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Students Teaching Students: An approach to improving Capstone design performance while enhancing learning for all

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Abstract

This paper describes three approaches to improving student performance in capstone design based on the idea of students teaching and learning from each other. Student attitudes about teaching and learning from peers are explored, along with the relative importance of factors highlighted in the Self-Determination Theory (SDT) of intrinsic motivation- autonomy, mastery and relatedness (i.e., feeling a connection to a larger group). The first approach described is the use of capstone design projects with explicit educational objectives to enhance the hands-on experience of younger university students. Successes and lessons learned are reported from a capstone design project whose scope included development of four Arduino rover lab activities for a freshman class. The second approach described involves having all capstone seniors complete an individual assignment to document a specific "tool for student success" that might be useful for a future team. Senior surveys indicated support for this idea and confirmed that future students may benefit from this transition of knowledge across future classes. Both experience and survey results suggest that seniors have an innate appreciation for the importance of improving the undergraduate learning experience, and are well positioned to identity any gaps in the curriculum needed for success in capstone design. These two approaches provide a unique opportunity for engineering students participating in capstone design to take an active role in future learning at their university. The third approach was to introduce an open-ended group project called "Teams Teaching Engineering" to a first-year introductory engineering class to give younger students experience with team design activities and to increase their comfort with the idea of teaching others. It is believed that activities focused on students teaching and learning from each other can promote intrinsic motivation if framed to consider student needs for autonomy, competence, and relatedness.

Introduction

Universities and their faculty are currently experiencing unique challenges that make it more important than ever to explore creative solutions to improve the curriculum and promote student motivation and engagement. Limited faculty and staff resources may create obstacles to implementing "non-critical" curriculum improvements, so perhaps a paradigm shift is in order- instead of viewing the students as passive recipients of an educational experience supplied by the university, they could be seen as potential contributors capable of enhancing the university's learning environment if given the proper guidance. This paper seeks to explore student attitudes about teaching and learning from each other and describes efforts to leverage the talents of capstone design students to promote learning at the author's university. Capstone design plays a unique role in the engineering curriculum because it provides a "culminating engineering design experience" and it provides a talent pool that can be used to promote curricular initiatives. First-year students are an important target for curricular improvements, and two interventions described here focus on that group. The author believes that student desires for autonomy, competence, and relatedness can be supported through activities related to teaching others, so the SDT framework is used when exploring different approaches to use the idea of "student teaching students" to improve learning within the university.

Background and Motivation

The work in this paper was motivated by a desire to improve student performance in Aerospace Engineering (AE) capstone design at a mid-sized southeastern private university. At this school, capstone design covers three semesters- a one-credit AE Junior Design class, and two three-credit senior classes (Senior Design 1 and 2). In Junior Design, students define topics, form teams, and then complete a proposal that scopes their project for their senior year. Some projects are faculty-proposed or industry-sponsored, but most are proposed by the students, and the entire class votes on which topics are selected for that year. Once topics are downselected, individual students identify which topic they wish to work on, and typically get their first or second choice of assignment. One professor is responsible for grading the entire class- typically about 10 teams with an average of eight students per team. In the senior year the CATME peer feedback system is used to calculate 20% of the class grade, with another 20% coming from individual assignments and a a team time card/instructor evaluation system that helps to differentiate individual student contributions to team success [1]. The remaining 60% of the grade comes from team products. Most teams have a faculty advisor or external mentor available for technical advice, but their level of involvement varies from team to team.

Though the aerospace engineering students are typically very enthusiastic about the projects they propose, they often underestimate the level of complexity associated with the fabrication and test of their project hardware. They can attempt to recruit students from electrical engineering, computer science, and mechanical engineering, but most teams consist of only AE majors. As a result, students may have to learn topics not covered in their curriculum (e.g., electronics) and all have to complete their initial design in the fall without the benefit of their last semester of AE classes. In this environment, capstone student success is often linked to their prior experience with hands-on projects (either in the curriculum or through co-curricular activities) and the availability of technical guidance associated with their particular project. Though most faculty would agree that adding hands-on projects throughout the curriculum would enhance learning and better prepare students for capstone design, finding the time and resources to implement such projects can be difficult. Similarly, the level of technical guidance available from faculty advisors may vary with their workload, their personal interest in the topic, and the expectations identified by the school.

