IMPROVING MOTIVATION AND ENGAGEMENT IN CORE ENGINEERING COURSES WITH STUDENT TEAMS

BY

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DISSERTATION

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Team-based projects are common in capstone engineering design courses and increasingly common in first-year engineering programs. Despite high enrollments and budget cutbacks affecting many programs, second- and third-year students can also benefit from team-based project experiences, which motivate them to succeed in engineering and prepare them for a globally competitive workforce. My dissertation research demonstrates that team design projects can be incorporated into the curricula of engineering departments, and these projects result in positive affective outcomes for students. Using ABET outcomes and Self Determination Theory (SDT) as the background for my studies, I investigated students' confidence, motivation, and sense of community after experiencing team design projects in two different engineering departments at a large public institution. In the first study, I used a sequential mixed methods approach with a primary quantitative phase followed by an explanatory qualitative phase to evaluate a chemical engineering program that integrated team design projects throughout the curriculum. The evaluation methods included a survey based on desired ABET outcomes for students and focus groups to expand on the quantitative results. Students reported increased confidence in their design, teamwork, and communication skills after completing the projects. In my second and third studies, I used qualitative interviews based on SDT to explore student motivation in an electrical and computer engineering course redesigned to support students' intrinsic motivation to learn. SDT states that intrinsic motivation to learn is supported by increasing students' sense of autonomy, competence, and relatedness in regard to their learning. Using both narrative inquiry and phenomenological methodologies, I analyzed data from interviews of students for mentions of autonomy, competence, and relatedness as well as course events that were critical in changing students' motivation. Analysis revealed that individual choice, constructive failures, and a strong sense of community in the classroom were critical to moving students toward intrinsic motivation. Further, community building through team experiences characterized the essence of the student experience in the course. My research highlights a need for better quantitative measures of students' affective outcomes, specifically motivation, in the context of a single course. Based on the results of my studies, SDT should be reevaluated in terms of possible interdependencies between autonomy, competence, and relatedness, and how the social context of large engineering courses may create a deeper need for supporting relatedness.

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CHAPTER 1

INTRODUCTION

Team-based project experiences are an important component of a well rounded education for engineering students. Students who experience team design projects gain a variety of benefits, such as improved content knowledge, problem solving skills, critical thinking skills, communication skills, and teamwork skills (Bailie, Shaeiwitz, & Whiting, 1994; Hirt, 1998; Clark, DiBiasio, & Dixon, 2000; Dixon, Clark, & DiBiasio, 2000; DiBiasio, Comparini, Dixon, & Clark, 2001; Pierrakos, Pappas, Nagel, & Nagel, 2012). Although capstone design courses and first-year engineering programs provide team-based project experience for engineering students, core required courses in the second and third years of most engineering programs typically lack this team experience. Without the benefits of continued team experience, second- and third-year students often experience a phenomenon called the "sophomore slump" and disengage from their academic pursuits (Boivin, Fountain, & Baylis, 2000; Lemons & Richmond, 1987; Sanchez-Leguelinel, 2008). To address this disengagement and loss of motivation, I studied the affective outcomes of team-based project experiences for second- and third-year students. My dissertation presents three studies of student teams in engineering courses at a large, public institution.

Chapter 2, "Integrating Team-Based Design Across the Curriculum at a Large, Public University," details the evaluation of a program implemented in the Chemical and Biomolecular Engineering (CHBE) Department at the University of Illinois at Urbana-Champaign (UIUC) that incorporates team design projects into five required courses throughout the CHBE curriculum. A preliminary report of the study was presented at the 2012 Frontiers in Education (FIE) Conference (Trenshaw, Henderson, Boyce, & DeStefano, 2012). Chapter 2 has been accepted for publication in *Chemical Engineering Education* and will appear in 2014. The Chemical Engineering Division of the American Society for Engineering Education (ASEE) holds the copyright for the content of Chapter 2 and has provided written permission to reprint it herein. The authors for Chapter 2 are as follows (listed in order of appearance): **Kathryn F. Trenshaw**, Jerrod A. Henderson, Marina Miletic, Edmund G. Seebauer, Ayesha S. Tillman, and Troy J. Vogel. As the head evaluator of the study, I wrote the Methods, Evaluation, Results and Discussion, and Conclusions sections of Chapter 2. As the original program developer, Miletic drafted the Background and Significance and Structure and Organization sections of Chapter 2. The remaining authors provided edits and suggestions throughout the text and approved the final draft for publication.

Chapter 3, "Fostering Motivation as a Course Objective in a Large Engineering Course for Second Year Students: A Narrative Approach," presents a pilot study of an electrical and computer engineering course at a large, public institution in which two out of eight discussion sections of the course were redesigned to support students' intrinsic motivation to learn. Preliminary reports of the study were presented at the 2012 FIE Conference (Herman, Trenshaw, & Rosu, 2012b), the 2013 ASEE Annual Conference and Exposition (Herman, Trenshaw, Loui, Green, & Goldberg, 2013b), and the 2013 FIE Conference (Trenshaw, Revelo Alonso, Earl, & Herman, 2013b). Chapter 3 was submitted for journal publication on September 15, 2013. The authors for Chapter 3 are as follows (listed in order of appearance): **Kathryn F. Trenshaw**, Geoffrey L. Herman, Kerri A. Green, and David E. Goldberg. As the lead researcher, I wrote the bulk of Chapter 3 independently and collaborated with Herman to write the vignettes in the Results section, the Discussion section, and the Conclusion section. Herman provided edits and suggestions throughout the text. He and the remaining authors approved the final draft for submission.

Chapter 4, "A Phenomenological Study of Promoting Engineering Students' Intrinsic Motivation to Learn," investigates the essence of the student experience in an expanded version of the pilot study in Chapter 3. Preliminary reports of the study were presented at the 2013 ASEE Annual Conference and Exposition (Herman et al., 2013b), and the 2013 FIE Conference (Trenshaw et al., 2013b). Chapter 4 will be submitted for journal publication in December 2013. The authors for Chapter 4 are as follows (listed in order of appearance): **Kathryn F. Trenshaw**, Renata A. Revelo Alonso, Katherine A. Earl, and Geoffrey L. Herman. As the lead researcher, I wrote the Introduction, Background, Context, Method, and

Conclusion sections of the text and conceptualized the models presented in the Discussion section. I used an annotated bibliography created by Earl to inform the Background section and portions of both the Discussion and Conclusion sections. I collaborated with Revelo Alonso to write the Results section and with Herman to write the Discussion section. All the authors provided edits and suggestions throughout the text.

In Chapter 5, “Conclusion,” I briefly summarize the overall conclusions and future directions suggested based on the results of all three studies. No appendices are included after Chapter 5 and all tables and figures appear immediately after they are referenced within the text.

CHAPTER 2

INTEGRATING TEAM-BASED DESIGN ACROSS THE CURRICULUM AT A LARGE PUBLIC UNIVERSITY

2.1 Background and Significance

Team-based design is a distinguishing practice in engineering and one of the principal criteria programs use for assessment of student outcomes. The importance of teaching students strong fundamental engineering principles as well as creative problem solving, conceptual understanding, adaptability, communication, and diverse leadership skills has been emphasized by broad groups of engineers and constituents for many years (Clough, 2004; Spinks, Silburn, & Birchall, 2006; Armstrong, 2006; National Science Board, 2007; Blue, Blevins, Carriere, Gabriele, Kemnitzer, Rao, & Ulsoy, 2005).

Chemical engineering departments have contributed significantly by studying new approaches to design instruction. Specialty design courses (Mitsos, 2009), freshman design projects and classes (Allam, Tomasko, Trott, Schlosser, Yang, Wilson, & Merrill, 2009; Sauer, 2004; Barritt, Drwiega, Carter, Mazyck, & Chauhan, 2005; Farrell, Newell, & Savelski, 2002), unique design competitions (Kundu & Fowler, 2009), and smaller projects within existing courses (McCallum & Estevez, 1999; Lombardo, 2000; Glennon, 2004; Shaeiwitz & Turton, 2001; Gurumoorthy & Byron Smith, 2013) have enabled the evolution of design from senior level process or plant development to a multi-year discipline-inclusive experience.

In 1992, the Chemical Engineering Department at West Virginia University (WVU) implemented design projects throughout the sophomore and junior years as preparation for the capstone process design course (Bailie, Shaeiwitz, & Whiting, 1994). Three sophomore year projects and five junior year projects built on one another, exploring the same process or

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product, but posing a different challenge each time. Faculty observed students displaying creative, independent thinking and developing communication and teamwork skills (Bailie et al., 1994). This multi-year design-focused curriculum is still in place at WVU. In 1998, the Chemical Engineering Department at Clemson implemented a similar sequence of design courses throughout the curriculum using a case study approach (Hirt, 1998). These projects, incorporated across five semesters from sophomore to senior year, all dealt with different problems related to the same general production process taken from industry examples. Students reported they learned the course material better as a result of the projects and many reported the combination of homework and design projects, as opposed to homework alone, was of great benefit to understanding course material (Hirt, 1998). In 1997, the Chemical Engineering Department at Worcester Polytechnic Institute also developed a "spiral" design sequence that threaded laboratory and design projects through the Material and Energy Balances, Thermodynamics, and Separations courses, combining them into one year-long course (Clark, DiBiasio, & Dixon, 2000; Dixon, Clark, & DiBiasio, 2000; DiBiasio, Comparini, Dixon, & Clark, 2001). The faculty developed an approach that reinforces fundamental topics by revisiting and incorporating chemical engineering material in different projects with increasing difficulty at each stage. One cohort completed the new course while another followed the traditional sequence of courses as a comparison group. Faculty measured higher performance in team and individual problem solving as well as higher performance in junior and senior level courses with the experimental group. The laboratory and design project students also reported higher confidence levels, a more positive attitude towards chemical engineering as a discipline, and higher retention rates in the major compared to the control group students (Clark et al., 2000; Dixon et al., 2000; DiBiasio et al., 2001).

Sequences of design courses culminating in capstones are slowly being developed all over the country in non-chemical engineering departments as well. Pierrakos and colleagues at James Madison University created a six course design sequence at their School of Engineering: two sophomore design courses and a four semester capstone design experience (Pierrakos, Pappas, Nagel, & Nagel, 2012). They found students' perceptions of ABET-based learning outcomes increased by twenty percent between freshman and junior years. At the

University Park campus of The Pennsylvania State University, a similar course sequence is under development (Schiano, 2012). The Department of Electrical Engineering started with cornerstone freshman and capstone design courses only and added a new sophomore-level design tools course, a new junior-level design process course, and a revised senior capstone design course.

As we implemented team design projects across the Chemical and Biomolecular Engineering (CHBE) curriculum at the University of Illinois at Urbana-Champaign (UIUC), we asked the question, "How can authentic design experiences integrated into the CHBE curriculum affect student confidence in their project-related skills and perceptions of Chemical Engineering as a whole?" Instead of focusing on quantitative test score improvement, which could be linked to a variety of factors, we instead assessed student perceptions of improvement in teamwork, professional, and technical skills specifically as a result of design projects implemented across a six course sequence.

2.2 Structure and Organization

Design Across the Curriculum at UIUC is a CHBE-focused program in a large, public research institution. The CHBE Department has a high student to faculty ratio (~50:1). This program is managed at the department level and is fully integrated into the curriculum. Many projects in departments can feature an ad hoc "sprinkling" of design in several courses, but these elements are not formally integrated in the curriculum or assessed as a whole. In the context of a large public research institution, this design program is unique because it incorporates

1. A multi-tiered organizational structure which allows students to work in groups even in large classes and receive individual attention.

2. A mentoring system featuring student interaction with an upperclassman for technical and professional guidance.

3. A program that includes all CHBE students every semester from freshman to senior

year, not just those students who self-select to participate in a department- or campus-sponsored design project.

4. A mixed methods assessment of the design program as a whole, including open- and close-ended exit surveys as well as focus groups.

Design Across the Curriculum within the CHBE Department was developed between 2008 and 2010 and first implemented Spring 2011. The primary objective was to address recurring requests from students, alumni, and advisory board members for a curriculum which features more leadership and teamwork experience, more practice with communication and presentation to wide audiences, greater experience with practical real-world challenges, incorporation of creativity and innovation within coursework, developing students' time management and organization skills, and facilitating students' interaction with individuals of diverse skills (Department of Chemical & Biomolecular Engineering, 2007-2011). Built on a foundation of strong technical fundamentals, Design projects threaded throughout the curriculum could enable these outcomes through repeated and continued practice of creative and conceptual problem solving, communication, and development of leadership skills, as shown in Figure 2.1. Working in groups on real-world open-ended projects every semester throughout their undergraduate experience gives students repeated practice in solving practical engineering challenges in teams.

