The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #42550

Scaling an Aerospace Engineering Senior Design Program to Handle Increased Enrollment

Dr. Kathryn Anne Wingate, University of Colorado Boulder

Dr. Kathryn Wingate is an associate teaching professor at University of Colorado Boulder, where she teaches design and mechanics courses. She holds her PhD in mechanical engineering, and worked at NGAS as a materials scientist.

Dr. Marcus Holzinger, University of Colorado Boulder

Scaling an Aerospace Engineering Senior Design Program to Handle Increased Enrollment

Introduction

This paper details the approach taken at the University of Colorado Boulder to scale an aerospace senior design course with an undergraduate enrollment that has more than doubled within a 10-year span to over 200 students annually. We examine the initial course structure, the challenges encountered as enrollment increased, and the subsequent restructuring of the course to address these issues. In addition, a Large Language Model (LLM) analysis of the student course evaluations over the past 5 years will be performed to understand how student sentiment and growth in the course has changed.

Importance of capstone design courses in engineering

Capstone design courses were introduced into engineering programs around the 1960s to strengthen students' ability to practice engineering, inspired by the clinical practicums utilized by medical schools [1]. The overarching goal of many capstone design programs is for students to apply their analytical knowledge from previous courses and newly learned practical skills to a real-world design problem [1], [2]. Most programs require students to work in a team to solve an open-ended design problem, which exposes them to a diversity of perspectives, strengthens their communication and collaboration skills, and introduces program management skills [2]. Further, capstone design courses teach students design thinking, specifically to tolerate ambiguity, iterate on solutions, utilize systems engineering, and make decisions [3]. Overall, the engineering industry is a strong supporter of capstone classes, often funding programs, providing projects, and acting as project customers or mentors [2]. The Accreditation Board for Engineering Technology (ABET) recognizes that capstone design is a critical aspect of engineering curricula and requires all engineering programs to 'culminate in a major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work' [4]. Further, capstone design courses often support the attainment of ABET student outcomes 1, 2, 3, 5 and 7, preparing students to enter the professional practice of engineering [4].

Challenges faced by students and faculty with increases in enrollment

In the United States, enrollment in undergraduate engineering programs has increased by 63% between 2006 and 2015, to roughly 610,000 undergraduate engineering students [5]. In the Ann and H.J. Smead Department of Aerospace Engineering and Sciences, our undergraduate enrollment has more than doubled, from 688 students in 2013 to 1605 students in 2023. These increases in enrollment mean that engineering departments must scale their curriculum to handle more students. In large courses, research indicates it is difficult to accommodate different student learning styles, to track multiple student experiences, to meet students at their different levels of academic preparation, and to maintain uniformity across sections [6]. Increased student enrollment also results in resource constraints such as limited lab or classroom spaces, increased faculty load, inadequate TA/grading support, and constrained administrative resources. Problems faced by large course enrollment can result in high DWF rates, frustrated students, and low skill retention [6]. Project-based design classes can be especially difficult to scale due to the need to provide high quality timely feedback across many projects [7]. It is critical to determine a path to scale engineering design classes for large student enrollments while maintaining open-ended problem-based learning.

Strategies for scaling large classes

The literature shows several successful strategies for scaling up courses while acknowledging the difficulty in doing so. Twigg et al. points to the use of technology in the classroom, which has grown substantially over the past few decades [6]. Integrated learning systems, grading software such as Gradescope, and online assessments can often be implemented to streamline large lecture classes. However, project-based design classes require the assessment and feedback be tailored to a specific team's project and progress. Data science courses have utilized peer-graders and meta reviewers with clear rubrics to successfully scale projects [7]. These techniques lend themselves well to software projects that fall into the same technical field. However, open-ended capstone design projects have interdisciplinary solutions. Therefore peer-graders, TAs, or reviewers may not have the technical bandwidth to provide timely quality feedback.

Impact of scaling the senior projects course on student sentiment and growth

The Ann and H.J. Smead Department of Aerospace Engineering and Science's capstone course offers multiple industry-sponsored projects each academic year that span the aerospace field, from aircraft design to space situational awareness. Further, students not only design and analyze their system on paper, but they also then fabricate, integrate, and test their design in a prototypic environment. While this offers our students a very realistic experience in aerospace design, each project requires reviews from experts across various aerospace, mechanical, electrical, and software fields. The myriad of design projects coupled with the need for specialized technical feedback for each project has made this course difficult to scale. This paper has two distinct goals; 1) To detail the strategy implemented over the past two years to scale this capstone design course to fit a senior class of over 200 students while maintaining course learning objectives and 2) to better understand the student perception of the capstone course and subsequent restructure. A student's perception of a course can impact their engagement, learning, and performance [8]. The instructional team's explanation of the course structure, learning objectives, and resource constraints to the students can change their perception of the course and encourage student engagement. To do this well, we must first understand the student perception of the course and how it has changed over time. To this end, we strive to answer the following research questions:

- Research Question 1: How does student sentiment change between the new course design vs the old course design.
  Where we define sentiment as students perceiving this class as a positive or negative experience in their undergraduate academic career.
- Research Question 2: Is there a difference in self-reported student growth between the new course design vs. the old course design.
  One of the main learning goals of senior projects is for students to overcome a hard problem, or to experience a design failure but learn from the failure. We classify this as growth.
- Research Question 3: Is there a difference in student feedback on emergent topics when comparing the new course vs. old course, or when clustered by growth and sentiment?

To explore these research questions, a sentiment analysis is employed to study student evaluations of the course over the past five years. The sentiment analysis discerns trends in student satisfaction and growth on a Likert scale and is compared with anonymous student scores over available data. The amalgamation of sentiment analysis and emergent topic modeling via LLMs identifies recurring themes in feedback and allow a deeper understanding of the student impressions of the course prior to the restructuring, during the roll-out year, and in the first year of the restructured course. This analysis can be utilized to drive future changes of the senior design course.