In such an environment, one way to help students succeed is to increase the skills and hands-on experience of students before they start the capstone design sequence. Previous work published by this author describes an open-ended group project designed for this purpose called "Teams Teaching Engineering", where student teams build a visual aid illustrating a class concept, use it to teach someone outside the team, and then write about what they learned from the process [2]. Detailed teaching materials on this assignment are available on the KEEN Engineering Unleashed Website [3]. These references show how the project increased student interest in using university makerspaces and fabrication facilities for hands-on personal projects, but the prior work did not explore student attitudes about the teaching elements of the project.

In various educational settings, peer teaching and peer-assisted learning have been used as a way to promote student motivation and engagement and as a cost-effective way to supplement traditional instruction [4] [5] [6] [7]. One strategy used in engineering schools is the use of capstone teams to design new experimental apparatus and develop instructional materials for undergraduate teaching laboratories [8] [9] or having first-year students design teaching experiments for K-12 use [10]. Both student teachers and learners may benefit from these interactions, and motivational factors such as self-efficacy and an increased level of interpersonal engagement have been reported.

Self-Determination Theory (SDT) provides an overarching framework to study human motivation, and argues that conditions that support an individual's experience of autonomy, competence, and relatedness (i.e., feeling a connection to a larger group) are essential to fostering intrinsic motivation [11] [12]. Many have used SDT in an educational setting when attempting to understand and improve student motivation, and researchers have used SDT as a framework to examine graduate teaching assistants' motivation to teach [13].

Purpose and Research Questions

This work seeks insight on student attitudes towards students teaching students, and explores the viability of using capstone design students to promote learning at the university.
Student attitudes on the following questions are sought:

- How do students feel about teaching and learning from each other, and how important are the different elements of Self-Determination Theory- autonomy, competence and relatedness? How do the views of first-year and senior design students compare?
- Are senior design students able to identify gaps in their preparation for capstone design, and are they willing and able to reduce those gaps for future students?
- How do first-year AE students feel about teaching aspects of their group project, "Teams Teaching Engineering"? And can some of the reasons they like the project be traced back to the elements of SDT?

Questions associated with the viability of using capstone design students to promote learning at the university include the following

- Can capstone design teams create content for the first-year curriculum that will improve student readiness for capstone design?
- Can a structured process of transferring knowledge and technical references between old and new teams be incorporated into capstone design?

Design/Method

Multiple approaches were taken from 2019-2021 to explore these questions. Though diverse in nature, they were united by the theme of students teaching and learning from each other.

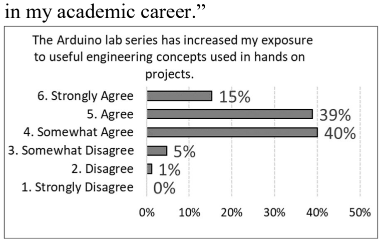
2019-2020 Capstone Design Project: Adding Arduinos to the first-year curriculum. During the 2019-2020 AE capstone design cycle a faculty-defined capstone project with education as its primary focus was launched. The original scope was to create multiple lab experiments for the first-year "Aerospace Practicum" class and a junior-level Aerospace Experimentation class. Though the COVID-19 pandemic prevented the team from completing the aerospace experimentation labs, the team successfully implemented the Arduino labs before the pandemic shut down in-person learning. Additional details and survey results from the first-year students are reported later in the paper.

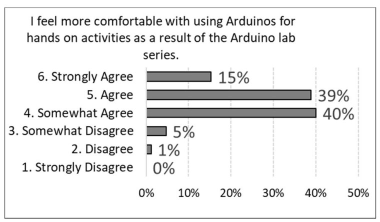
Fall 2020 Surveys: Senior and first-year student attitudes about SDT and students teaching and learning from each other. In late Fall 2020, all students taking AE Senior Design 1 and the first-year Introduction to Aerospace Engineering class had the opportunity to complete anonymous surveys. Both surveys were optional, but a small amount of extra credit was provided for participation. Both surveys contained the same questions about SDT factors and teaching and learning from peers, but also included customized questions relating to the different classes. For the seniors, questions focused whether they would be willing and able to develop educational materials to help younger students. For the first year students, questions explored their attitudes about the teaching aspects of their group project, "Teams Teaching Engineering".

Spring 2021 "Tools for Student Success": Knowledge transfer from senior to junior capstone teams. After reviewing the fall 2020 survey results, an individual assignment was added to Senior Design 2 in Spring 2021: "Tools for Student Success." This assignment asked seniors to showcase technical skillsets and engineering knowledge (hopefully aligning with SDT competence goals), which must be captured in a format that might be helpful to future generations of students (linking to relatedness). The assignment had two parts- a plan and an implementation. Five weeks into the spring semester, members from each team used one of their recurring meetings to present their plan and get instructor feedback on each tool idea. Their plans were uploaded as a preliminary assignment, and the final product was uploaded for grading near the end of the semester. Though this could be completed as an individual assignment, up to three students could work together on one tool and get the same grade.