The Department Head of CHBE and a CHBE Lecturer teaching design courses at the time developed this program over two years. Its goals, organization, and structure were conceived as a means of facilitating the development of a more well-rounded graduate with team, problem solving, leadership, and real-world project skills. Prior to implementation, this program was discussed with the faculty as a whole to ensure instructors of core courses felt there was inherent value to incorporating projects in their courses. Faculty responded favorably to implementing the program because they recognized the benefits to students of incorporating projects in their courses, while relieving them of the burden of additional time and resource costs on their part, as described below.

Incorporating design projects in courses with enrollments of over 200 students mandates a well-planned and organized process with sufficient resources. Since most core chemical

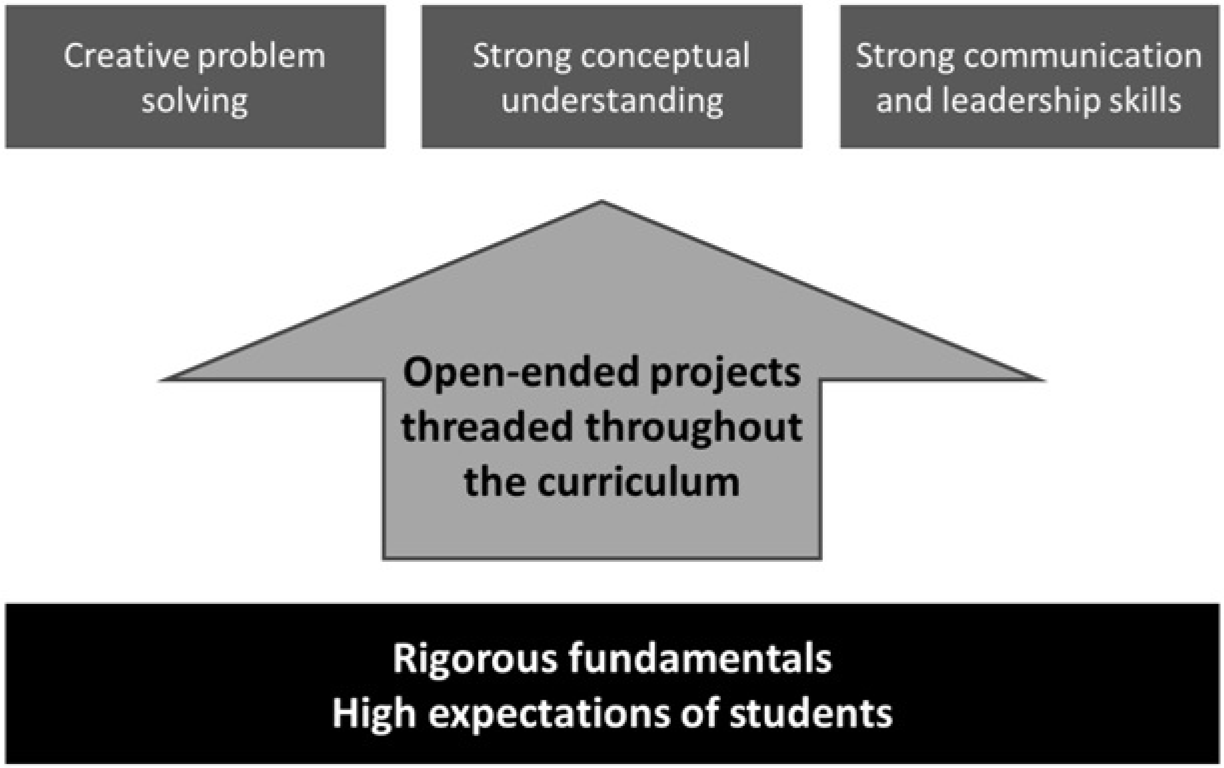

Figure 2.1: Schematic of Design Across the Curriculum as a bridge to achievement of relevant outcomes.

engineering classes are only offered once a year at UIUC, projects were implemented in specific courses to provide students one design experience per semester leading to their senior capstone project. These projects generally escalated in requirements and complexity with each subsequent semester, as shown in Figure 2.2.

To efficiently implement these projects and provide students with a meaningful level of personal attention, a hierarchical structure was developed that leverages faculty members in charge of administering the projects, a head teaching assistant (TA) in charge of team organization and general concerns, and a group of undergraduate peer mentors in charge of guiding student design teams. Each individual plays a critical role in project implementation and facilitating student learning, as shown in Figure 2.3.

During this study, two lecturers served as the faculty members in charge of administering and developing design projects each semester, with each in charge of one project each semester. This administrative role could have also been assumed by tenure-system, emer-

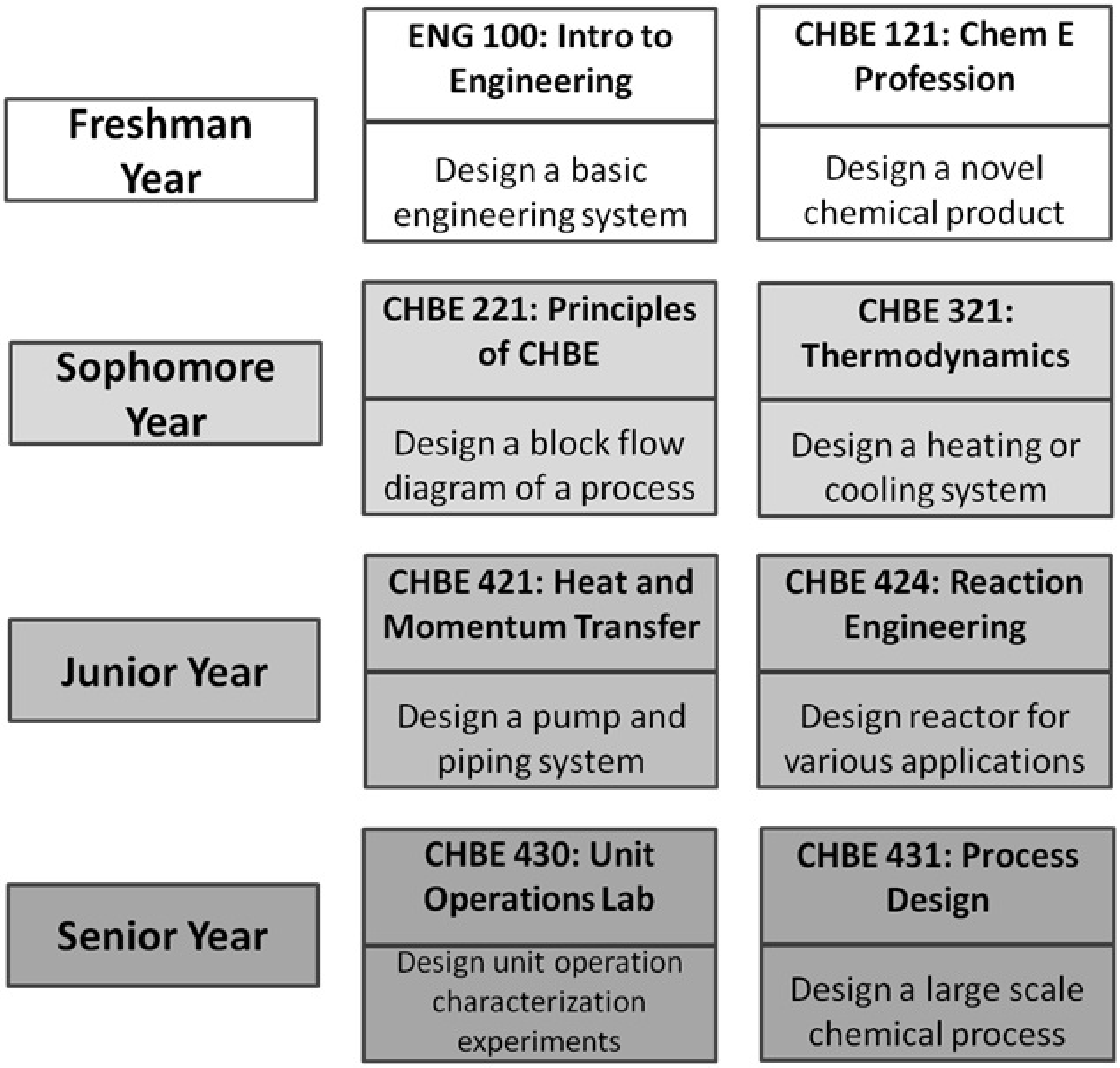

Figure 2.2: Progression of design projects threaded throughout the curriculum. Projects listed are examples of a variety of options implemented any given year.

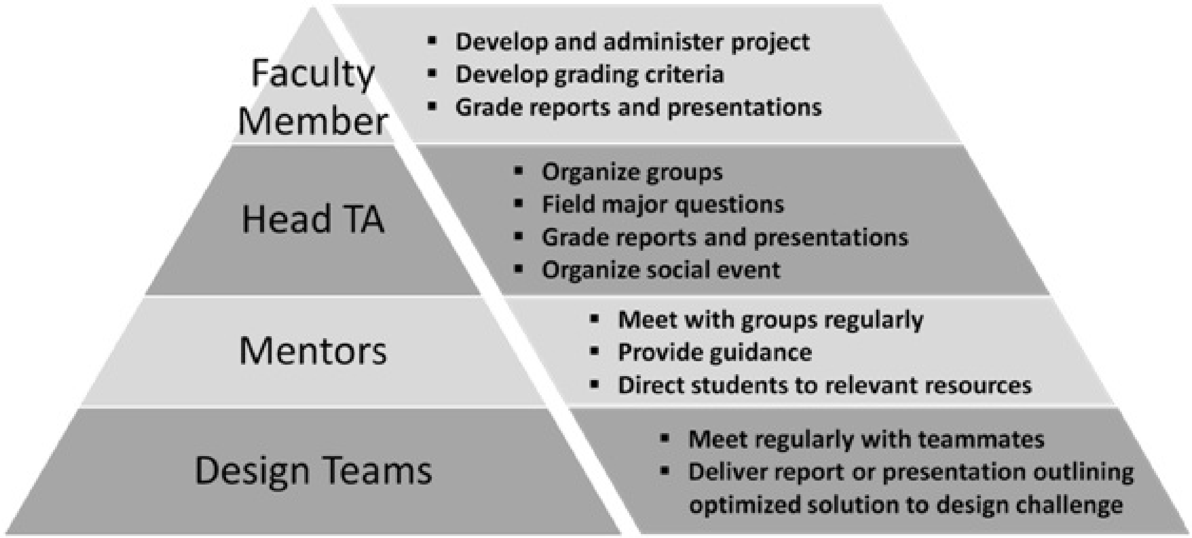

Figure 2.3: Design Across the Curriculum administrative structure showing responsibilities at each level.

itus, or adjunct faculty depending on interest and availability. The head TA position was assumed by either a senior undergraduate or graduate teaching assistant. Mentors were students who elected to earn individual study credit for serving as manager and providing technical and professional guidance to between one and seven teams. Mentors were required to have taken the course for which they managed teams in a previous year. In some cases where too few undergraduate mentors were available or interested, this role was assumed by graduate students. Initially, to incentivize students to participate in a new and untested program, mentors earned one credit hour per team. After the program's first semester, mentors earned one credit hour for every three teams. Currently, mentors earn a maximum of one hour of independent study credit per semester. Mentors were graded based on written team feedback collected at the end of each project.

Each course had between 30-50 design teams who were assigned to meet with their mentors at least once a week for the duration of each project. Any questions or conflicts which could not be addressed by the mentors were referred to the head TA. The faculty member administering the project generally did not meet with student teams, but provided project clarification as necessary. These layered roles are described visually in Figure 2.4.