Methods

Large Language Models demonstrate increasing utility in the analysis of natural language. Free-form student feedback comments, such as those provided by Faculty / Course Questionnaires (FCQs) at the University of Colorado at Boulder, are potentially an excellent source of additional information that is useful in course and instruction refinement. Sentiment analysis [9], the scoring of a sample text for positive, neutral, or negative feelings or perceptions, is an excellent example. Recent research has shown that LLMs can be effectively used for sentiment analysis in straightforward situations [10] (such as FCQ comments). The same techniques can be used to assess the student's perception of their growth based on the comment text. Additionally, substantial recent work has investigated the use of LLMs for emergent topic discovery [11]. The following sections explain how LLMs are used in this research to generate growth and sentiment Likert scores for each sentiment, and how emergent (latent) topics are discovered and analyzed.

Sentiment and growth Likert scale assessment

All 737 anonymous comments from AY 2017-2018 through Fall AY 2023 are loaded as entities in a json list, assigned unique identifier numbers (UINs), and their comments, term, and year captured. Comments from AY 2019-2020 and AY 2020-2021 were excluded from the analysis due to remote learning that occurred during the Covid-19 pandemic. The remaining comments are randomly re-ordered before sending them one at a time embedded in a system prompt to OpenAI's `'text-davinci-003'` model for text completion (prompt in appendix, 4,000 token input limit). Each comment is sent to the LLM without any metadata (i.e., UID, term, or year information) in random order and is independently scored according to growth and sentiment. Care is taken to ensure that each comment assessment is zero-shot (i.e., the LLM being queried is not aware of any other comments or their previous Likert scores). Likert scores are decimal with two digits of precision (e.g., 3.0), and are on the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (e.g., higher is better). Short summaries of the 'growth' and 'sentiment' Likert scores used in the prompt are:

- **Growth**: The student indicated or demonstrated growth in their ability to work in a team, in technical skills, or in soft skills. They overcame a challenge or tough experience. They learned about themselves and/or the world around them. They are better prepared for their future career. If the comment does not indicate or demonstrate growth (or lack thereof), please select 3.0.
- **Sentiment**: The student comment indicated or demonstrated a positive or negative sentiment towards the course, the instructor, the project, or the team. Constructive feedback is neutral (3.0); you are assessing the student comment sentiment, not the content.

Emergent topic discovery

Topic discovery is achieved by taking all comments, randomly re-ordering them again, and simultaneously passing along a list of 90 randomly sampled comments to the LLM 'emergent topic discovery' process (prompt in appendix). The list of comments is limited to 90 to ensure that the comments and prompt together fit within the OpenAI `'gpt-4-0125-preview'` context window limit of 16k tokens using the LangChain Python module. The top 10 emergent topics from these 90 comments are then captured.

Emergent topic mentions

Next, all 737 comments are assessed against the emergent topic list using OpenAI's `'text-davinci-003'` text completion model to determine whether any of those topics are present in the comment. A list of mentioned topics in each comment from the emergent and research topics list is appended to the comment's json object. Note, many comments don't mention an emergent topic at all (e.g., 'loved it!' is non-specific and would not classify as a 'mention' of one of the emergent topics). Such comments have empty topic lists from this process. An example json object from the list of fully processed comments is shown in Figure 1.

Finally, once each comment's Likert scores for growth and sentiment have been determined, emergent topics have been identified, and topics mentioned in each comment identified, quantitative analysis of Likert scores and emergent topics is initiated. The full derived data generation process is outlined below in Figure 2. Note that the growth and sentiment Likert assessments and topic discovery / comment classification workflows are parallel.


````
```json
{
        "UID": 632,
        "term": "Fall",
        "year": 2022,
        "comment": "Great professor, very helpful
        always there for questions. Does a great
        job of giving feedback to our teams to
        improve.",
        "growth": "4.0",
        "sentiment": "3.0",
        "topics": [
                "Advisors/Instructors Support",
                "Feedback and Communication",
                "Team Dynamics",
                "Effectiveness of Feedback"
                ]
}
```
````


Figure 1. Example Fully Processed Comment json Object

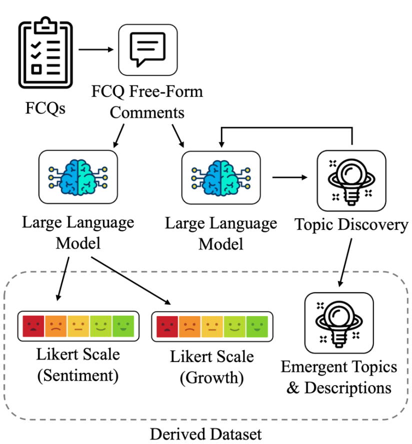


Figure 2. Block diagram for derived data generation for FCQ comments.

Initial senior projects course structure, assessment and learning goals

The initial senior design course spanned two semesters, and each student team had their own aerospace project which was provided by an industry, government, or academic sponsor. In 2014 the course had 10 teams, and a wide variety of projects, from remote sensing to mechanical design to propulsion. Table A1 in the appendix gives further project details. Note that at this time the projects were advised by a team of 8 faculty members, and project teams were roughly 9 students.

In the fall, student teams utilized requirements, trades, and analyses to develop a detailed design. In the spring, teams built, integrated, and tested the design to verify requirements. Student teams fabricated components within the machine and electronics shops on campus and integrated their systems in project build spaces. Students then performed testing using facilities and hardware within faculty research labs, campus teaching labs, or industry sponsored facilities. Teams then analyzed test data and assessed what portions of their system met requirements. Design progress was assessed by design reviews, which were oral presentations given by the student teams to a review board of all eight faculty members. The design development, modeling, integration, and test results were documented in final reports at the end of each semester. Figure A1 in the appendix shows a timeline of the original course schedule and assignments.

Course learning objectives

The initial senior projects course design was carefully developed in a full curriculum redesign, which rolled out in 2000. Over time this course became viewed as the ‘crowned jewel’ in the department’s curriculum. There were six major learning objectives in the initial senior projects course.