Results and Discussion

Adding Arduinos to the First-Year Curriculum as part of a Capstone Design Project. As mentioned earlier, the scope of this faculty-defined topic was to have the students create multiple lab experiments for the first-year Aerospace Practicum class and a new junior-level Aerospace Experimentation class. When the project was first introduced to the students, parts of the aerospace experimentation scope was well defined (design, build, and test an instrumented shear web that could demonstrate buckling), but other topic areas were very open-ended (e.g. create introductory vibration experiments for the juniors, expose the first year students to Arduino programming, etc.). Though overall student response to the topic was lukewarm, a team was formed for the 2019- 2020 capstone design cycle. At first the team struggled with the challenge of solving a classic ABET "complex engineering problem"- having no obvious solution, involving diverse groups of stakeholders, including many component parts or sub-problems, and having significant consequences [14]. After a period of slow progress, team momentum began to build after the team received greater guidance from the instructors involved. The team came up with four Arduino labs based on an inexpensive "smart car" kit, developed materials for the GSAs, taught them how to run the labs, successfully implemented the labs in February 2020, and collected student feedback via an anonymous survey. Student survey participation was high at 65% (85 of 125 students) and largely enthusiastic. "I enjoyed the lab and learned how cool Arduinos are." "I really enjoyed the hands-on learning these labs brought and hope we continue to do more in the future." Over 59% of the students reported no prior experience with Arduinos prior to the lab, and as seen below, many increased their comfort level with the technology. As one commenter said, "This Arduino lab series has opened my horizon to new possibilities, which I thought to be more complex and less obtainable at this particular time in my academic career."





Like all Spring 2020 Senior Design teams, the team was unable to complete their original scope because of the pandemic shutdown, but the first-year Arduino labs were seen as a considerable victory by the teaching staff. When these labs were launched, none of the professors or GSAs involved had experience with Arduinos, and though all saw the value of adding Arduinos to the curriculum, no one had the time to do it. Though the capstone team's instructional materials had to be edited to improve clarity and robustness, the students were solely responsible for the original lab concept, selecting the Arduino smart car kit to be used, writing the sketches to program the Arduino, and teaching the GSAs to execute the lab. Their efforts made a significant positive impact on every first-year student in Aerospace Engineering in that year. It is expected that this early exposure to Arduinos will set the stage for future success when that freshman class enters AE capstone design, and now Arduinos are a permanent part of Aerospace Practicum.

Fall 2020 Senior and First-Year Student Surveys. Survey results are organized by themes- general attitudes about students teaching students and SDT, senior design student attitudes about helping younger students, and first-year student attitudes about their teaching-themed project. Participation rates on the Fall 2020 surveys were 67% for first-year students and 76% for seniors. (Table 1). The surveys contained Likert scale questions with scores ranging from 1 (strongly disagree) to 6 (strongly agree).

Table 1 Participation rates for First-year and Senior surveys

Fall 2020: First Year Intro to AE Class		
Survey Participants	**number of respondents**	**% of total**
Female	19	21%
Male	71	79%
Other/Do not choose to respond	0	0%
Total	90	100%
Total Class Enrollment	134	
Participation	**67%**	

Fall 2020: AE Senior Design I Class		
Survey Participants	**number of respondents**	**Percentage of total**
Female	7	11%
Male	54	86%
Other/Do not choose to respond	2	3%
Total	63	100%
Total Class Enrollment	83	
Participation	**76%**	

Survey Results: Comparing Seniors and First-Year Student responses on SDT and Peer learning. Results from the Fall 2020 Senior and first year AE student surveys indicate that both seniors and first-year students agree that the SDT elements are generally important to them, that students should help each other learn, and that students can increase competence and connect with their peers through teaching and learning. Distinctions within the two group responses are provided below.

The first block of questions address the importance of autonomy, competence, and relatedness- three elements that SDT identifies as major contributors to intrinsic motivation. Both student groups strongly value autonomy and competence (Figure 1 and 2) but seniors feel relatedness is more important than the first- year students (Figure 3). One possible reason for this is that at the time these students took the survey, they are at the midpoint of their senior design project, which requires teamwork to complete.