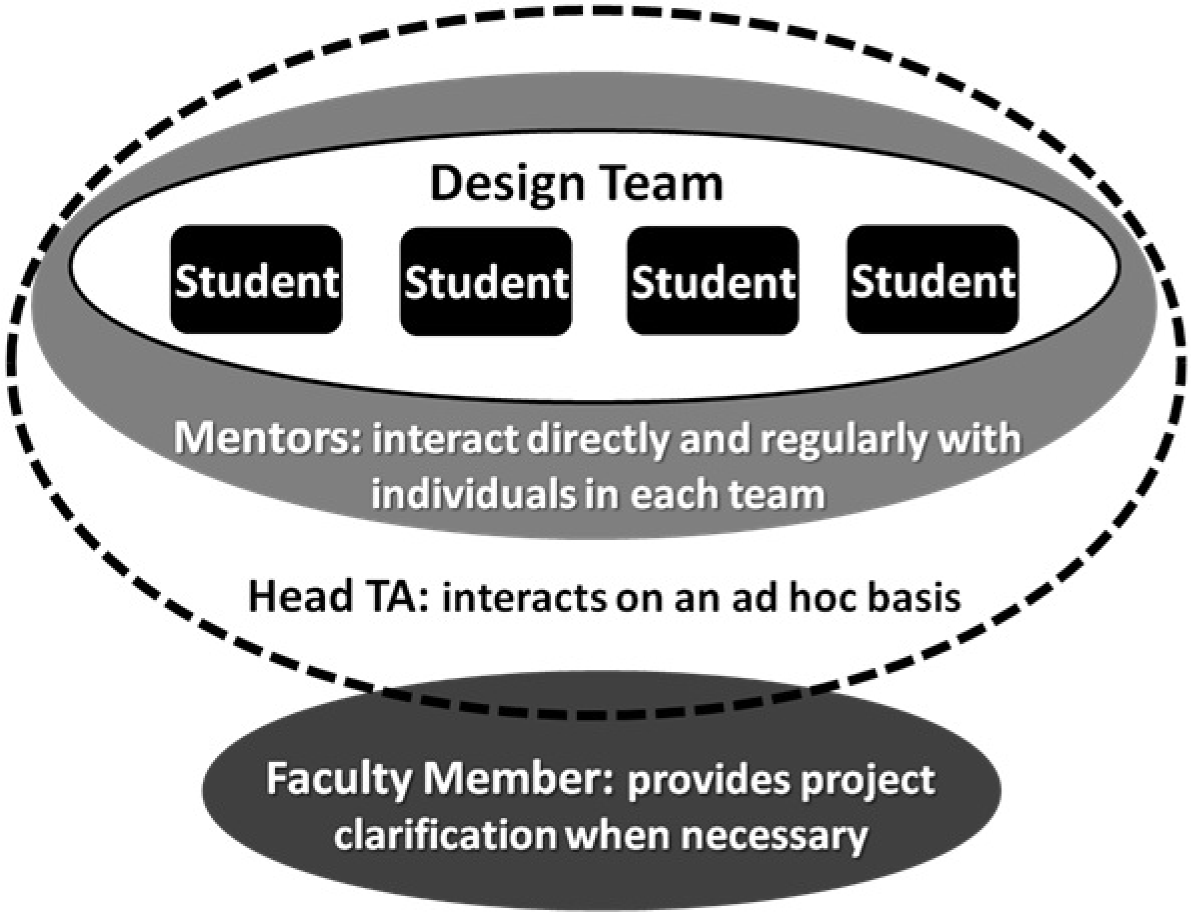

Figure 2.4: Layered roles of the mentors, head TA, and faculty member in student project support.

The size of this program necessitated a multi-tiered structure since meetings with up to 50 teams of students on a regular basis would have been burdensome for any one faculty member or small group of TAs. Since almost all questions and conflicts were resolved directly by mentors, and the head TA intervened only as needed, this structure minimized the time commitment of the faculty member in charge of the project, as shown in Figure 2.5.

The faculty member in charge of administering the design project was distinct from the faculty member teaching the course in all cases except CHBE 121. In other words, for almost all projects, there were no individuals who played dual roles as regular course instructor and project administrator. This arrangement relieved the course instructors and TAs from the burden of project management. Providing student teams with multiple levels of support helped ensure tenure-track faculty serving as course instructors were not diverting time

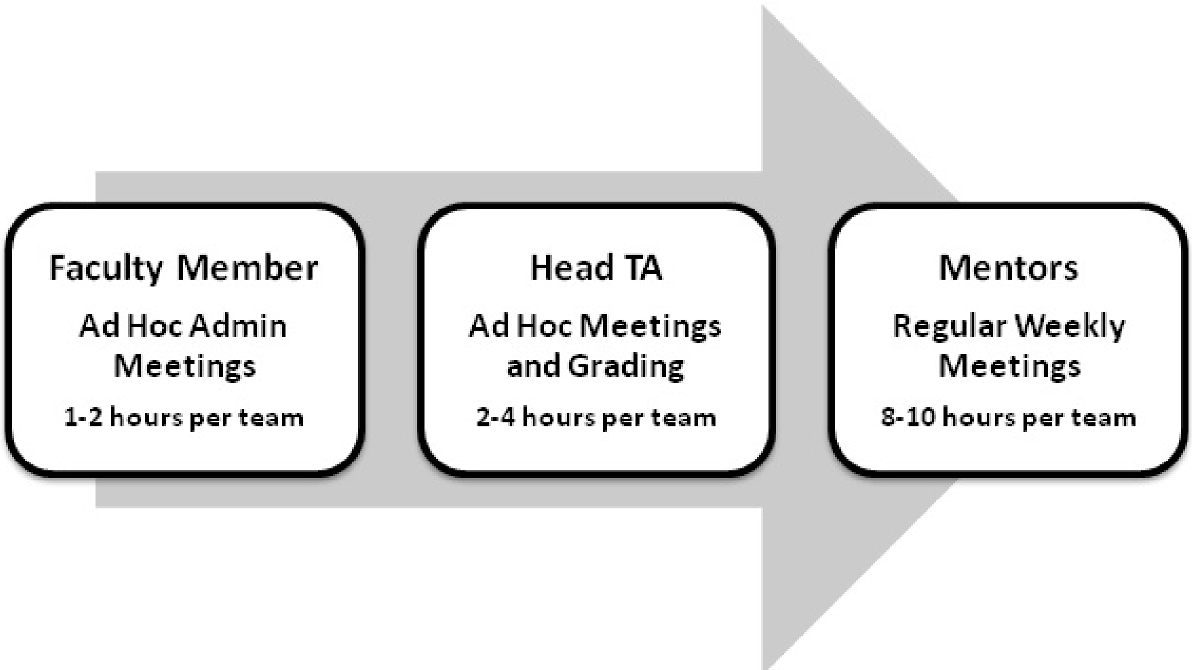

Figure 2.5: Time commitment per student team for the mentors, head TA, and faculty member per semester.

from lecture or office hours to assist with the design project. However, each course instructor was given the opportunity to modify the design project statement at the beginning of the semester to best align with their course curriculum that semester.

2.3 Methods

Design projects were integrated into five single semester courses in the CHBE curriculum: Principles of Chemical Engineering (CHBE 221) and Momentum and Heat Transfer (CHBE 421) in the Fall 2011 semester and Chemical Engineering Profession (CHBE 121), Thermodynamics (CHBE 321), and Chemical Reaction Engineering (CHBE 424) in the Spring 2012 semester. All five courses are required in the CHBE curriculum and are taken in numerical order over five consecutive semesters. One course-specific design project with physical and economic constraints, such as size of process, energy requirements, and cost limits, was incorporated in each course and accounted for ten percent of the final course grade. We assessed four out of the five courses over the 2011-2012 academic year. A summary of course content and accompanying design projects for these four courses can be seen in Table 2.1.

Table 2.1: Design projects by course content.

Course	Course Content Summary	Design Project
CHBE 221	Material and Energy Balances	Optimize the mass balance for a chemical production process to maximize profit. Deliverable: final report, some teams selected to present to BP
CHBE 321	Fundamental concepts and laws of Thermodynamics; first and second law applications to phase equilibrium and chemical equilibrium	Design a process to heat a house using an unconventional fuel source (i.e., not coal or traditional fossil fuels). Deliverable: final report
CHBE 421	Introduction to Fluid Statics and Dynamics; dimensional analysis; design of flow systems; introduction to heat transfer; conduction, convection, and radiation	Design an above-ground pumping and piping system to supply cooling water to a distillation column condenser. Deliverable: final report, some teams selected to present to BP
CHBE 424	Chemical Kinetics; Chemical Reactor Design; the interrelationship between transport, thermodynamics, and chemical reaction in open and closed systems	Evaluate the feasibility of a reactor retrofit in a chemical production process. Deliverable: final report

The majority of students were full time, residential, and of traditional undergraduate age. During the two semesters studied, there were approximately 33% female students in each course, consistent with other large chemical engineering programs. Students came from various ethnic backgrounds in each course, with approximately 50% white, 30% Asian, and the remaining percentage either identifying another background or with no background information available. These student demographics are an accurate reflection of students in the UIUC CHBE program as a whole.

Students completed the projects in teams of three to five and stayed in the same team for the duration of the project. Students in CHBE 221 were grouped into diverse teams by their Myers-Briggs Type Indicator (MBTI) type (Shen, Prior, White, & Karamanoglu,

2007) and in CHBE 321, 421, and 424 by selection based on GPA quartiles. Mentors were assigned up to three teams each. The head TA and the faculty member who developed the design project statement assigned grades for the final reports. The course instructor did not participate in grading the design projects.

Students were not given any formal design training before starting these projects. Instead, this program aimed to help students develop these skills gradually through small projects in each course, each counting for less than the value of a typical exam. This progression helped students become familiar with the design process in a relatively low stakes environment.

Students were quantitatively assessed by their final reports, but neither final reports nor test scores were used to assess the efficacy of this design program since there was no control group for comparison. Having a control group for this study would arbitrarily increase or decrease the workload requirement for half the students in the course, creating an inequitable classroom environment and impartial evaluation of the program. Scores from the final Process Design course were not compared to scores after the Design Across the Curriculum program was implemented because the instructors of the Process Design course had changed, resulting in the adoption of different teaching and assessment methods.

2.4 Evaluation

To evaluate student outcomes, an integrated concurrent mixed-method research design with joint data analysis incorporating both surveys and focus groups was employed (IRB Approval #12193). Students in all four courses completed an online exit survey which gathered students' perceptions of the learning outcomes from the design projects. The surveys consisted of closed- and open-ended questions based on critical design- and team-related outcomes, as seen in Table 2.2. These project outcomes were written by the original CHBE Process Design Lecturer who began the program, based on ABET Engineering Accreditation Commission outcomes (c), (d), (e), (g), (h), (i), and (j).

Closed-ended questions were a mixture of 4 and 5-point Likert scale rated items. An exploratory factor analysis on the 15 post-survey questions common to both semesters was performed and Cronbach's alpha values for all 15 questions ($\alpha = 0.90$) and for each of the

Table 2.2: Number and type of questions in exit survey.

Semester	**Fall 2011**		**Spring 2012**	
	Closed	**Open**	**Closed**	**Open**
Total	**19**	**3**	**21**	**6**
Improvement of Teamwork Skills ($\alpha = 0.84$)	5		5	
Appreciation for Engineering ($\alpha = 0.77$)	4		4	
Perceived Future Benefits ($\alpha = 0.72$)	3		3	
Improvement of Design Skills ($\alpha = 0.68$)	3		3	
Other	4		6	

four individual factors were calculated. The exit survey and focus group response rates can be seen in Table 2.3.

Table 2.3: Student response rates to exit survey and focus groups.

Semester	**Fall 2011**		**Spring 2012**	
Course	**CHBE 221 (N= 194)**	**CHBE 421 (N = 130)**	**CHBE 321 (N = 187)**	**CHBE 424 (N = 122)**
Post-survey	32% (N = 63)	27% (N = 35)	24% (N = 44)	8% (N = 10)
Student Focus Group	8 students	3 students	1 student	7 students
Mentor Focus Group	None	None	4 Mentors	

A one-hour semi-structured focus group was held for each course after the design projects were completed. Students received pizza and beverages for focus group participation, but no monetary compensation. Data were analyzed from a post-positivistic perspective in which researchers attempted to minimize their biases in relation to surveys and focus groups. To this end, only authors who were uninvolved with project grading and had not interacted with students moderated focus groups such that no preconceptions about the students based on their performance were brought to the sessions. Survey analysis and theme development for open-ended questions and focus groups were carried out by the same authors who moderated focus groups with subsequent consultation from more student involved faculty members for clarification and peer debriefing. A thematic approach (Guest, MacQueen, & Namey, 2012) was used in the analysis of the qualitative data. The authors individually coded the open-ended survey responses and focus group transcripts and then came together for consensus building and theme development. An open coding scheme based on the goals of fostering teamwork, professional, and technical skills was used as a starting point for the coding and theme development process. When negative cases surfaced, themes were adjusted until all negative cases were accounted for. Seven major themes were identified from the qualitative data, including 1) feedback and grading, 2) project design, 3) presentation opportunities, 4) team design and experience, 5) overall experience, 6) learning outcomes, and 7) mentor experiences. Results from feedback and grading, project design, presentation opportunities, and team design and experience were used primarily for administrative purposes. Student comments were considered representative when at least three separate students from the same course commented similarly about the same topic.