1) Project based learning
   Student learning shall be by doing. Students shall apply knowledge learned in previous courses to tackle an open-ended engineering design project.
2) Student-lead design
   Students shall have ownership of their project, freedom to make their own decisions in the project, and primary responsibility for the outcome.
3) ‘Design Build Fly’ approach
   Students shall have an end-to-end engineering experience that culminates in testing.
4) Program management and technical communication
   Program management tools shall be used to break the process down into manageable steps. Students shall gain experience in documenting and communicating their design progress according to professional engineering standards.
5) Systems engineering and integration
   Projects shall be complex enough that cooperation within large teams is needed. Students shall utilize systems engineering methods to track requirements and integrate the final system.
6) Teamwork
   Students shall tackle the open-ended design problem in teams. The project's complexity shall provide opportunities for all students to develop leadership skills.

When the course initially rolled out in 2000, there was an average enrollment between 50 to 75 seniors. While small changes were made to the course over time, the overarching structure, assessments, and learning goals remained the same. Over time, industry sponsorship increased. In 2018 we had 12 student projects, and 70% were industry sponsored. Student team size had grown to roughly 10 to 12 students per team.

Enrollment challenges
Enrollment in the department has rapidly increased over the past 5 years. In AY (18-19) there were 140 students enrolled in senior projects, which were split into 12 project teams. Currently (AY 23-24) there is an enrollment of roughly 215 students in senior projects, split into 21 student teams. This massive growth, combined with the Covid-19 pandemic, caused significant challenges in the course regarding building space, faculty expertise, coordination of industry sponsors, and student learning.

Building space
The increase in enrollment made it difficult to find enough building space to hold student team meetings with faculty advisors, conduct design reviews, and build and test hardware. The department's move to a new building in 2019 temporarily alleviated this problem. However, the subsequent increase in enrollment resulted in persisting space challenges in terms of project build, team meeting, and hardware storage spaces.

Faculty expertise
In the senior projects course, a single faculty advisor advises two teams, and each team has their own project. As enrollment increased and industry sponsors developed most projects it became difficult to align the project topic with the faculty advisor's technical area. Therefore, faculty were often advising project topics that were well outside their technical area, which made it hard to give student teams strong technical guidance. In the senior projects course, each faculty advisor also serves on the Professional Advisory Board, which is the technical board that reviews the design presentations of all teams at Preliminary Design Review (PDR), Critical Design Review (CDR), Manufacturing Status Review (MSR), Test Readiness Review (TRR), and the Spring Final Review (SFR). In 2018, 9 faculty advisors were participating in the design reviews of 12 different design projects, which made it difficult to recall project details and assess if appropriate progress had been made. Further, the number of faculty on the review board sometimes led to conflicting feedback. In addition to faculty advisors for the projects, three faculty members support the course as manufacturing, safety, electronics, and testing technical advisors. These faculty members now had to track the electrical design, support manufacturing, and ensure student safety during the integration and test of 12 different projects. Overall, the increase in student enrollment resulted in overworked faculty, and therefore student teams did not always receive clear guidance.

Industry sponsor coordination
A faculty member called the course coordinator manages the course across all the student teams, faculty advisors, and industry sponsors. The course coordinator works with the department's business development staff to find industry sponsors, and then with the industry sponsor to scope

a senior project for a student team. As the number of projects grew, it became tricky to find enough industry sponsors with appropriate aerospace capstone projects. Some industry sponsors wanted projects that required graduate level work. Sponsors often assumed that the correct difficulty level of a project was similar to what they would give a new hire. However, a new hire at a company will be surrounded by technical experts in the project area and have access to the company resources and test facilities. In contrast, in senior projects the student teams had a 1-hour weekly meeting with the industry sponsor, and often did not have access to the sponsor's facilities. In some cases, the industry sponsors would become too busy to meet with teams. In other situations, the industry sponsors would have evolving goals for what the teams needed to accomplish, which often conflicted with the course learning goals. Some student teams found themselves 'serving two gods'; the industry sponsor with the project funds and goals, and the faculty advisors providing the grade. Other student teams did not have the necessary technical support to accomplish the project.

Student feedback

Towards the end of the spring of 2021, it became clear that the enrollment increases were going to force a significant restructuring of the course. After the course concluded, the course coordinator organized a small focus group of students to understand their take on the course. The students highlighted the space constraints mentioned earlier, along with the typical problems that come with working in large student teams. However, their focus was on the lack of technical feedback for their project. Some teams had followed the advice of their industry sponsors only to be given different feedback and poor grades in design reviews from the faculty advisors. Others were given a project with a technical thrust outside their faculty advisors' areas of expertise and had no input from their industry sponsor. One student aptly stated *'In my internships, my manager states that I need to design this mechanism, and to watch out for these specific parts of the design as they have had these failures in the past. In this course, a lot of times we felt like we were flying blind.'*

Scaling of senior projects course: goals

The senior projects and design faculty determined five major goals for the course redesign:

1) Maintain the course learning objectives.
2) Ensure students have strong technical guidance specific to their project throughout the design process.
3) Reduce the faculty workload to a manageable level, thus avoiding faculty burnout.
4) Optimize the course for easier tracking of projects and a more streamlined use of resources during fabrication, integration, and test.

During the course restructure discussions, the course learning objectives were reviewed. We realized that the 'student led design', 'design build fly' and 'systems engineering and integration' learning objectives often led to students learning through failure. This became an important aspect of the course that we wished to preserve. However, we were concerned that the traditional course structure and subsequent enrollment may have put some student teams in a position where the course demands were high and resources were not available, resulting in a design failure and student frustration. This led to the fifth goal of our course redesign:

5) Ensure that students can fail in a safe learning space with resources that promote recovery and learning, which we define as ‘growth.’

New course structure

In the new course structure, we harness the faculty expertise we already have in the department by having each senior projects faculty advisor develop a project in their research area. All projects must have a clearly defined mission with an aerospace application and require integration of subsystems. This change ensures the faculty advisor is a technical expert in the project and can guide teams through the design challenges that arise while grading fairly. Each faculty advisor advises three teams on a single project. These three teams can work together as different subsystem teams (for example a rocket project with an engine team, ground support team, and structures team). Alternatively, faculty members can structure their project with a red vs blue vs gold team scenario where each team develops different designs for the same mission. This is also a common method in the aerospace industry, akin to Northrop and Boeing both bidding on the USAF KC tanker request for proposal. Each project’s scope is determined in collaboration with the electronics, software, and manufacturing technical advisors and course coordinators. This collaboration ensures that any interdisciplinary areas of the project outside of faculty advisors’ area can be supported by other faculty members participating in the course. It also makes certain the department has resources to support the fabrication and test of the possible designs.