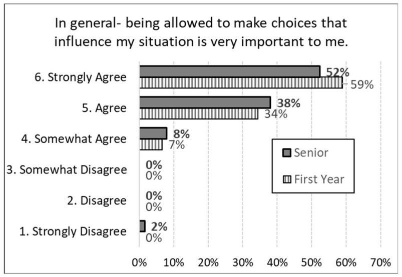


Figure 1: Autonomy needs comparison

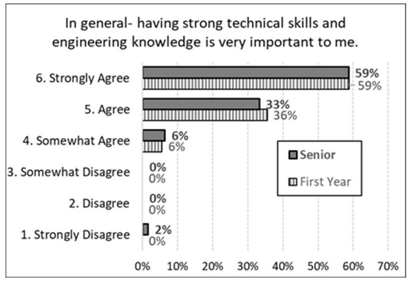


Figure 2: Competence needs comparison

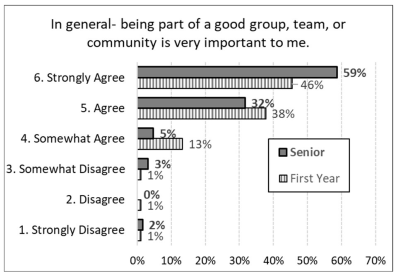


Figure 3: Relatedness needs comparison

Figure 4 illustrates student attitudes about students helping each other learn. As seen in the graphs below, seniors have stronger positive associations with both teaching and learning from other students, presumably from over three years of experience in an engineering program. When compared to the first-year students, seniors more comfortable as peer learners, though both groups preferred to be in the teaching role.

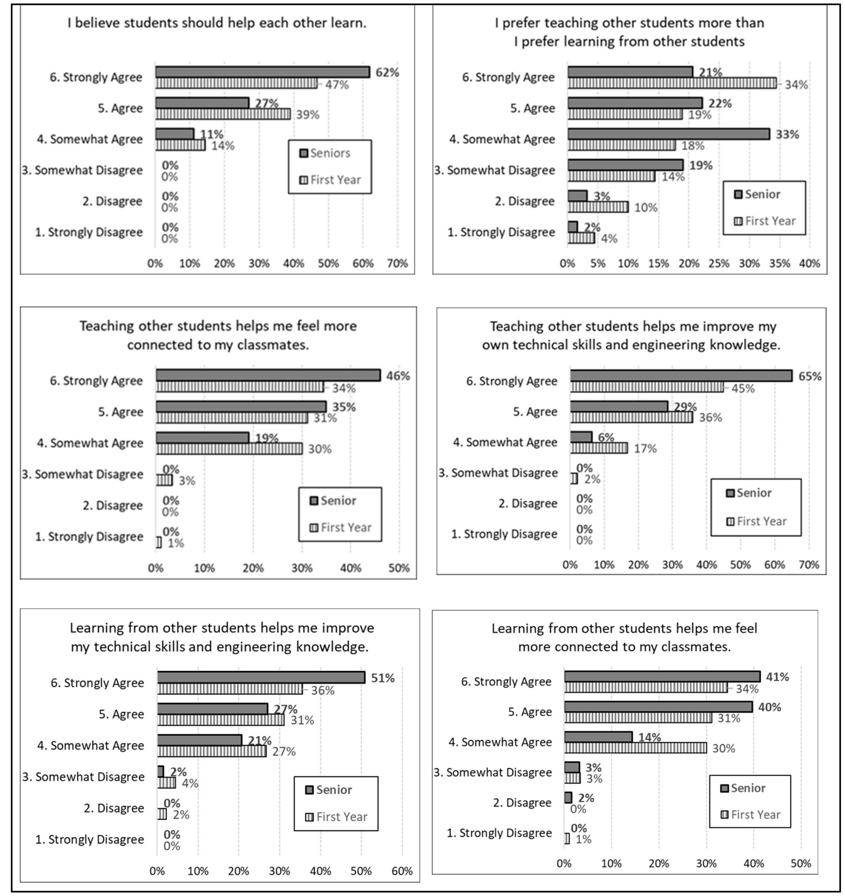


Figure 4: General Student attitudes about teaching and learning from other students

Senior Design student attitudes about helping younger students. Survey results in Figure 5 address the question about whether senior design students are capable of developing content that could help the next cohort of students. Results were consistent with the author's assumptions- that capstone design required new knowledge and skills, that seniors understood what skills were needed, and that seniors had the knowledge to help the next generation of capstone students starting junior design.