2.4.1 Limitations

In Spring 2012, only one student volunteered for the CHBE 321 student focus group, making it more of an interview. However, the student was asked the same questions as students in the CHBE 424 student focus group and the contributions of the interview are included below because they still represent the view of a CHBE 321 student. Because of this limitation, any quotations presented from the CHBE 321 student cannot be considered representative of at least three separate students from the same course. Additionally, the response rate from CHBE 424 students on the post-survey was considerably lower than the response rates from other courses. We hypothesize this low response rate occurred because the post-survey was administered during finals week when the vast majority of CHBE 424 students were attempting to finish their capstone design projects, pass all their final exams, and ultimately graduate. Their schedules likely did not permit them to provide even the 15 minutes required to fill out the survey in their end of semester rush. This limitation should be considered when comparing post-survey responses across different courses as the sample sizes and response rates vary. In future evaluations of the program, the post-survey will not be administered during finals week in the hopes of receiving a higher response rate from students.

2.5 Results and Discussion

We report results for overall experience, learning outcomes, and mentor experiences below.

2.5.1 Overall Experience

Overall, quantitative and qualitative data suggest that students perceived the design projects to be a positive learning experience. When asked the closed-ended exit survey question, "How did the design project affect your opinion of chemical engineering as a discipline?" survey respondents were slightly positive about the discipline, as shown in Table 2.4.

Table 2.4: Mean responses by course of the exit survey question: *How did the Design project affect your opinion of Chemical Engineering as a discipline?* Response was on a five point scale: Extremely Positive (5) - Extremely Negative (1).

Course	**CHBE 221 (N = 64)**	**CHBE 321 (N = 44)**	**CHBE 421 (N = 35)**	**CHBE 424 (N = 10)**
Mean (SD) (Out of 5)	3.29 (0.95)	3.64 (0.74)	3.39 (0.99)	3.40 (0.66)

Focus group participants stated they were satisfied with the experience provided by the addition of a design project to the course, and several mentioned that after completing the project, their attitudes toward Chemical Engineering as a discipline improved. Representative student comments from the focus groups are shown below:

> *Overall, though, it was a pretty good experience because ... I [received] a really good insight into a little flavor, a little free sample of what is [going to] be going on in the future.* - CHBE 221 student

> *A couple of years ago I didn't want to do chemical engineering at all. I felt that I don't want to be stuck in a factory or power plant the rest of my life, but if it was*

something like this, you meet good people, you meet a good team and I thought it helped a lot. I have a more positive outlook in terms of what I'm going to do in the next few years. - CHBE 421 student

Some students also compared their experience with the Fall 2011 design projects with those during the Spring 2012 semester. Students mentioned the design process was easier after having completed it before. Representative student comments from the focus groups are shown below:

> *[The project] certainly went better than last time ... comparatively speaking, this time around it was a lot smoother.* - CHBE 321 student
>
> *... for my first project, "I don't know what's going on here," but after that for the second and this semester I think that my group [was] very good ...* - CHBE 424 student

2.5.2 Learning Outcomes

During focus groups, students mentioned perceiving an improvement in their teamwork skills as well as their understanding of the relationship between coursework and industrial applications. A representative student comment from the focus groups is shown below:

> Interviewer: *... what portion of the design project do you believe helped you the most for your future career ...?*
>
> CHBE 321 student: *... it's a tossup between the ability to sort of effectively organize a group into a project and get people to work together toward a goal, or the ability to start from nothing and build something from scratch.*

Survey respondents reflected similar gains on the exit survey. Since open-ended questions were not prompted, students created individual responses, rather than choosing from a menu of learning outcome options. When asked the open-ended question, "List the three most important things you learned from this design experience," Fall 2011 survey respondents

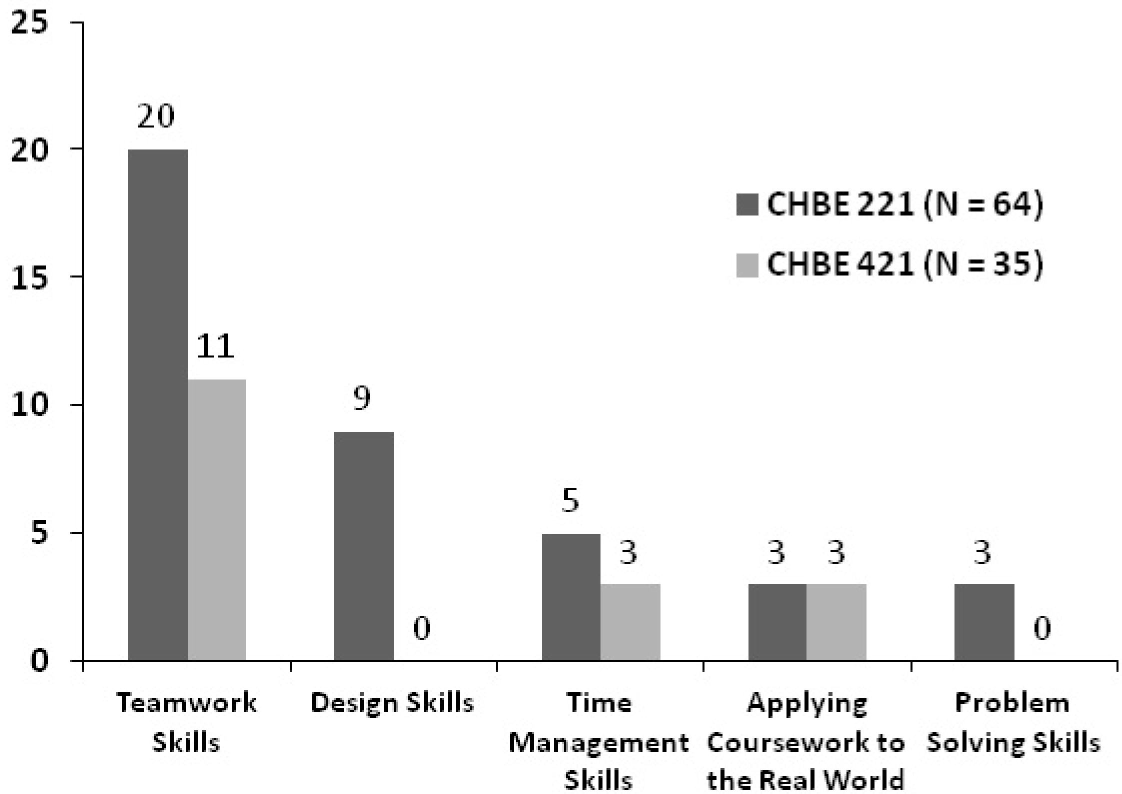

Figure 2.6: Responses by course to the post-survey question: *List the three most important things you learned from this design experience.*

indicated several common outcomes, which were classified into five categories by the authors. These survey responses are shown in Figure 2.6.

Survey respondents were also asked to respond to rated items about specific learning outcomes. Tables 2.5 and 2.6 summarize the items rated highest and lowest on the exit survey, respectively. The highest and lowest rated items from Fall 2011 were comparable to the results in Spring 2012, with a few exceptions as noted below.

Table 2.5: Highest rated learning outcomes, as measured from exit surveys. Response was on a four point scale: Very useful (4) - Not at all useful (1).

	CHBE 221 N=64	**CHBE 421 N=35**	**CHBE 321 N=44**	**CHBE 424 N=10**	**Total N=153**
Q: How would you rate this design experience with regard to...	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	**Mean (SD)**
Improving your ability to communicate with teammates?	3.1 (0.78)	3.0 (0.84)	3.1 (0.77)	3.1 (0.83)	**3.0 (0.78)**
Improving your ability to work in a team?	2.8 (0.89)	2.8 (0.79)	3.1 (0.81)	2.8 (0.87)	**2.9 (0.84)**
Improving your ability to take a leadership role?	2.8 (0.86)	2.8 (0.91)	2.9 (0.80)	2.7 (0.46)	**2.8 (0.89)**
Improving your ability to compromise on decisions?	2.8 (0.90)	2.8 (0.87)	2.9 (0.90)	2.9 (0.70)	**2.8 (0.89)**
Learning how equations in class can be applied to make a product or piece of equipment?	2.7 (0.80)	3.2 (0.75)	2.3 (0.74)	2.9 (0.54)	**2.7 (0.83)**
Learning how to design a product or piece of equipment?	2.1 (0.86)	2.9 (0.67)	2.7 (0.67)	2.8 (0.40)	**2.5 (0.83)**
Improving your confidence that you can design a system?	2.3 (0.93)	2.7 (0.87)	2.7 (0.71)	2.8 (0.75)	**2.5 (0.86)**

The three highest rated learning outcomes from the exit survey were all related to a perceived improvement of teamwork skills. These closed-ended question outcomes correspond with the highest rated outcome from the open-ended survey questions, where students suggested the same set of skills as the most important learning outcome from the project experience. This general pattern continued with the third most commonly identified outcome from the open-ended survey corresponding to the next highest rated outcome, applying coursework to the real world. Developing design skills was the next highest rated outcome for both open-ended and closed-ended exit survey questions. These data suggest reliability between both open-ended and closed-ended questions on the surveys. Three notable low scores are underlined in Table 2.5. The low rating associated with applying equations in class was also present in focus groups with the student reporting a disconnect between the course material and the design project.

> *... in terms of actually getting a better understanding of thermodynamics, it didn't do a whole lot for it. The calculations were pretty simple.* - CHBE 321 student

Students in CHBE 221 gave low ratings on the development of design-related skills. Because the project focus was an open-ended mass balance problem, students assumed they were not learning design skills. However, this response did not appear in the focus groups and remains as a consideration for improving the CHBE 221 design experience.

Table 2.6: Lowest rated learning outcomes, as measured from exit surveys. Response was on a four point scale: Very useful (4) - Not at all useful (1).

	CHBE 221 N=64	**CHBE 421 N=35**	**CHBE 321 N=44**	**CHBE 424 N=10**	**Total N=153**
Q: How would you rate this design experience with regard to...	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	**Mean (SD)**
Improving your report writing skills?	2.0 (0.79)	2.3 (0.79)	2.7 (0.80)	2.5 (0.84)	**2.3 (0.83)**
Improving your ability to communicate with a mentor?	2.3 (0.90)	2.4 (0.88)	2.3 (1.0)	2.5 (0.97)	**2.3 (0.92)**
Making class more interesting?	2.5 (0.90)	2.5 (0.92)	2.3 (0.93)	2.2 (0.42)	**2.4 (0.89)**
Improving your organizational skills?	2.4 (0.89)	2.5 (0.82)	2.4 (0.97)	2.4 (0.52)	**2.4 (0.86)**
Improving your ability to be an expert in engineering?	2.4 (0.91)	2.6 (0.97)	2.5 (0.88)	2.7 (0.67)	**2.5 (0.90)**

Because there was no formal lecture, course, or training related directly to organizational skills, the relatively low ratings on the related outcomes were not surprising. A notable improvement across semesters is underlined above. Students rated the design projects as more useful in improving their report writing skills across semesters. Similarly, student commented in focus groups about design projects "going smoother" or "being easier to conceptualize" with each iteration. These results are consistent with an increase in confidence and self-perceived skill level found by others implementing design projects throughout the curriculum (Clark et al., 2000; Dixon et al., 2000; DiBiasio et al., 2001). The authors believe this indicates students felt more prepared to write the final reports with each design project they experienced in the sequence.

2.5.3 Mentor Experiences

In Spring 2012, Mentor focus groups were conducted, and additional mentor related questions were added to the exit survey in an effort to collect additional feedback for improving project structure. While some students reported mentors who were generally not present or fulfilling their responsibility, 72% of students who responded to the Spring 2012 exit survey viewed their mentor as useful. Both mentors and students stated they understood the role and responsibility of the mentor within the team, but both groups felt mentors lacked authority.

> *... just from being a project mentor I noticed that sometimes my job was difficult because ... I don't have authority.* - CHBE 424 student and previous mentor

Overall, mentors felt they were underprepared for their role and requested that mentor training be provided. Related to this, many mentors stated that managing many teams at once was overwhelming.

> *We all only underwent one design project before we became mentors. We only had one class, and now we have to implement it in all these classes.* - Mentor

> *[It would be useful] ... if you did an hour a week on how to lead a group, and an hour a week on what this group project is ...* - Mentor

> *Five groups is a lot.* Mentor

If made available, mentor training should have featured elements of any teaching training program, such as guidance for meeting preparation, developing a working knowledge of available technical resources, facilitating discussion in a group setting, and answering questions while not imposing decisions or opinions. In fact, mentor training should as much as possible leverage campus- or college-wide teaching training often offered by teaching and learning centers. These programs are oftentimes the best way of leveraging expert training without burdening faculty with additional student training obligations. Furthermore, this training should also be extended to the head TA who must be trained in organizing large number of groups, resolving team conflicts, and answering common project questions while not suggesting a "correct answer." If this training is not available on the campus level, then the faculty member in charge of the projects should be responsible for developing these training modules. Despite some negative comments, mentors generally conveyed a positive attitude towards student performance, admired students' dedication to the project, and felt invested in a positive student experience.