Industry role: funding and student mentorship

From both a student and resource perspective, it was important that our industry partners continue to play a strong role in the course. Through discussions with the industry partners on our department’s External Advisory Board (EAB), we found that many industry sponsors want to be involved in the course from a workforce development perspective. Our industry partners want to support the development of strong engineers and encourage them to apply to positions at the sponsor’s organization. Several industry partners pointed out that the project development on their end can be too time-consuming.

Therefore, we came up with a new mechanism for sponsoring the course. Industry sponsors now provide financing that goes into a central pool which funds all projects. In return, industry sponsors can attend the design reviews of any of the teams, have the option to mentor a team, and have their organization’s name posted on the senior project website and projects symposium materials. In the 23/24 academic year, we had 10 industry sponsors sign on to fund the course, and 9 of them chose to mentor teams. We allow industry mentors to select the project they want to mentor. This allows our industry sponsors to mentor a team of up to 12 students learning skills that the sponsor feels are pertinent to their organization. We find the student teams who receive industry mentors are excited about building this relationship. The mentors act as an external sounding board for the team, answering questions regarding systems engineering, program management, technical design areas, or career paths.

New course roll-out

The changes to the course structure were rolled out across ½ the class in Fall 2022 and rolled out to the entire class in Fall 2023. In Fall 2023 with the new course structure, the senior projects faculty are advising 7 projects with 21 teams. Note that the old course structure would have had 21 separate projects. Instead of all eleven senior projects faculty participating in each project's design review, a team of four faculty members are assigned to review the same projects throughout the academic year. From a faculty standpoint, having focused review teams and three teams on each project makes it easier to track project goals and ensure student safety through design, manufacturing, and test. Initially, there were concerns regarding the possibility of duplication or plagiarism among multiple teams working on the same project. However, no instances of such behavior have been observed. It is noteworthy that cheating would be challenging, given that the same four faculty members review the designs of all teams involved in a particular project. Additionally, it became evident that students were enthusiastic about (and even competitive when) developing their team's design.

In passing students have had both positive comments and concerns about the new course structure. It is difficult to know what the overarching student opinion is and how it has changed with the new course structure without doing a longitudinal study of the student course evaluation data. Note that the university implemented drastic changes to the course evaluation questions over the past five years, which makes them difficult to compare across the two course structures. However, the 'free comments' section of the course evaluation has remained the same. Therefore, to answer our research questions regarding the change in course structure, we utilized a LLM analysis to examine the comment section of the student course evaluations.

Results of LLM Analysis

To compare the 'Old Course Design' and 'New Course Design' assessments of growth and sentiment, we form two comment datasets from student course evaluation forms. The first (Old Course Design) is composed of all comments from AY17/18 and AY18/19 (the two years for which digital comment data exists before COVID and the course changes). There are 181 comments for the Old Course Design dataset. The student course evaluations from AY 19/20 and AY20/21 were not used due to remote learning utilized during the COVID pandemic. The second dataset (New Course Design) includes comments for AY22/23 and includes 199 comments. Figure 3 plots both growth and sentiment Likert scores for each comment as a scatter plot. Note, several comments have identical growth and sentiment scores both within each dataset and between them, causing their markers to overlap.

The empirical scatter plots in Figure 3 of derived data (growth and sentiment) show substantial overlap, but careful examination suggests improvement with the New Course Design set. Both sentiment and growth Likert scores seem to be larger on average amongst the New Course Design comments. To be certain, the marginal probability density functions (PDFs) and cumulative distribution functions (CDFs) are computed for both growth and sentiment Likert scores for both populations. PDFs and CDFs for both the Old Course Design and New Course Design populations are given (superimposed) in Figure 4.

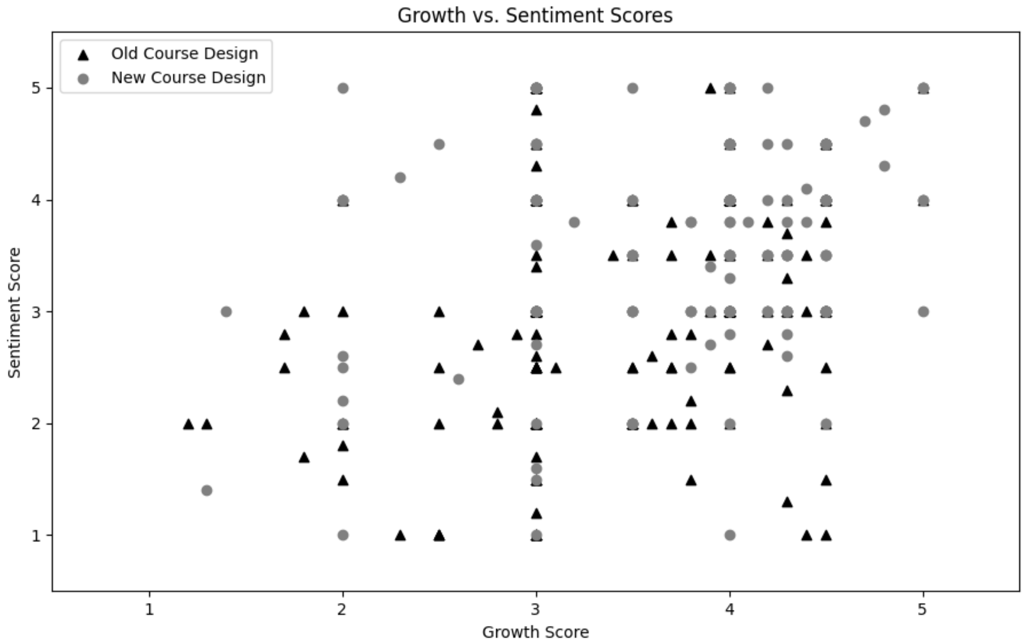


Figure 3. Scatter Plot of Growth and Sentiment Likert Scores for the Old Course Design (AY17/18 and AY18/19, N=181) and the New Course Design (AY22/23, N=199). Higher scores are better.

