key requirements from the RFP and scored each concept against those requirements. After selecting the best concept, they built preliminary CAD models and presented their work in a Concept Design Review (CoDR). They also submitted a proposal advocating their selected concept. This included a description of their trade studies to show that they had considered other options and determined that the selected concept was best.

After the CoDR, students began developing the details of their design. They created more refined CAD models, and they performed simple sizing analyses. Here, the engineering instructor provided targeted lessons on engineering principles and equations. For example, the bike wheel team was introduced to the concept of area moment of inertia as it affects the stiffness of the rim. Meanwhile, the vise team was shown how to calculate the torque needed to tighten the vise to achieve a specified clamping force.

With the CAD models and analyses mostly complete, the teams presented their status in a Preliminary Design Review (PDR). The emphasis was on showing the maturity of their designs and showing compliance to the RFP requirements. As the designs matured, the engineering instructor provided guidance on manufacturing methods and limitations as well as instruction on design-for-manufacturing and assembly principles.

The teams then began documenting their designs in formal engineering drawings. They also refined their analyses, but these analyses were incomplete because, as first year students, they lacked the engineering tools. The goal was to introduce them to the idea of demonstrating compliance through analysis without holding them to the rigor of a full analytical substantiation of their designs.

At the end of the semester, students presented their final designs in a Critical Design Review that was followed by a formal technical report documenting their design and demonstrating compliance with the requirements. A formal drawing package was submitted along with the report.

Teamwork and Communication Instruction

At the beginning of the team project students were provided a single presentation on organizing their team that covered the following topics: creating a positive team culture, getting to know team members, determining roles, developing shared understandings, and monitoring progress. This instruction was intended to help the teams establish a positive framework for working together. Most of the teamwork instruction took place in the form of team-by-team mentoring. Guidance was provided on how to assign team members tasks and how to follow up with team members about work in progress. The teams also needed assistance with knowing how to deal with conflicting viewpoints and how to address underperforming team members.

The students received engineering-specific writing instruction right from the start of the course. For the individual and team proposals, the professors provided students with a 5-page template that identified the main sections: Introduction, Requirements, Trade Studies, Design Description, and Summary. The template described the purpose for writing each section and outlined "Keys to Writing the Section." Part of this instruction included covering how writing an introduction in this context differs from what the students had been taught in other writing courses. Emphasis was placed on making engineering-specific arguments related to their design. Lastly, students were taught the formatting requirements they are expected to follow in capstone.

In addition to the writing instruction provided in class presentations, students had opportunities to submit drafts of documents and presentation slides. These drafts were primarily read by the communication professor, who provided detailed feedback. Additional team-specific instruction was provided as both professors met with teams individually to go over their feedback on the final drafts.

Instruction for the three oral presentations highlighted how each represented different milestones in the course of their project. The professors gave detailed explanations of what needed to be included in each presentation. In addition to the content-focused instruction, the communication professor provided instruction on delivering audience-focused presentations, and he also covered designing effective PowerPoint slides. Instruction on delivery was provided in the form feedback on the presentation; students also evaluated the video recordings of their presentations

Verification

To assess the effectiveness of the combined class, the authors first administered an anonymous mid-semester survey of the students. They were asked about their level of agreement with fourteen statements regarding the effectiveness and fairness of the class and their overall satisfaction with the class. Figure 2 shows the average results, where "1" indicates strong agreement with the statement, and "5" indicates strong disagreement. Although many students did not feel the SolidWorks quizzes were fair, nearly all the students reported that they found the study of the engineering process to be important and effective. They also reported that the teamwork and communication instruction was important and effective even though the assignments were not always clear.

1	I am learning the CAD skills I will need in my future career.	1.37
2	The study of the design process (i.e., Problem Statement, Requirements, etc.) is important for my future career.	1.21
3	I am learning to fully consider the manufacturability of my designs.	1.58
4	The sample modeling problems we do in class are interesting and effective.	1.79
5	The modeling work we do in class prepares me well for the quizzes and exams.	2.32
6	The modeling quizzes and exams are fair assessments of my CAD skills.	2.68
7	I am learning the writing skills I will need in my future career.	1.47
8	I am learning the presentation skills I will need in my future career.	1.37
9	I am learning the teamwork skills I will need in my future career.	1.37
10	he writing assignments are clear and effective.	2.16
11	The grading of the writing assignments is an accurate assessment of writing ability.	1.68
12	The grading of the presentations is an accurate assessment of my presentation skills.	1.74
13	I am learning a lot in this class.	1.26
14	I love this class.	1.95

1. Strongly Agree
2. Agree
3. Neutral
4. Disagree
5. Strongly Disagree

Figure 2: Mid-semester Survey Results

Students were also asked to comment on what was working in the class and what was not working. Overwhelmingly, they reported that they liked the combined class. They appreciated getting credit in two classes for the same work, and they appreciated receiving feedback on their writing and presentations from both a communication professor and an engineering professor. The main criticism of the combined class was that it was difficult to remain focused through the entire two hour and 40 minute class. Several students also expressed that there were too many large assignments stacked too close together.

The end-of-course student evaluations also provide valuable feedback. Unfortunately, students evaluated the EGR 201 and COM 221 separately, so there was little direct feedback on the combined nature of the class. Nonetheless, the scores for the EGR 201 class indicated that the students found the course effective and well structured. All scores were above the college average, and perhaps most significant, the scores were significantly higher than the instructor's scores in prior semesters teaching the class.

Benefits of Combined Teaching

One of the key benefits to the combined approach is that discipline-specific communication instruction can be provided without sacrificing the engineering content of the course. One reason engineering faculty are hesitant to include writing and oral communication assignments in their classes and provide the needed instruction is that these tasks reduce the class time for engineering topics.[4] In this case the engineering professor had already elected to include the design projects and communication assignments in the course. What was lacking in his initial iteration of the course was detailed instruction on how to complete the required tasks and present the information in discipline-appropriate ways. All of the missing instruction was able to be provided in the technical writing portion of the course.

This approach emphasizes situated learning.[5] The students learn engineering writing and oral communication practices by engaging in modified versions of the task they are required to complete in their capstone courses. This method differs significantly from approaches were students are asked to learn general technical communication principles in the hope that they eventually apply them correctly to an engineering setting. Instead, students learn specific forms of engineering communication that they will need to engage in in the capstone projects, and they are provided with the discipline-specific instruction needed. For these students, writing requirements will not be something new when they start their capstone sequence, and they will have experience giving briefings in which they explain how their design meets established requirements.

This approach is an explicit recognition and affirmation that "disciplinary writing is best taught as a partnership between composition and engineering faculty."[6] It builds on nearly a 20-year history of collaboration between the departments of Mechanical Engineering and Humanities and Communication in team teaching capstone courses. This collaborative expertise is now is now being used to benefit first-year mechanical engineering students, not just the capstone students.

Future

Implementation of the combined courses went so well that all three EGR 201 courses to be offered in the 2022-2023 academic year will be paired with a section of Technical Report Writing.

The course will become a key component of the Mechanical Engineering Department's participation in the university's Quality Enhancement Plan. As part of this program the department will articulate the sought-for communication skills that faculty in the Mechanical Engineering want all graduates to develop. The department will then develop a written plan that will outline how the communication skills will be developed.[7] In addition to the first-year course described in this paper, courses at the sophomore and junior level will be identified where writing assignments can be developed and additional writing instruction be provided. The goal will be to develop an outcomes-driven writing curriculum that is coordinated across all four years of instruction in the department.

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