2.6 Conclusions

Implementing design projects across the curriculum can provide students with meaningful teamwork experiences even at very large schools. With sufficient resources and planning, design projects can be incorporated into almost every required course in the curriculum, giving students approximately one design experience each semester leading up to the capstone experience. For each project, a layered structure in the form a faculty member, head TA(s), and mentor support help ensure that all students have a primary, secondary, and tertiary point of contact for guidance.

In revisiting our research question, "How can design experiences integrated into the CHBE curriculum affect student confidence in their project-related skills and perceptions of Chemical Engineering as a whole?" we found that students perceived improvement in a variety of project-related learning outcomes, most notably teamwork skills, bridging the gap between coursework and real-world engineering, time management, and design skills (Figure 2.6 and Table 2.5). Students generally had a positive attitude towards chemical engineering as a discipline after these design projects (Table 2.4) and felt more confident about future design projects after each one was completed. The focus groups and open-ended survey responses allowed students and mentors to describe their attitudes and perceptions in detail. These descriptions were supported by closed-ended survey responses that focused on affective outcomes rather than on cognitive outcomes exclusively.

In implementing a Design Across the Curriculum program in a large school, the program itself should be well organized in terms of resources and planning. Projects must balance open-ended objectives with sufficient specificity to appropriately challenge students. The percentage of the course grade allocated to the projects must be sufficient to ensure students feel that faculty members are significantly invested in the projects. Providing students with face-to-face time or presentation opportunities in front of corporate representatives is highly recommended. Training for mentors and head TAs would allow an even more efficient process if implemented correctly, as mentors could display greater authority in providing guidance and direction. In future study of the outcomes of team design experiences, we recommend investigating student motivation, attitudes, and perceptions to a greater extent than cognitive outcomes for a richer understanding of the student experience.

2.7 Acknowledgments

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CHAPTER 3

FOSTERING MOTIVATION AS A COURSE OBJECTIVE IN A LARGE ENGINEERING COURSE FOR SECOND-YEAR STUDENTS: A NARRATIVE APPROACH

3.1 Introduction

As the demand for more engineering graduates remains high, retaining students within engineering majors has been maintained as a national objective (Augustine, 2007). The urgency of this demand has led to radical innovations in first-year engineering courses and programs to make engineering more inviting and inclusive across the nation (Augustine, 2007). Unfortunately, the emphasis on improving first-year experiences may be exacerbating the "sophomore slump" that many students experience as they leave the welcoming environment of first-year programming and enter the "math-science death march" in the second and third years before they can again engage in profound engineering experiences in their final year design or capstone courses.

In academic settings, the sophomore slump has been defined as a "period of developmental confusion" in which students disengage from learning activities because of "struggles with achieving competence, desiring autonomy, establishing identity, and developing purpose" (Boivin, Fountain, & Baylis, 2000; Lemons & Richmond, 1987; Sanchez-Leguelinel, 2008). In the context of engineering education, the sophomore slump is seldom discussed. Few programmatic or instructional efforts offer to remedy it, despite the still present high attrition rates during the second year (Augustine, 2007; Clough, 2005, 2004).

The Low-Cost Intrinsic Motivation Course Conversion (Herman, 2012; Herman, Somerville, Goldberg, & Green, 2012a) is a pedagogical technique that was designed to improve students' motivation to learn in core second- or third-year engineering courses while minimizing the time and training required from faculty to make these meaningful changes in their courses.

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Given the critical importance of improving students' affective outcomes in the second year, we explore how a course that underwent a Low-Cost Intrinsic Motivation Course Conversion affected students' motivational orientations during the semester. In particular, we focus on answering the questions 1) what aspects of the course created positive shifts in students' motivational orientations toward an intrinsic motivation orientation and 2) how can faculty assess this shift in motivation as a method for course evaluation?

3.2 Background

An individual's motivation arises from human needs for competence, autonomy, relatedness, and purpose (Pink, 2011; Ryan & Deci, 2000). In an academic context, students feel competent when they master a body of knowledge, enjoy autonomy when they control their learning, achieve relatedness when they belong to a community, and gain a sense of purpose when the learning objectives of a course align with their personal values or goals. Motivation ranges on a continuum from extrinsic (receiving rewards such as grades, complying with rules) to intrinsic (satisfying personal interests, or deriving from the inherent value of an activity) (Ryan & Deci, 2000).

Intrinsic motivation (IM) improves cognitive development within local factors such as the academic subject, the characteristics of the students, and the institutional context (Atman et al., 2010; Pintrich, 2003; Sinatra, 2005). The Academic Pathways for People Learning Engineering Survey, APPLES, has also revealed that the strongest motivators to enter engineering were intrinsic, both psychological ("I enjoy engineering") and behavioral ("I like to fix things") (Atman et al., 2010). Motivation was positively correlated with persistence and the intention to complete the engineering degree. In engineering courses, active learning courses generally improve students' conceptual understandings, academic achievement, intrinsic motivation, and attitudes about the college experience (Prince, 2004; Ryan & Deci, 2002; Smith, Sheppard, Johnson, & Johnson, 2005). Despite the importance of intrinsic motivation in learning, it seldom has served as the focal point of pedagogical change in engineering.

Based on their research on intrinsic motivation, Ryan and Deci have developed what they call autonomy-supportive pedagogies (Ryan & Deci, 2002; Black & Deci, 2000). Autonomy-supportive pedagogies are based on both instructors' attitudes and the course structures. For example, the literature explains that autonomy-supportive teachers spend more time listening, articulate fewer directives, ask more questions about what the student wants, verbalize fewer solutions to problems, make more empathetic statements, and offer greater support for students' internalization of learning goals (Reeve & Halusic, 2009).

However, different learning environments are more or less conducive to an instructor's use of autonomy-supportive actions. For example, when K-12 teachers are led to focus on meeting national or state standards, they use fewer autonomy-supportive actions (Reeve, 2009). Similarly, we expect that graduate teaching assistants (TAs) will struggle to be autonomy-supportive when they are told what topics and examples to cover in their discussion sections. To effectively promote students' intrinsic motivation to learn, autonomy-supportive behaviors must be coupled with equally effective, well-defined course structures that guide student learning (Jang, Reeve, & Deci, 2010). These structures need to be student centered (not standard centered) and focus on meeting students' needs as their needs change throughout the semester.

Although the applicability of SDT has been extensively studied in elementary and secondary schools, there has been relatively little effort to bring the theory into the college classroom or the engineering classroom (Black & Deci, 2000). Given the different social environment and expectations of the college learning environment, we need a deeper understanding of the strengths and limitations of SDT when using it as a framework for designing pedagogical interventions. Further, the design of technical courses has historically focused on cognitive rather than affective outcomes (Herman, Somerville, Stolk, Trenshaw, & Goldberg, 2013a; Hansen, 2011). Our research questions will provide understanding both into how SDT applies to the college engineering classroom and whether a course designed to improve motivation can be successful.

3.3 Course Design

The IM-supportive course was designed with the goals of supporting students' sense of autonomy, competence, relatedness, and purpose as described by SDT. Complete details of the course design and its positive impacts on cognitive outcomes are discussed in other publications (Herman, 2012; Herman et al., 2012a), but a brief description of the course is provided as context for this study.

3.3.1 Student Demographics

Computer Engineering I is a large enrollment (on the order of 200 students per semester), second-year, digital logic and computer architecture course required for all electrical and computer engineering majors at a large public institution in the Midwest (Midwestern University). Each week students attend two lectures taught by a professor and one discussion section out of eight taught by teaching assistants (TAs).

As part of a quasi-experiment in the Fall semester of 2011, two of the discussion sections (37 students) were converted to be experimental IM sections and were taught with IM-supportive pedagogies where students were given the autonomy to choose their learning activities. Because this was the first offering of the IM-converted sections, we allowed students to leave or enter the sections at their discretion. In order to account for students' freedom to leave or enter sections, we took careful measurements of student preparation and student motivation in both the IM-converted sections and the traditional sections at the beginning of the semester. These measurements suggest no discernible difference in student populations between the two types of sections (Herman et al., 2012a).

3.3.2 IM-Supportive Pedagogy and Class Structure

To minimize faculty time and effort, we made the discussion sections the locus of change for the pedagogy. The professors delivered lectures as they normally would. The changes to the pedagogy were driven instead by the TAs in charge of the two IM-converted discussion sections.

Within these IM-converted discussion sections, students were organized into learning teams (to promote students' sense of relatedness) based upon the students' stated purpose for taking Computer Engineering I. Each learning team had four or five students. During the semester, these learning teams negotiated a series of three purpose-based learning contracts with the TA. In these learning contracts, students were given autonomy over three elements of the course: (1) what elective topics they would study (topic selection), (2) how they would learn mandatory and elective topics (practice selection), and (3) how they would demonstrate their mastery of those topics (mastery selection). The TAs supported students' sense of competence by giving the students time to adjust to the autonomy in the course. Autonomy was scaffolded such that students had fewer choices at the start of the semester and more autonomy as the semester progressed.

Based on the prior research in primary and secondary schools, we designed the sections to focus on promoting students' autonomy and scaffolding students into progressively greater autonomy. On the first learning contracts, students were allowed to select topics, mastery, and practice options only from preapproved lists. Students were given progressively more autonomy such that on the final learning contract students were allowed to choose whatever topics they wanted to study and practice those topics in whatever way seemed best. This final learning contract gave the students autonomy that was comparable to the autonomy that students might have in a senior design course, shown in Figure 3.1.

Increased levels of choice and autonomy in the experimental IM sections are highlighted in bold. The hypothetical level of autonomy in a senior design course is included for reference. Because of campus regulations, all students were required to take the same final examination (resulting in low autonomy at the end of the term).

3.4 Methods

To better understand how this pedagogy affected students' motivations to learn, we collected three types of data: motivation surveys (previously discussed in detail (Herman et al., 2012a)), classroom observations, and post-course exit interviews. We analyzed the data from a constructivist perspective in which we treated students' narratives about their motivation

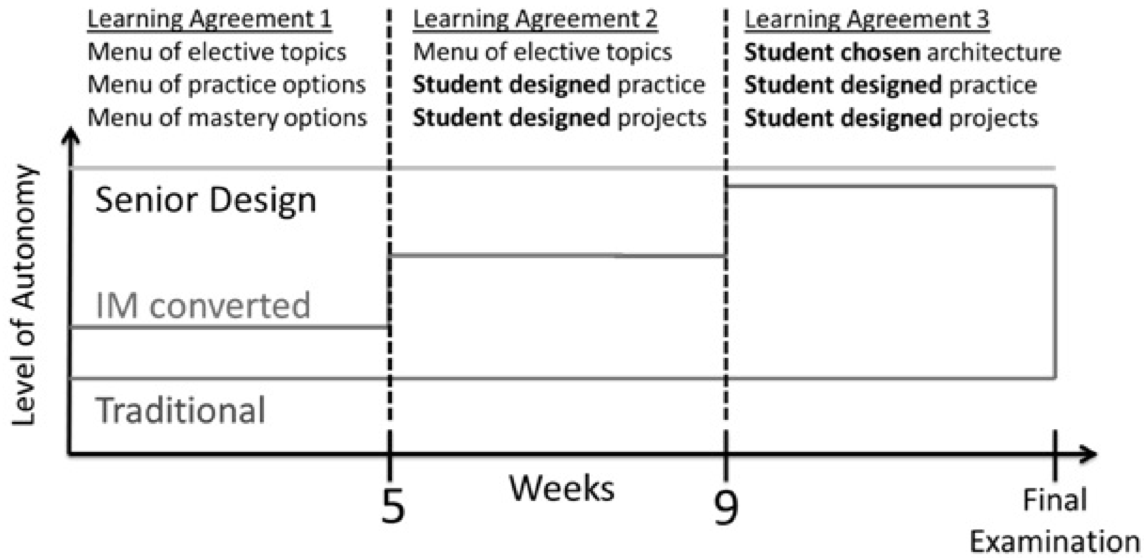

Figure 3.1: Comparison of learning activities for the traditional and IM-converted sections.

as the constructed truth of their experience in the course (Guba & Lincoln, 1994). We chose to conceptualize our study in the tradition of narrative inquiry (Clandinin & Connelly, 2000) because motivation is a difficult concept to articulate. Viewing motivation through the lens of narratives gives a rich description of the specific details and micro-events that affected students' motivation. Our narrative inquiry into the student experience focused on a paradigmatic analysis in which we sought commonalities among students' narratives in terms of what course events most influenced their motivational orientations (Case & Light, 2011). In the results section, we present composites of students' narratives through the use of crafted vignettes which combine students' statements from surveys, interviews, and the researchers' classroom observations and field notes. The use of multiple data sources allowed for triangulation of our interpretations to bolster their trustworthiness, credibility, and dependability.