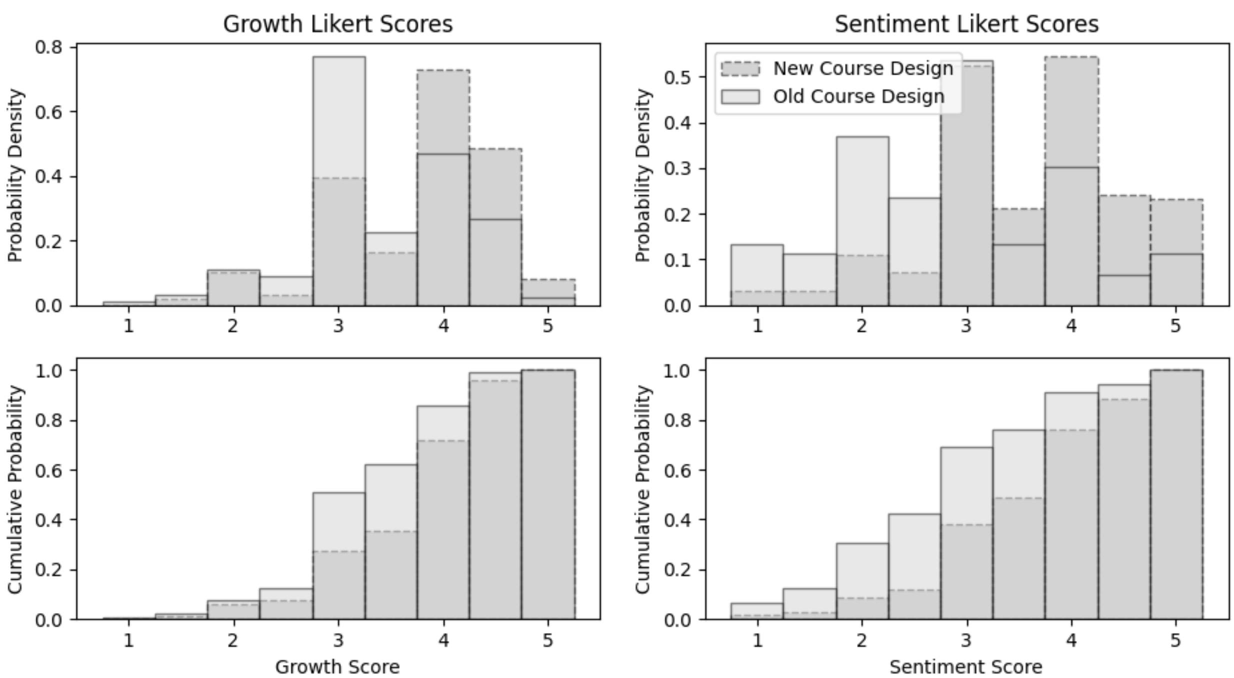
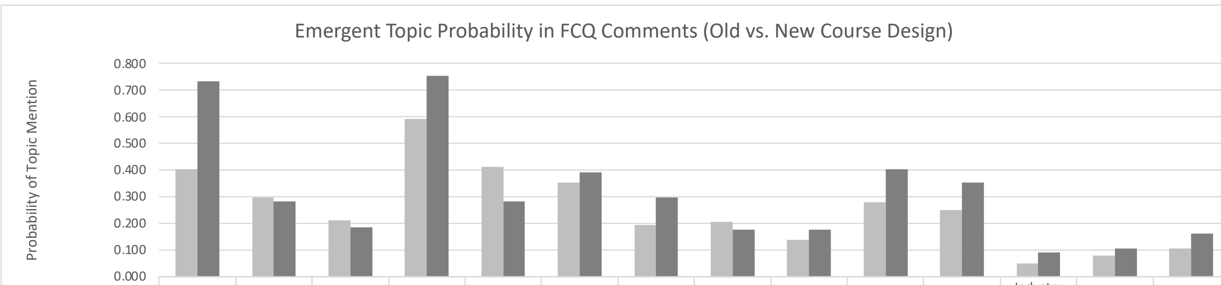


Figure 4. Probability Density Function (PDF, top) and Cumulative Distribution Function (CDF, bottom) as a function of Growth Likert Scores (left) and Sentiment Likert Scores. The Old Course Design dataset has 181 samples, and the New Course Design dataset has 199 samples.

Note that a '1' corresponds to strong negative growth or sentiment, while a '5' corresponds to strong positive growth or sentiment. For a population to possess a 'better' Likert score distribution, its CDF is expected to be further to the right of the plot. Both Growth (bottom-left) and Sentiment (bottom-right) CDFs demonstrate this property (i.e., 1st-order stochastic dominance [12]) of the 'New' course over the 'Old' course. Said differently, for every value of Likert scores from 1 to 5, the 'Old' course has a higher probability of a lower Likert score for both growth and sentiment. For the new course structure, the positive sentiment increased by roughly a single point on the Likert scale, which is a strong result.

Emergent Topics

LLM-based emergent topic analysis in all academic years produced the following top-10 emergent topics: 1) Advisors/Instructors Support, 2) Project Selection, 3) Structure of Class, 4) Feedback and Communication, 5) Lectures and Presentations, 6) Team Dynamics, 7) Project Scope and Feasibility, 8) Peer Evaluation and Grading, 9) Industry Relevance, and 10) Effectiveness of Feedback. The faculty also requested examining research topics of A) Faculty Advisor Technical Guidance, B) Industry Sponsor or Mentor Technical Guidance, C) Industry Sponsor Relationship, and D) Mentor Relationship. Figure 5 has a table that shows the number of comments by academic year, and a bar graph that shows the probability of each of these topics appearing in a given comment sorted by the old course and new course designs.