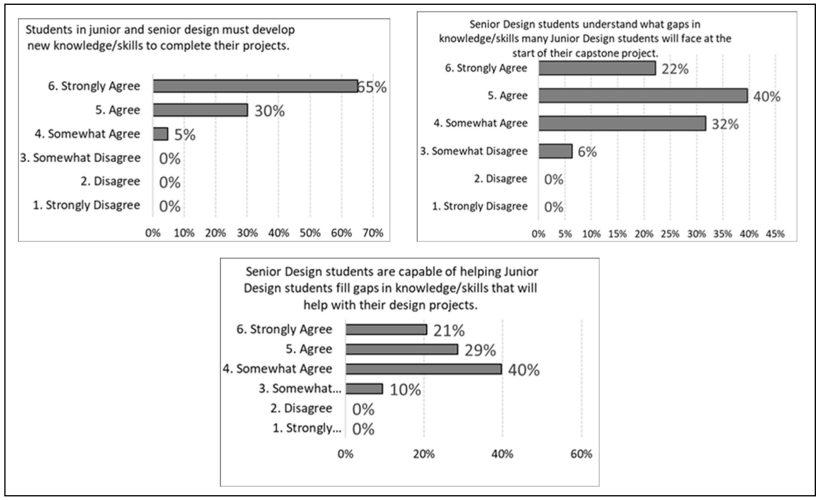


Figure 5: Questions reflecting senior student ability to help junior design students.

Results in Figure 6 suggest seniors would be willing to providing technical advice or teaching materials on topics related to my senior design project for academic co-curricular use, for student projects in other classes, or for future junior design teams. As seen below, students were somewhat more interested in helping future capstone teams than other classes and clubs.

These two themes in the survey- senior student ability and willingness to help others- were considered very important results, and encouraged the author to attempt the "Tools for Student Success" assignment. It is possible that this result was tied to an existing positive relationship between the class and its instructor, and the absence of such a relationship might result in the students taking a more cynical attitude about whole idea of helping the next cohort of capstone design students. Faculty who would like to replicate some of the ideas in this paper may want to conduct a similar survey to gage the attitudes of their own students.

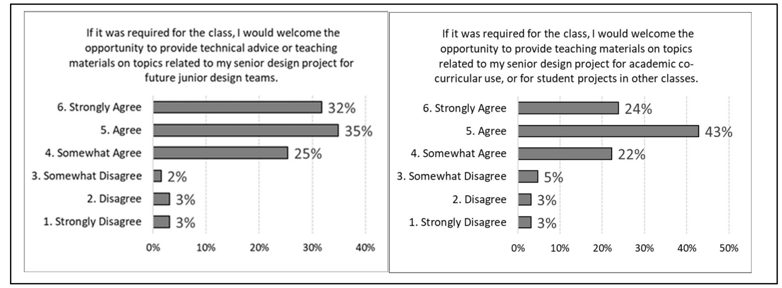


Figure 6: Senior student willingness to provide technical advice or teaching materials

First-year survey results about "Teams Teaching Engineering": a team project with a teaching emphasis. The Fall 2020 first-year survey included questions about their team project, which was first introduced in 2019 as an open-ended project promoting makerspace usage. When the university transitioned to a mix of in-person and virtual classes in 2020 due to the global pandemic, there was some concern about the project being viable. Instead of being cancelled, it was decided to just relax the requirement to use the university making facilities. Even with the pandemic restrictions, student survey results suggest the project was still successful, possibly because it allowed them to exercise autonomy and make connections within the class.