We also present unaltered quotations from students' interviews and trajectories of students' experiences throughout the course. Vignettes and unaltered quotations are presented in block quotations. Unaltered student quotations in the vignettes are presented in italics. All research was performed with the approval of the local Institutional Review Board (IRB Protocol #12046).

3.4.1 Classroom Observations and Interviews

Classroom observations and interviews were conducted with a primarily narrative eliciting design aimed at understanding the student experience and motivation throughout the course. Our results focus on the events and features that were important to the students personally, as expressed through their narratives. This emphasis on describing the student experience is tempered by the goal of understanding students' motivation in the classroom through the lens of Self-Determination Theory (SDT). Consequently, our observations of student behaviors and our excerpts from interviews emphasize affective statements related to students' perceptions of their felt purpose, autonomy, relatedness, and competence. The results of these observations and interviews are reported by crafting vignettes that combine details from the observations with quotations from students' interviews. These vignettes are supplemented by additional quotations from the interviews as well as trajectories of students' motivational orientations derived from students' statements about their motivation during the semester. All names in the vignettes and quotations are pseudonyms for composite representations of students or TAs.

3.4.2 Classroom Observation Method

One author conducted observations of both the weekly IM-converted course sessions and students' presentations outside the classroom. Immediately after observations, the observer expanded on field notes while the experience was still fresh and more easily recalled. The observer debriefed with TAs and other observers when available. Field notes collected during these observations focused on students' interactions with each other in their learning teams and their interactions as a team with the TA rather than on the TAs' actions or conduct. When possible, quotations from students were captured in the field notes, but no recordings devices were permitted in the classroom because not all students had consented to participate in this study. Observations also focused on contextual factors such as weather, lighting, and seating arrangements to capture a richer understanding of students' experiences through conceptualizing the settings in which many of their narratives took place.

3.4.3 Interview Method

To supplement our understanding of what students found to be important in their course experience, we asked students to share their individual narratives through exit interviews. Eight of the 37 students in the IM sections volunteered to be interviewed. All eight interviews were audio recorded. Of the eight students, one was female and seven were male. They collectively represented six of the seven learning teams in the IM sections. The interview protocol was semi-structured and designed to take between 45 and 60 minutes. During the interviews, students were given a paper timeline of the semester and asked to fill in events during the semester that affected their motivation in the course. After the students completed their timelines, the interviewers asked questions to elicit narratives about what prompted students to include particular events, and what aspects of those events affected their motivation throughout the semester.

The audio recordings of the interviews were transcribed and analyzed without an a priori coding scheme, in keeping with our goal of understanding the student experience from the student perspective. We created, reduced, and synthesized these open codes using a five step process (Case & Light, 2011; Strauss & Corbin, 1998):

1. Three authors individually coded the interview transcripts with an open coding scheme that attempted to describe students' motivational and affective statements with a particular emphasis on noting how students discussed their sense of purpose, autonomy, relatedness, and competence as well as what factors (extrinsic vs. intrinsic) mediated their motivation (Pink, 2011; Ryan & Deci, 2000). We also noted which events students discussed in their narratives as critical in shaping their motivations.

2. To improve, trustworthiness, we compared codes for each interview and discussed our interpretations until we had a unanimous agreement on all codes. These codes were long and descriptive of the students' motivational orientations.

3. Thematic analysis of the codes revealed that students' motivations could be reduced to a set of four motivational codes. This reduced set of codes mapped to four of the motivational orientations described in SDT (Guay, Vallerand, & Blanchard, 2000): (1)

no motivation or disengagement, which mapped to amotivation (AM); (2) motivation by grades or requirements, which mapped to external regulation (ER); (3) motivation by career or bettering oneself, which mapped to identified regulation (IR); and (4) motivation by learning, excitement, interest, or fun, which mapped to intrinsic motivation (IM).

4. We reduced our code set from the original descriptive codes to the four motivational codes and looked for patterns across the interviews.

5. Using the reduced code set, we indicated each student's motivational orientation with a numerical identifier at several time points during the semester. From these quantized motivational orientation points, we identified three distinct trajectories that a student's journey through the course could take. These trajectories are described in the results section.

We identified trajectories by the frequency of student comments that fell into a particular motivation theme when a student was discussing a particular time point during the semester. For example, if a student mentioned grades three times and their career seven times while discussing the second learning contract, we identified that student as motivated by a combination of external regulation (ER) and identified regulation (IR) and favoring IR.

During the interviews, all students marked at least five events or time periods during the semester on their timelines: (1) prior to the first learning contract (Prior), (2) during the first learning contract (LC1), (3) during the second learning contract (LC2), (4) during the third learning contract (LC3), and (5) after the final examination (Final).

The identified time points for each student were plotted on a scale from 0 to 12: (0) AM, (1) favoring AM and some ER, (2) even combination of AM and ER, (3) some AM and favoring ER, (4) ER, (5) favoring ER and some IR, (6) even combination of ER and IR, (7) some ER and favoring IR, (8) IR, (9) favoring IR and some IM, (10) even combination of IR and IM, (11) some IR and favoring IM, and (12) IM. Trajectories for all eight students are shown in Figure 3.2 with a numerical identifier of the quotation description of the trajectory included in a circle along the trajectory line.

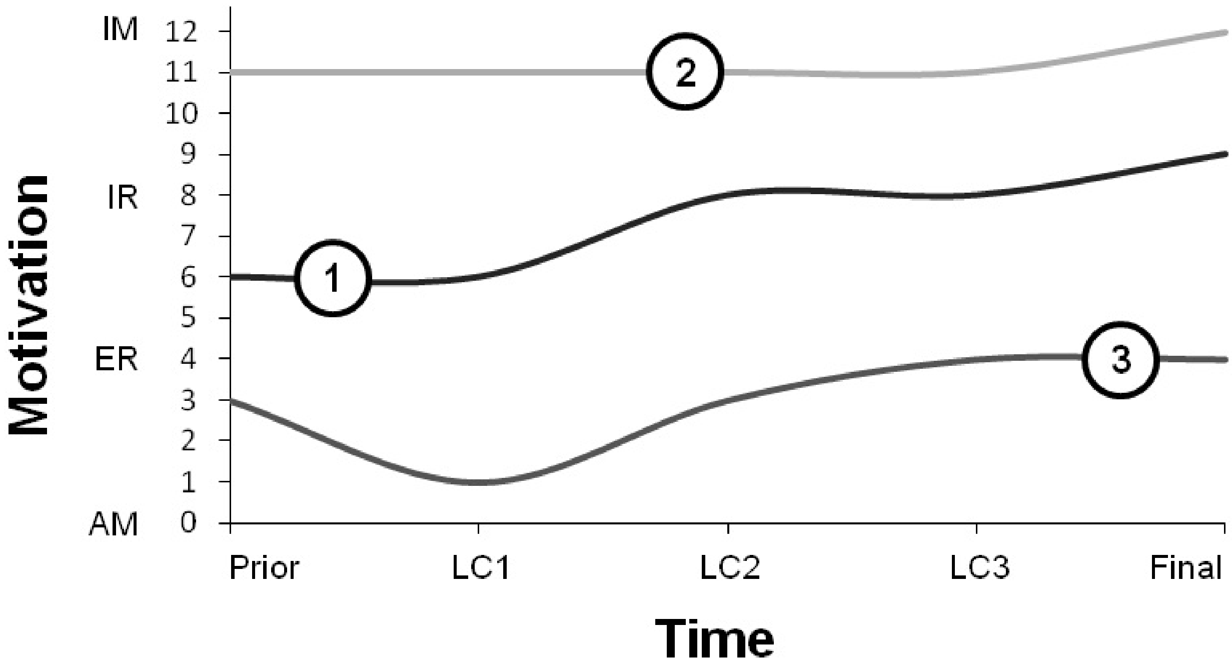

Figure 3.2: Trajectories of student motivation throughout the course. Trajectories (1) and (2) are composites of multiple similar students. Prior refers to prior to Learning Contract 1. LC1, LC2, and LC3 refer to Learning Contracts 1, 2, and 3 respectively. Final refers to after the final examination.

Member checking was carried out by sharing a complete draft of the manuscript with the interviewed students and asking whether it accurately reflected their experiences in the course. All students approved the trajectories, vignettes, and presentation of their quotations as accurately portraying their experiences in the course. No students requested any changes to the manuscript.

3.5 Results

Through the coding of the interviews and the plotting of students' motivational orientations over the semester, we identified three primary trajectories for students' motivational orientations. Consequently, we condensed similar trajectories into three composite trajectories. We present our results by describing the three composite trajectories in Figure 3.2: (1) students progressing from a combination of ER and IR to a combination of IR and IM, (2) students progressing from a combination of IR and IM to full IM, and (3) a student slightly progressing from a combination of AM and ER to ER.

After experiencing the IM-supportive course conversion, students in all three trajectories expressed shifts in their motivational orientations toward IM through their narratives. However, we focus primarily on the experience of the students who experienced trajectory (1), because they experienced the greatest changes in motivational orientation. Their motivation changes provide greater insight into how IM-supportive pedagogies can affect students' motivations in technical engineering courses than the relatively flat trajectories of their peers. While we focus on these students, we will also supply evidence and quotations from trajectories (2) and (3) to create a fuller understanding of the student experience in the course and to create foils for our interpretation.

3.5.1 Trajectory 1: Progressing from a combination of ER and IR to a combination of IR and IM

In this section, we describe the experience of students whose motivational orientations shifted from a combination of ER and IR to a combination of IR and IM. The vignettes and quotations are organized by the events that the students identified as important.

Vignette 5.1.1: Prior to the first learning contract and during the first learning contract

> The classroom was hot and clammy with the occasional breeze from the window. With its whitewashed walls, dusty chalkboards, and hard blue plastic chairs with hinged half desktops, the room seemed designed to make Jamie uncomfortable. The ancient overhead projector sitting in the center of the classroom as the lone piece of instructional technology seemed ironic for a course titled Computer Engineering I. As Jaime's classmates wandered into the room, the TA stood at a table at the front of the classroom flipping through a pile of papers. The bell rang at 2 p.m., and the TA introduced himself. "Hey everyone, my name is Andy. I'm your TA this semester. We have an exciting opportunity for you in this section of the course, as it is one of the experimental sections of Computer

> Engineering I."
>
> *Experimental?! What are we, guinea pigs?* Jaime's mind raced with questions.
>
> The TA continued, "In this section, we will be giving you choices over how, why, what, and when you learn. You will be working in learning teams, and your team will get to shape the course to your personal goals and interests. For example, if you don't want to do the written problem sets, you can choose to replace them with a different activity that helps you better practice the course material."
>
> *Oh, crap, I'm never gonna do any work! When I get a group, I have to tell them the first thing we need to do is to do all the homework. If we don't do the homework ... I won't learn anything if I don't.* Jaime fretted.
>
> "If you don't want to take the exams, tell us what you want to replace them with," the TA continued, "something that demonstrates your mastery of the material, like a project. If you decide you don't want to learn one topic, you can suggest replacing it with a different one."
>
> Alex interrupted, "It seems that we will get lower grades simply because we're in the experimental section."
>
> Sam continued, "Yeah, I really don't want to mess up my basics. This is a prerequisite for so many other courses, and I don't want to screw up my GPA."
>
> "I can guarantee that we won't 'mess up your basics,' because the topics that are listed as essential are the basics. So as long as you make sure you learn the essentials, you should be fine and you won't need to worry about your grades." The TA responded.
>
> "Can you at least tell us which are the easiest activities that will help us get an A?" Alex pleaded.

During the interviews, the majority of students described their initial response to the course structure with a mixture of external regulation and identified regulation statements (shown in braces).

> ... this is going to be something that can save our grades because we do care about grades {ER} and we think this is something new that we want to learn this way as long as we can accomplish everything {IR}.
>
> ... I don't particularly like [the requirements of] academia {ER} ... I'd like to go work and design things {IR} ...

The students with these motivational orientations chose options that they thought would give them the highest chance for an A grade in the course. For example, one team of these students chose to do a no-partial-credit group examination, reasoning that working as a team would better their chances of a good grade. Other students chose to write examination problems for their first learning contract, an option they admitted they chose because they thought that it "was the easiest thing [they] could do."

Vignette 5.1.2: Between the first and second learning contracts

> Alex sat on the tile floor outside the professor's office trying to anxiously pass the time as other teammates petitioned their grades. Hearing the click of the office door, Alex quickly looked up from the cell phone. "So what did the professor say?"
>
> "Bad news, he agreed with the TA and isn't going to change our grades."
>
> "Seriously?! What are we going to do then? Doesn't seem like we can change his mind."
>
> *"Should we drop out of this section?"*
>
> "Even if we change sections, we're still stuck with a D for the first mastery option."
>
> *"We thought this option would be easy, but it turns out we all just got bad grades."*
>
> "I need to finish this course this semester though, *we shouldn't just give up.*"
>
> "We could try one of the project options. We'd probably *get more out of the course.*"

Yeah! It'd be great if we could design something that works well like my friend Pat's team did last time. It'd be more practical and interesting than writing exam questions."