	Advisors/Instructors Support	Project Selection	Structure of Class	Feedback and Communication	Lectures and Presentations	Team Dynamics	Project Scope and Feasibility	Peer Evaluation and Grading	Industry Relevance	Effectiveness of Feedback	Faculty Advisor Technical Guidance	Industry Sponsor or Mentor Technical Guidance	Industry Sponsor Relationship	Mentor Relationship
Old Course Design	0.402	0.296	0.212	0.592	0.413	0.352	0.196	0.207	0.140	0.279	0.251	0.050	0.078	0.106
New Course Design	0.734	0.281	0.186	0.754	0.281	0.392	0.296	0.176	0.176	0.402	0.352	0.090	0.106	0.161

Figure 5. Emergent and Research Question Topic Probability in Old Course Design (N=179) and New Course Design (N=199) FCQ Comments

Discussion

New course structure shows increased (positive) sentiment and growth

Our first research question is 'How does student sentiment change between the new course design vs the old course design.', where we define sentiment as students perceiving this class as a positive or negative experience in their undergraduate academic career. The Probability Density Function (PDF) and Cumulative Distribution Function (CDF) in figure 4 show that the new course structure has a higher probability of positive sentiment (higher Likert scores) than the old course structure. These results suggest that student sentiment became more positive with the introduction of the new course structure. Our second research question is 'Is there a difference in self-reported student growth between the new course design vs. the old course design.' where we define growth as students overcoming a hard problem or experiencing a failure but learning from it. The Probability Density Function (PDF) and Cumulative Distribution Function (CDF) in figure 4 also show that the new course structure also has a higher probability of growth (higher Likert scores) than the old course structure. These results again suggest that student growth became more positive with the introduction of the new course structure. In AY 22/23, note that only half of the students were in the new course design, and the rest of the students were in a hybrid design between the old and new course design where two teams worked on a single industry project. For AY 22/23, the comments could not be sorted by which course structure they were in. In AY 23/24, all students were in the new course design. While we see a trend of increasing student positivity and growth, we will have a clearer picture this spring when we can look at AY 23/24 comments.

It is important to note there are several variables that were not controlled in the comparisons between the new and old course structures. During the old course structure, students manufactured, integrated, and tested their designs in an old engineering building with less space and older facilities. In the new course structure, students manufacture, integrate, and test their designs in a brand-new building with more project space and new manufacturing, composites, and electronics shops. Each year faculty teaching assignments change, so faculty have rotated in and out of the senior projects course between the old and new course structures. Finally, the students have changed over time; students in the old course design had never experienced remote learning, while students in the new course design started their freshmen or sophomore years during the Covid-19 pandemic.

Emergent topics correspond to course restructure goals

Our final research question is 'Is there a difference in student feedback on emergent topics when comparing the new course vs. old course, or when clustered by growth and sentiment?'. When we look at emergent topics, in the new course structure we see an increase in the probability by >0.1 that 'Advisor/Instructor support', 'Feedback and Communications', 'Project Scope and Feasibility', 'Effectiveness of Feedback', and 'Faculty Advisor Technical Guidance' are mentioned. This tells us that student evaluation comments mention these emergent topics more in the new course structure. To determine if the student comments from either the Old Course Design or New Course Design populations mentioned these emergent topics with a positive or negative sentiment and growth, scatter plots of comment growth and Likert scores are plotted for each topic in Figure 6.

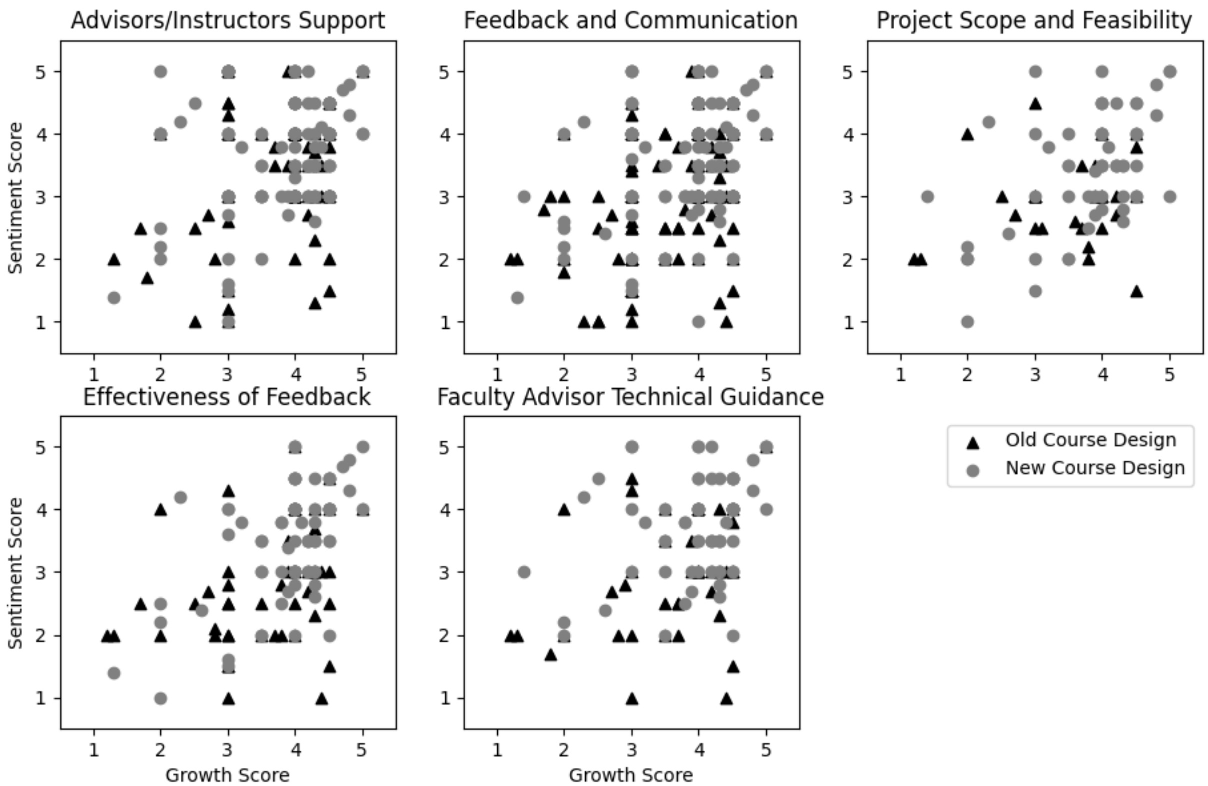


Figure 6. Topic Sentiment and Growth Comparison for Emergent Topics Between Old Course Design and New Course Design