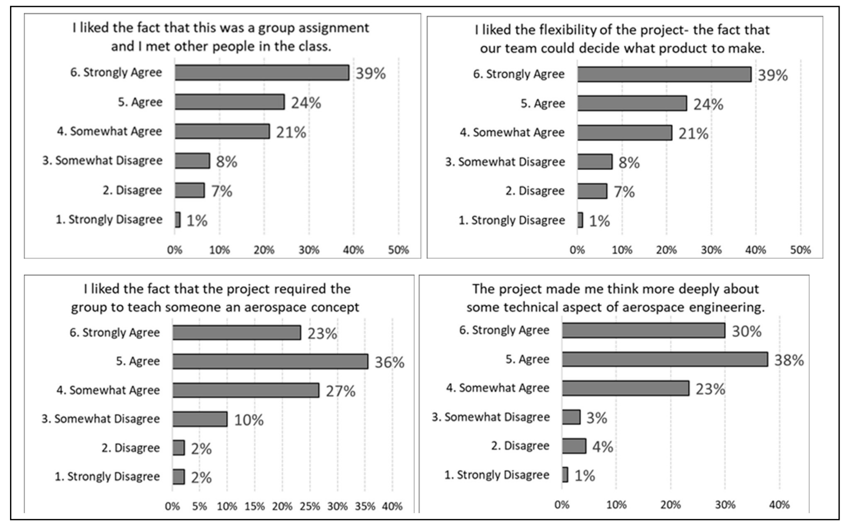


Figure 7: Aspects of the class project appreciated by the students

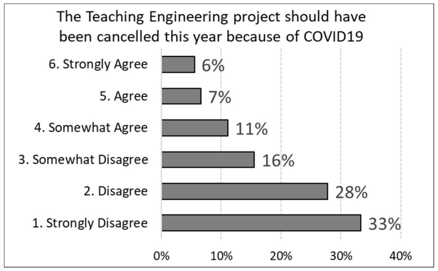


Figure 8: Attitudes about the hands-on project during hybrid learning

Results and Discussion: Knowledge transfer from seniors to juniors using "Tools for Student Success." The results from the first iteration of "Tools for Student Success" in Spring 2021 was encouraging, though areas were identified where the process could be improved in future years.

Students proposed a wide variety of tools that reflecting the diverse nature of the projects completed. For example, one described a process for naming and organizing CAD files for structural models, another described guidelines for sizing control surfaces on fixed wing aircraft, and another described best practices for designing 3D printed parts. Individuals addressed the relative merits of different free online aircraft design tools and which structural software packages were offered free to student competition teams, how to get started on CubeSat design, and how to program a Pixhawk flight controller. These tools should be invaluable to future senior design students and a useful reference for the instructor managing the capstone program.

The assignment left the format of the assignment open ended. Most students created PowerPoint presentations, while others created videos or word files. These student products were uploaded in the course management software (CANVAS) like any other assignment, and after the semester is complete, the instructor plans to organize the collected materials into a separate CANVAS repository organized by technical area that all capstone design students can use and build upon in the future. Once the first iteration of the canvas repository is established, future versions of the assignment will require students to identify where in the tool hierarchy their work should be placed. More clarity will also be provided on the formatting of the assignment and the due date for the final product will be moved to the middle of the semester.

Conclusion

This paper describes approaches inspired by the desire to improve student performance in Aerospace Engineering (AE) capstone design that are united by one theme- the idea of students teaching and learning from each other. Survey results from both first-year students and seniors indicate that students embrace the idea of students helping each other to learn and they value the principles of autonomy, competence, and relatedness.

Student performance in capstone design is influenced by their level of preparation at the start of the process, so approaches were explored to improve the technical knowledge, hands-on experience, and comfort with open-ended design problems among younger students, with a special focus on first-year students. A 2019-2020 capstone project developed four new Arduino lab activities for the first-year AE Practicum class as part of a larger project; survey results indicated that indicate the first-year students felt it was a valuable addition to the curriculum.

In another AE first-year intervention, an open-ended group project called "Teams Teaching Engineering" was introduced to the first-year Introduction to Aerospace class to give students experience with a totally open-ended project, to introduce students to university fabrication facilities available to students, and to increase their comfort with the idea of teaching others. Fall 2020 surveys showed that even with limitations caused by the pandemic, most students liked the teaching aspects of the project, appreciated the group nature of the project (tying to relatedness), the freedom and flexibility of the assignment (tying to autonomy), and the opportunity to think more deeply about a technical topic (tying to competence).

Another focus was the immediate transfer of knowledge of senior capstone teams about to graduate to the incoming class starting in Junior Design. To accomplish this, the "Tools for Student Success" assignment was created to harvest and transfer knowledge across student cohorts. This assignment gave seniors an opportunity to showcase some of their hard-earned skills learned in senior design and capture them in a format to help to future teams at the start of their capstone journey.

Throughout all these interventions, the self-determination theory of intrinsic motivation was used as a framework that guided these approaches. Autonomy was emphasized by giving students freedom in how they accomplished the required assignments. All teaching activities described could support the desire for competence because stepping into the role of a teacher often motivates others to increase their own technical skills, and many get great satisfaction and fulfillment from that role. Relatedness provides the motivation to teach, and students believe that it is enhanced by both teaching and learning from others. Overall these approaches provides a unique opportunity for engineering students to take an active role in future learning at their university. Previous studies have suggested that both students teaching and learning from other students can receive benefits from this interaction.

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