Most of the students who chose these easy options experienced unexpected failure upon completing the first mastery component of the course. The team that chose to do the no-partial-credit group examination received a C grade (below average) on the examination. A different team that wrote examination problems received a D grade (near failing) for the quality of problems they wrote. As described in the vignette, the latter team petitioned the professor to overturn the TA's decision on their grades. Discussions about this failure during interviews revealed statements that were coded as identified regulation or intrinsic motivation (shown in braces).

> ... the end of the first learning contract, we got stuck because we got very low grades ... {ER} we were very upset and we were thinking, 'Should we drop out of this section or not?' But then we kind of came out of that. **We shouldn't just give up** ... {IM} (emphasis added)
>
> But after the first one when we were designing the questions, we decided to do a design thing more, to **get more out of the course** {IR}.... The project aspect, trying to design something that really works well {IM}. To design things that work efficiently as much as a student [in the course] could probably do {IM}. (emphasis added)

Vignette 5.1.3: During the second and third learning contracts

> Jaime returned to the basement computer lab of the engineering library where the rest of the learning team has been working diligently on their project, "Hey, did you realize it's already midnight?"
>
> Alex replied with a hint of surprise, "We've been here for six hours? Doesn't seem like it."
>
> "I think we should call it a night and meet back here tomorrow," said Sam.

> Jaime nodded, “Yeah. I think we got some good work done and I could use some sleep. It was fun tonight. Same time tomorrow?”
>
> The team began to pack their bags as they made plans for when to meet again.
>
> “Sam, it’s pouring rain outside. Did you need a ride home?” Alex asked.
>
> “That would be great! Thanks!”

As students discussed the projects that they completed for the second learning contract, they described the importance of their teams and how they enjoyed working with them. In particular, students highlighted small actions such as getting rides home or eating dinner together as significant events in improving their relatedness and motivation. This sense of relatedness to their teammates was often described as a contrast to negative situations that threatened to demotivate them. Further, these statements of relatedness were often coupled with statements that reflected intrinsic motivation to learn by emphasizing accomplishment and enjoyment rather than grades.

> ... we did a project as our learning assessment thing, which in retrospect I think we should have done for all three.... We had a good group. I think we stayed on task a lot. I think the first project was also very indicative of our ability to work. We split up work evenly, everyone got their work done and then we all got together and put our parts together. The only problem was when you’re transferring ... [CAD] files to one computer, it pulls files from other things, libraries that are specific to your computer so then ... we all sat there and we’re trying to figure out what was going on, so I think that was a good team building thing even though it kind of stunk.
>
> ... on the day we were going to show the whole thing ... we came together and each explained each individual part, how it works, how many gates and everything. Then ... the TA, who’s actually grades us, said, ’Well, it’s pretty good.’ So we feel good. Yeah, a great product. But we feel good, why? Because we actually made something. Instead of solving some problem [online] or score

> grades on the exams, we actually make something.... **In our sophomore year we feel good, right, and we are pretty inspired by this.** (emphasis added)

For the third learning contract, these students were required to demonstrate their mastery and understanding of any computer architecture. Some students found this requirement too restrictive to match with their desired modes of learning, while the previous two learning contracts had dealt with more general concepts and allowed for more freedom of choice around the application of the projects.

> ... we feel like, I think this experimental section was supposed to be what we **chose** to learn instead of what we **were told** to learn ... number three they just told us, 'This is what you are going to do.' (emphasis added)
>
> So if learning contract three is something similar to two, or we make an advanced version of number two, we will feel way more motivated than making a new architecture.

When asked to reflect on their overall experience in the course, students' statements primarily indicated an orientation toward an intrinsic motivation to learn. They expressed desires to be "free to learn" and to learn and work on problems that were personally meaningful or exciting.

> I mean, if [the course] is a lot easier, we [will] ... save a lot of time, we [will] go to bars, it would be fun, but I also think that after [we're] done with [the course] ... the working process, the learning process is something we really appreciate. [We're] actually more excited about ... [working] together to get it done instead of ... just [getting] it done, so it's the process [we're] excited about.
>
> ... after my graduation, I [will] probably go to some technology company and instead of knowing nothing ... [I'll] know, well, how to solve a problem.... That's kind of like learning contract two, so we have a feeling of how we're going to do this and I think it really helped us.
>
> ... I think instead of grading strictly based on what you accomplished, what you missed, you actually focus on 'this is how we learned'.... So really make it free,

for us, [so] that we know ... everything we did wrong is not gonna affect us that bad. We know ... everything we accomplished is not gonna affect us that bad either. So **we wanna know we are free to learn** ... (emphasis added)

... it all seems very pointless when you're filling in ones and zeros into a chart I think, but when you're filling in ones and zeros into a chart because you're trying to figure out something that will make a larger system work, I dunno, it looked much more interesting and much more useful to me.

3.5.2 Trajectory (2): Students progressing from a combination of IR and IM to IM

In this section, we describe the experience of students whose motivational orientations began as a combination of IR and IM and moved toward IM throughout the semester.

Vignette 5.2.1: Prior to the first learning contract and during the first learning contract

After announcing the design of the experimental section, the TA formed the learning teams and directed the teams to meet in different corners of the room. Pat's team haphazardly arranged their desks into a jagged oval and began chatting. The TA approached Pat's team first.

"So we can literally do whatever we want for this learning contract?" Pat blurted.

"As long as it helps you learn the basic material and demonstrates that you understand combinational logic circuits," the TA responded.

"Then we definitely need to do a project. I want to make something."

"Me too! What if we did a game like Simon®, Snake, or tic-tac-toe?"

"Or we could build something useful like a stop watch, logic equation solver circuit, or..."

"Ha! It would be like we did 'circuitception' where our circuit could design other circuits!"

"That'd be awesome!"

"Or how about we design a calculator with buttons and display?"

"What if we just designed our own architecture?"

"Definitely!"

During the interviews, these students emphasized the importance of experiencing relatedness to their teammates and having a shared communal purpose.

> It was still collaborative but everyone was doing their own part and it all came together at the end, which was cool. Seeing their ideas, their thoughts, what they learned, it was really exciting. One of the biggest things was the three of us were really excited to learn and that made it exciting.

Vignette 5.2.2: During the second learning contract

"To be honest, I'm somewhat disappointed with what you guys delivered this learning contract," the TA explained. "After your first learning contract, I was so impressed and had high hopes for what you were going to do this time, but this project was at best a minor extension on your previous work."

"I mean, you're right," Pat responded. "We slacked a little this time and don't deserve an A for our work on this project."

After their initial success, the team relaxed in their efforts to learn and delivered poor work. In response to their failures and a lack of motivation on the second learning contract, the team revealed a deeper level of intrinsic motivation to learn during their third learning contract.

Vignette 5.2.3: During the third learning contract

"One last question, what are the advantages and disadvantages of your architecture's pipeline?" the TA asked.

> It was 10pm on a Friday night as Pat began his reply. The smell of Papa Jimmy's Pizza and garlic butter still lingered in the air. Pat's teammates alternatively sat on lab tables or chairs as the team logo remained displayed on the projector. The team had found an open lab space with a projector around noon and had camped out there all day to make sure they had a place to give their final presentations. Pat answered by giving three advantages and disadvantages to the pipeline design as the rest of the team nodded and smiled.
>
> "Wow!" the TA paused, "That was some advanced material. Just out of curiosity, what resources did you use to learn that?"
>
> "Well, I started with books, something I thought I would never do. They helped a little, but then I started attending the lectures of [a senior level course]. They just happened to be covering that material when I needed it. I liked that they were discussing x86 processors, because everything made so much more sense once I understood how architectures work and are built in real life."

These students came out of the course with a sense of accomplishment and enthusiasm for the course, not only saying that they would take a similar course again, but also wishing that all courses followed the same structure.

> ... we were presenting the third project the TA really spoke highly of how much we learned. It was really ... I can go learn things now. On top of that he was like, 'This is real life. You guys are touching at stuff you would have to go to jobs to find out.' **We ... did it because we wanted to.** That was really rewarding, not just the grade. (emphasis added)

3.5.3 Trajectory (3): Student began as a combination of AM and ER and progressed only slightly

In this section, we describe the experience of one student whose motivational orientation began as a combination of AM and ER and changed only slightly.

Vignette 5.3.1: Prior to the first learning contract

> "So the instructions say to think about why you want to learn the course material. So what are your goals for taking Computer Engineering I?"
>
> *"Honestly, I have no idea..."*
>
> "Me neither, I don't get what we're supposed to do with this thing. I like that it sounds like we don't have to take tests or do the homework."
>
> "Yeah, but what would be the easiest option?"

Unlike the students who transitioned form EM/IR or IM/IR, this student received a grades of A or B on the first learning contract, despite low levels of effort and low identification with the material.

> I'd say I did almost no work for the first learning contract and neither did anybody else in the group and from that standpoint it went pretty well.

With continued success, motivational orientation stayed the same.

> ... during this time I was doing stuff for a [student organization], which took up a lot of my time, so, again the whole 'try to do as little as possible' thing really entered in there.... So from the end of the second learning contract, throughout the entire third learning contract I did absolutely no work towards [the course] and neither did anybody else in my group.

This student left the course with a similar perspective to the beginning, focusing on grades and the ease with which high grades could be obtained.

> If their goal is to get a good grade in the course, then yeah just do what we did, but I mean if your goal is to actually learn about the material I wouldn't advise taking the experimental section, or at least not the format we had.... I had friends who actually took the real course and they learned much more about the architecture than anybody in the experimental section did.

However, after reflecting on the course, the student recognized a missed opportunity by taking the easy way out and highlighted projects as possibly worthwhile experiences.

> I think it would have been cool to do a project. I think, I know one of the other groups tried to make a calculator I think, for one of the first two projects and it sounded like that would have been kind of fun.

3.6 Discussion

Students' narratives revealed three primary experiences that shifted their motivational orientations: (1) perceived support of autonomy, (2) quality of relationships with teammates, and (3) responses to success or failure.

As expected from the SDT literature and the intent of the course design, students cited autonomy over their learning as critical to their motivation. The impact of this autonomy seemed to be moderated by the students' prior motivational orientations. For example, the students with trajectory (1) felt confused and intimidated by their autonomy at the beginning of the semester based on extrinsic motivations, but felt liberated and even possessive of that autonomy at the end of the semester as they moved toward intrinsic motivations. In contrast, students with trajectory (2) began with, and maintained, intrinsic motivations throughout the semester and always regarded their autonomy as liberating or essential to their learning. It is possible students' responses to autonomy was based solely on their motivational orientations, but we propose another more autonomy focused explanation.

The students with trajectory (1) and trajectory (2) revealed different perceptions of the third learning contract. The trajectory (2) students perceived the third learning contract as fully supportive of their autonomy as was intended by the course design, but the trajectory (1) students perceived the third learning contract as being restrictive ("[learning contract three] was supposed to be what we chose to learn instead of what we were told to learn"). Triangulating the classroom observations with research on the TA's teaching journals reveals that one TA had pigeonholed these trajectory (1) students as "bad students" because of their early failures in the course and attempts to get an easy A grade (Herman, Trenshaw, & Rosu, 2012b). The TA had developed a lack of trust in these students and adopted controlling behaviors toward them. In contrast, the TA trusted the trajectory (2) students and adopted autonomy-supportive behaviors. This breakdown of the trusting relationship and autonomy support confirms the critical importance of autonomy-supportive behaviors for maintaining and cultivating students' intrinsic motivations to learn.

In accordance with SDT, students also discussed relatedness as a critical element in shifting their motivation toward intrinsic motivation. Students with trajectories (1) and (2) frequently discussed team interactions and described how the team developed stronger relationships through difficulties and struggles. In contrast, the student with trajectory (3) (Kelly) rarely discussed relationships with teammates. Kelly even revealed feeling disconnected from the rest of the students in the IM-converted sections of the course. Contrary to Kelly's assertions that no teammates did any work in the course, the observer's field notes indicate that some of Kelly's own teammates explored topics well beyond the scope of the course. Further, Kelly surmised that other Computer Engineering I students were jostling to get into the IM-converted sections so that they could get an easy A grade. In actuality, only a single student asked to switch into the IM-converted sections, and remarkably, that student completed the most complex and difficult project attempted in the course: writing a computer program to implement a state minimization algorithm; neither programming nor state minimization was covered by the course. We believe it is possible that since Kelly was disconnected from other students in the course, Kelly constructed biased interpretations of their actions, projected a personal attitude onto others, and created a perception that was significantly skewed from the constructed reality described by most students. Another possible interpretation is that Kelly was extremely competent prior to the course. Kelly received an above average grade on the final examination despite the assertion of doing "no work" in the course. Perhaps because Kelly already had high technical proficiency, the motivation level needed to obtain a personal definition of success was very low, so Kelly's low levels of motivation still allowed achievement of a subconscious idea of success in the course while consciously knowing more work could have been done.