Note that the top right quadrant of these graphs indicates positive growth and sentiment, while the bottom left quadrant indicates negative growth and sentiment. Studying the graphs of emergent topics, the distribution of new course design comments are shifted more towards the top right quadrant than the comments in the old course design. This shift suggests an increase in student growth and sentiment in the new course structure for these emergent topics. Encouragingly, these topics are tied to some of our initial goals when restructuring the course. One of our course goals was to 'Ensure students have strong technical guidance specific to their project throughout the design process.', and an increase in comments with a positive sentiment and growth regarding 'Advisor/Instructor Support' and 'Faculty Advisor Technical Guidance' may indicate that we have improved this. The increase in comments with a positive sentiment and growth regarding 'Project Scope and Feasibility' may be due to our faculty developing and scoping the projects. Faculty teach a lot of undergraduate students and have a good idea of what an undergraduate team of students can accomplish. Further, this corresponds well with 'Faculty Advisor Technical Guidance' and 'Effectiveness of Feedback'; if a student team is well supported, the project will feel more feasible. Anecdotally, the faculty have observed the student teams appear to have much stronger technical designs when the faculty advisor is a technical expert in the project. Note that in the new course design, there are still negative comments across all these emergent topics. While improvements to the course have been made, we still have room to grow. For example, AY22/23 student comments indicated they were frustrated that the feedback in the design review comes in the form of comments and a final grade as opposed to a rubric with points that break out each portion of the presentation. This is done purposefully as students will be transitioning from an academic environment with grades and point systems to an industry environment with written and oral feedback. However, we can do a better job explaining to students the industry environment we are attempting to replicate.

Remaining Issues

Despite the course restructuring, significant challenges remain. Our department is invested in giving students open-ended projects that involve hands-on integration and test of their final design. However, enrollment continues to grow, and we are running out of space for project teams to meet, manufacture, and test. The three faculty who advise all senior projects teams in terms of manufacturing, software, electronics, and safety are stretched thin with 21 teams. Next year we expect a 25% increase in enrollment in the course for a total class size of 275 seniors or 24 teams. We may need to move some projects to be purely software based or scale down the size of project hardware. Finally, communication in a class of 275 students, 4 TAs, 14 faculty, and 24 industry mentors becomes difficult as one piece of incorrect information spreads quickly.

Conclusion

In conclusion, we have changed our senior projects course from each team having a unique project developed by an industry sponsor to three teams working on a project developed by an aerospace faculty advisor. From a faculty perspective, this change makes it easier to advise projects, assess grades, and track progress across projects. As we have implemented the senior projects course restructure, we are seeing an increase in positive student sentiment and growth. Faculty scoping projects in-house appears to be a good solution, as we see an increase in positive student sentiment towards faculty advisor technical guidance, project scoping, and technical feedback. At this time, our industry sponsors and mentors seem happy with the student team collaborations. We expect more feedback from students and industry sponsors in the spring of 2024. While the course restructuring is positive, significant challenges remain in terms of building space and electronics, manufacturing, and test faculty time.

References

[1] A.J. Dutson, R.H. Todd, S.P. Magleby, and C.D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," Journal of Engineering Education, vol. 86, pp. 17-28, 1997. Available: https://doi.org/10.1002/j.2168-9830.1997.tb00260.x

[2] S. Howe and J. Goldberg, "Engineering Capstone Design Education: Current Practices, Emerging Trends, and Successful Strategies," in Design Education Today, D. Schaefer, G. Coates, and C. Eckert, Eds. Cham: Springer, 2019. Available: https://doi.org/10.1007/978-3-030-17134-6_6

[3] C.L. Dym, A.M. Agogino, O. Eris, D.D. Frey, and L.J. Leifer, "Engineering Design Thinking, Teaching, and Learning," Journal of Engineering Education, vol. 94, pp. 103-120, 2005. Available: https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

[4] ABET, "Criteria for Accrediting Engineering Programs, 2022-2023," 2023. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

[5] National Science Board, "Undergraduate Education, Enrollment, and Degrees in the United States," 2018. [Online]. Available: https://www.nsf.gov/statistics/2018/nsb20181/report/sections/higher-education-in-science-and-engineering/undergraduate-education-enrollment-and-degrees-in-the-united-states

[6] C. Twigg, "Improving Learning and Reducing Costs: Redesigning Large Enrollment Courses," The Pew Learning and Technology Program, 1999.

[7] Bhavya Bhavya, Jinfeng Xiao, and Chengxiang Zhai, "Scaling Up Data Science Course Projects: A Case Study," in Proceedings of the Eighth ACM Conference on Learning @ Scale (L@S '21), New York, NY, USA: Association for Computing Machinery, 2021, pp. 311–314. Available: https://doi.org/10.1145/3430895.3460168

[8] J. Ferrer, A. Ringer, and K. Saville, "Students' motivation and engagement in higher education: the importance of attitude to online learning," High Educ, vol. 83, pp. 317–338, 2022. Available: https://doi.org/10.1007/s10734-020-00657-5

[9] Y. Meng, Y. Zhang, J. Huang, Y. Zhang, and J. Han, "Topic Discovery via Latent Space Clustering of Pretrained Language Model Representations," in Proceedings of the ACM Web Conference 2022 (WWW '22), New York, NY, USA: Association for Computing Machinery, 2022, pp. 3143–3152. Available: https://doi.org/10.1145/3485447.3512034

[10] W. Zhang, Y. Deng, B. Liu, S.J. Pan, and L. Bing, "Sentiment Analysis in the Era of Large Language Models: A Reality Check," arXiv preprint arXiv:2305.15005, 2023. Available: https://doi.org/10.48550/arXiv.2305.15005

[11] W. Medhat, A. Hassan, and H. Korashy, "Sentiment analysis algorithms and applications: A survey," Ain Shams engineering journal, vol. 5, no. 4, pp. 1093-1113, 2014. Available: https://doi.org/10.1016/j.asej.2014.04.011

[12] H. Levy, "Stochastic dominance and expected utility: Survey and analysis," Management science, vol. 38, no. 4, pp. 555-593, 1992.

Appendix

Growth and Sentiment Likert Score Prompt

```
template = """You are an engineering education and education assessment expert. For
each comment text, score the comment on the following DECIMAL Likert scale (1 =
strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree):
1) **Growth**: The student indicated or demonstrated growth in their ability to work
in a team, in technical skills, or in soft skills. They overcame a challenge or tough
experience. They learned about themselves and/or the world around them. They are
better prepared for their future career. If the comment does not indicate or
demonstrate growth (or lack thereof), please select 3.0.
2) **Sentiment**: The student comment indicated or demonstrated a positive or negative
sentiment towards the course, the instructor, the project, or the team. Constructive
feedback is neutral (3.0); you are assessing the student comment sentiment, not the
content.

Comment:
{comment}

Your response should be a number between 1 and 5, inclusive, with exactly 2
significant digits. If you are unsure, please select 3.0. If you are unable to score
the comment, please select 0.

Think through your task step by step. First, read the comment. Then, score the comment
for growth. Then, score the comment for sentiment. Then, respond with the scores.

You MUST respond with the following format: 'X, Y' where X is the score for growth and
Y is the score for sentiment. The comma is very important. For example, if you think
the comment is a 4.1 for growth and a 2.6 for sentiment, you should respond with '4.1,
2.6'.
"""
```

Emergent Topic Discovery Prompt

```
template = """You are an engineering education and education assessment expert. You
have a list of comments that have been grouped together into a single group
designating them as similar in some sense.

Comments:
{comment_list}

Think carefully and step by step. First, read the comments. Then, identify the
emergent topics for the group of comments. Then, respond with the emergent topic list.

Each emergent topic name should be 1-2 words and should be mutually exclusive with
other emergent topics. If you are unsure, please select 'unsure'. If you are unable to
identify emergent topics, please select 'unable'. For each emergent topic, please
provide a short description elaborating on what this topic is or means. For example,
if the topic is feedback on project selection, then the topic should be 'Topic
```

```
Selection', a possible description could be 'Project topic selection was limited'. If
you are unsure, please select 'unsure'. If you are unable to provide a description,
please select 'unable'. Positive, negative, or neutral topics are all acceptable.

Your output should be an ordered json list of the most prevalent emergent topics. The
list should have the number of elements requested by the user. For example, if you
think the emergent topics are "teamwork" and "communication", you should respond with
a json list with two objects, each with a "topic" and a "description" key and value.
"""
```

Table A1. Diversity of senior projects in AY 2014/2015.

Project	Field	Description
1	Communications	Design and construct an autonomous tracking and communication support system for an antenna to be used to track unmanned aircraft during flight
2	Remote Sensing	Develop a protoflight high-altitude balloon payload capable of measuring infrasonic events of frequencies between 0.1 and 20 Hz with a minimum amplitude of 0.1 Pa
3	Aerodynamics	Develop a 3-dimensional U-,V-,W- inertial wind vector in a measurement cylinder defined by a 100-meter radius and 200-meter height computed from in-situ measurements and an observation of the cloud conditions above the defined cylinder
4	Remote Sensing	Create and test a prototype Earth horizon sensor, that will be tested in a laboratory environment while simulating a specific spectrum of the Earth as seen from simulated altitudes of 250 to 750 km
5	Propulsion	Modify an existing JetCat P90-RXI engine that uses a kerosene-oil mixture for both fuel and lubrication to run off gaseous methane as a fuel source
6	Aircraft Design	Develop a small, low-cost system to exhibit phugoid, spiral, and Dutch roll modes that are visible from the ground, downlink and display real-time flight data, and record in-flight video
7	Remote Sensing	Develop and test a 2U cubeSat mid-wave infrared camera proto-flight payload, a precursor to the flight camera unit for the LMCO bus mission
8	Mechanical Design	Design, build, and verify a rappelling child rover that can deploy from the legacy TREADS mother rover.
9	Controls	Design and prototype a heliogyro sail blade controller for a proposed heliogyro cubesat mission
10	Environmental Testing	Design, build and validate the functionality of a test bed that will characterize a range of commercial off the shelf (COTS) non-contact infrared temperature sensors in a simulated space environment.

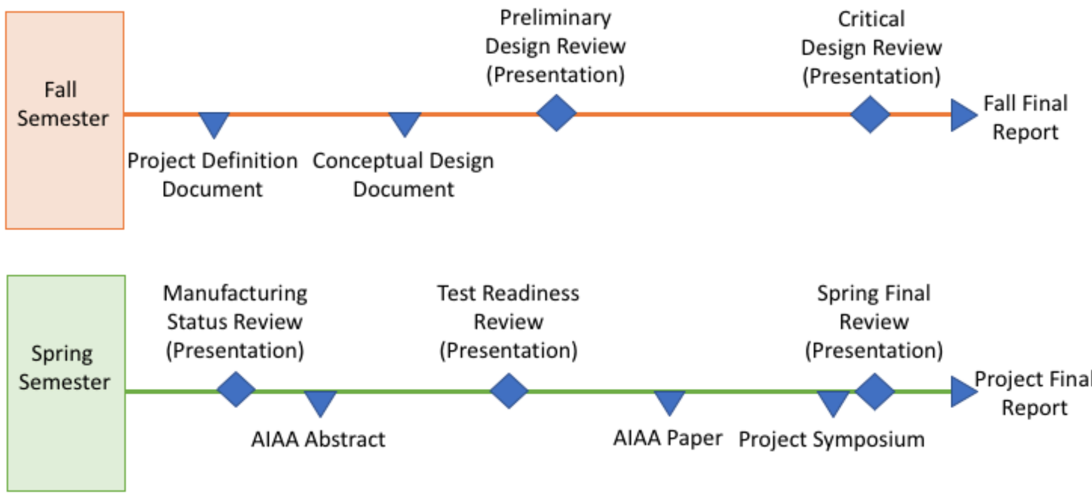


Figure A1. Senior projects course timeline. Assessments are shown in blue: triangles indicate written documents, and diamonds indicate oral presentations to the Project Advisory Board, which is a board of faculty advisors. Each semester culminates in a final written report.