Kelly's success despite low motivation reveals a major divergence in our observations from SDT. Most students with trajectories (1) and (2) described moments of crisis when their level of effort and motivation led to failures. These failures often led to dramatic shifts toward intrinsic motivation and impressive increased effort (e.g., taking on ambitious projects, attending additional courses). In contrast, one student with trajectory (2) and Kelly described constant success (even despite self-acknowledged poor quality work) throughout the course. They never identified dramatic shifts in intrinsic motivation or increased effort. These observations diverge from SDT in that shifts toward intrinsic motivation depended less on the fulfillment of psychological needs and more on specific events such as failure.

One possible avenue to interpret this divergence is to look at alternative theories such as Attribution Theory to explain the change. The three-dimensional model of attribution suggests that when a student's causal attributions of a success or failure are stable, internal to an individual, and controllable, such as a student's own decisions, that student will identify more with their behavior and be more motivated to change it in the face of failure (Weiner, 1992). In other words, students with a strong sense of autonomy who experience failure are more likely to change their motivation and behaviors. While the course's general autonomy supportiveness provided the environment for the shift to intrinsic motivation to occur, the students' productive failures created the impetus for the shift.

Alternatively, an interpretation focused on relatedness may be equally compelling. After experiencing failure, students described specific interactions with their teammates or the TAs that coincided with the shift in their motivation. For students in trajectory (1), the group resolution to persevere created a deeper sense of relatedness that led to change. For students in trajectory (2), the group responded to the disappointment of the TA. The stress of failure on these students' relationships may have been the impetus for the shift in motivation. In contrast, the students who experienced continued success did not describe moments of deeper relatedness with teammates or TAs.

Regardless of whether autonomy or relatedness drove change in students' motivation, the students' narratives revealed that specific, relatively small critical incidents are just as vital for inducing shifts in students' motivations as the careful construction of ongoing, holistic IM-supportive environments.

3.7 Conclusions

We describe our conclusions for each of our research questions and then conclude by describing implications for research and teaching practice.

3.7.1 Research question 1: What aspects of the course created positive shifts in students' motivational orientations toward an intrinsic motivation orientation?

Our analysis of students' narratives reveals that courses based on SDT can in fact shift students' motivations toward intrinsic motivation. As would be expected from SDT, when course structures meet students' psychological needs such as autonomy and relatedness, they provide necessary support for these shifts. Contrary to SDT, however, critical incidents such as failure are equally important for creating these shifts.

The prominence of both autonomy and relatedness in our students' narratives suggests future research into a construct of trust as the mechanism for shifts in students' intrinsic motivation. To give students autonomy, the instructor must trust the students with their own learning. For students to embrace that autonomy, students must experience and internalize that trust. For example, despite the course's design to create high levels of autonomy, the students in trajectory (1) did not experience the intended autonomy because they lacked the trust of the TA. Consequently, the students described lowered motivation. In contrast, when students with trajectory (1) experienced failure due to a lack of effort, reflection on their performance and the honest feedback from instructors resulted in trust building and reevaluation of their autonomy in the course. This trust-based reevaluation might provide a more powerful construct than autonomy or relatedness alone in explaining the students' dramatic shifts in motivation.

3.7.2 Research question 2: How can faculty assess this shift in motivation as a method for course evaluation?

Our analysis revealed that measurement of students' perceived support of their autonomy and relatedness within a course may provide a basis for evaluating course designs. While existing SDT instruments assess students' perceived support for these constructs during specific tasks or generally toward academics, no current instrument specifically evaluates these SDT constructs in the context of a single course. Instruments such as the Learning Climate Questionnaire (Williams & Deci, 1996) are based on SDT, but they lack the resolution to evaluate specific factors and constructs. Other instruments such as the MUSIC Model of Academic Motivation Inventory focus on the course level but involve other factors not included in SDT (Jones, 2009). A new instrument focused on the SDT constructs of purpose, autonomy, relatedness, and competence could likely be validated by corroborative qualitative methods.

3.7.3 Implications for research and teaching practice

Our analysis confirms that SDT provides a productive framework for the design of courses and teaching methods in engineering. The IM course conversion informed by SDT stimulated shifts toward intrinsic motivation for most of the students in this study. These results warrant greater effort in the design of motivation-centric course design methods that can supplement existing cognition-centric course design methods.

Our analysis also confirms that the adoption of autonomy-supportive behaviors documented by other SDT researchers and an attitude of trust can be successfully applied to the engineering classroom. Adopting IM-supportive course designs in second- and third-year technical courses may combat the sophomore slump (Boivin et al., 2000; Lemons & Richmond, 1987; Sanchez-Leguelinel, 2008) and other retention problems in engineering without the need for more expensive programs and initiatives. In particular, we suggest that the following IM-supportive pedagogy features may be most vital to include in a course when fostering students' IM is a primary course objective:

- A structured environment in which students can take full ownership of the autonomy provided to them without fear of negative, extrinsically motivation consequences like grade disadvantages or reduction in cognitive outcomes.

- Class design elements that provide the space for relatedness to grow and prosper, such as collaborative activities in discussion sessions, group assignments that require meeting outside of the classroom, and opportunities to provide and receive constructive peer feedback.
- Instructors who are committed to creating an IM-supportive environment for students and who show this support in a sincere way to students, both through their interactions with students and through providing honest and constructive feedback to students about their progress in the course.

While these features may sound daunting to include in a course, we have attempted to illustrate that IM-converted courses are possible without increasing the time cost for faculty and are preferred by most students to technical engineering courses with content mastery as the primary course objective.

3.8 Acknowledgments

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CHAPTER 4

A PHENOMENOLOGICAL STUDY OF PROMOTING ENGINEERING STUDENTS' INTRINSIC MOTIVATION TO LEARN

4.1 Introduction

Motivated students learn more and retain that knowledge for longer (Sinatra, 2005), so how can instructors improve students' motivation to learn in their courses? Self Determination Theory (SDT) provides a theoretical framework of motivation that can be applied in a classroom context (Ryan & Deci, 2000). SDT is based on three psychological needs: autonomy, competence, and relatedness (Ryan & Deci, 2000). *Autonomy* refers to a sense that people control their own choices, and they can exercise their freedom of choice to proceed in whatever way they see as best. *Competence* refers to a sense that an individual has the knowledge and skills necessary to succeed. *Relatedness* refers to a sense of community, belongingness, and shared purpose in an individual's efforts. When all three of these needs are met in a particular context, an individual's motivational orientation in that context can move through a continuum of motivation toward internalizing that motivation until something intrinsic about the activity or context drives the individual (Ryan & Deci, 2000; Deci & Ryan, 2000). This same drive can theoretically be harnessed in an academic context to improve student learning.

We redesigned an electrical and computer engineering course for sophomore students to support students' autonomy and to facilitate improved student motivation. In our autonomy-supportive course redesign, students completed three autonomy-scaffolded design projects which replaced the midterm examinations in the traditional offerings of the course. Course lectures were taught according to each instructor's preferred teaching style. To build students' competence, discussion sessions led by teaching assistants (TAs) focused on collaborative solving of design problems. Further, the redesigned course included increased contact time outside of lecture and discussion with team-based meetings led by an instructor or TA to assist students with their projects and homework. Following the precedent set by the SDT literature, our redesign focused on autonomy and competence as the most important psychological needs for improved student learning (Ryan & Deci, 2008; Black & Deci, 2000).

This study employs a phenomenological analysis of interviews with students to elucidate the essence of the student experience during this redesigned course. In particular, we focus on answering two research questions: 1) how do students' motivational orientations in a sophomore engineering course change in response to an autonomy-supportive classroom environment, and 2) how do students experience the phenomenon of motivational change with respect to the three psychological needs, autonomy, competence, and relatedness?

4.2 Background

Autonomy and competence support are commonly mentioned in the literature as important for fostering motivation to learn (Ryan, Lynch, Vansteenkiste, & Deci, 2011; Sierens, Vansteenkiste, Goossens, Soenens, & Dochy, 2009; Ryan & Deci, 2008; Black & Deci, 2000; Deci & Vansteenkiste, 2004), but relatedness support is generally absent from the research conversation about Self Determination Theory (SDT). Further, competence and autonomy are often posited to be interrelated, if not dependent on one another in the process of motivational change (Atman et al., 2010; Ryan et al., 2011). Based on SDT, instructors support competence when they provide students with the knowledge and tools necessary to build competence. For example, instructors can articulate course goals clearly and deliver on those promised goals, offer individual students appropriate levels of challenge, and remove autonomy-related obstacles to learning by giving students choices (Jang, Reeve, & Deci, 2010; Sierens, Vansteenkiste, Goossens, Soenens, & Dochy, 2009). SDT researchers have also postulated that shifts toward intrinsic motivation, specifically, can be facilitated through autonomy-supportive environments where instructors consider the student's perspective, allow for choices around learning, and reduce unnecessary stress and demands on students by focusing on learning gains rather than on grades (Black & Deci, 2000; Ryan & Deci, 2008).

Relatedness is generally considered as less important than autonomy and competence (Ryan & Deci, 2000). In his book on motivation, Pink presents both autonomy and competence as they appear in the SDT literature, but carves the concept of relatedness down to its component parts and presents only purpose, a small portion of the full psychological need suggested in SDT (2011). Pink describes purpose as simply a "context" for the "essential" needs of autonomy and competence (2011). A full description of relatedness encompasses "feeling connected to others, to caring for and being cared for by those others, to having a sense of 'belongingness' both with other individuals and with one's communities," much more than simply a feeling of purpose (Ryan & Deci, 2002). Despite arguments for the positive effect of a sense of relatedness on supporting intrinsic motivation (Ryan et al., 2011), no studies of "relatedness-supportive" classroom environments have been undertaken. Even our study followed the literature by focusing on autonomy support.

4.3 Context

To investigate the outcomes of redesigning a course to support students' autonomy, we chose Computer Engineering I as the context for our study. Computer Engineering I is a large course on digital logic and computer architecture course required for all second-year electrical and computer engineering (ECE) majors at a large, public university. Each semester, the course enrolls about 200 students. Other universities across the United States offer similar courses.

In traditional offerings of Computer Engineering I, students attend two lectures taught by a professor and one discussion session out of eight taught by teaching assistants (TAs) each week. Several professors in the ECE department rotate through the role of primary instructor. Their teaching styles vary from entirely didactic lectures to lectures that include significant use of active learning techniques. TAs also rotate through the course and very few lead a discussion session for the same course over multiple semesters.

4.3.1 Fall 2011 Course Redesign

In the Fall of 2011, we conducted a pilot study of the redesigned course. Details of the Fall 2011 course design are discussed in other publications (Herman, 2012; Goldberg, Herman, Somerville, & Stolk, 2012; Herman, Somerville, Goldberg, & Green, 2012a; Herman, Trenshaw, Loui, Green, & Goldberg, 2013b; Trenshaw, Revelo Alonso, Earl, & Herman, 2013b). Quantitative and qualitative measures of students' affective outcomes in the Fall 2011 offering demonstrated that students' motivation and attitude toward learning computer engineering improved more in the redesigned course than in the traditional offerings of the course (Herman, 2012; Trenshaw et al., 2013b). As measured by the Digital Logic Concept Inventory (Herman & Loui, 2012), cognitive outcomes for students in the Fall 2011 offering were equivalent to those of students in the traditional offerings of the course (Herman et al., 2013b).

4.3.2 Fall 2012 Course Redesign

In this paper, we analyze the outcomes of the redesign of Computer Engineering I that was offered in the fall of 2012. Based on the results of the Fall 2011 study, the Fall 2012 course provided students with autonomy through design projects. Because Fall 2011 students requested additional project-related contact time with TAs, we added *weekly consultation meetings* to the Fall 2012 course in lieu of grading written homework assignments. During weekly consultation meetings, students met in teams of four to six students with an instructor or TA to discuss their written homework and design projects. This additional time with instructors and TAs was also intended to give students a safe space in which to gain competence with the autonomy provided with the design projects. Student teams were constructed to align students' self-identified learning goals for the course and to support their autonomy and relatedness. Team construction also provided relatedness support by minimizing women and minorities who were isolated on a team. Students remained in the same team during the entire semester. This extended duration of contact in team-based learning was unique in the department.

During the Fall 2012 semester, students completed three autonomy-scaffolded design projects which replaced the midterm examinations of the traditional offerings of the course. The first project required students to design a multi-module combinational logic circuit. To provide students with autonomy, they could choose from a menu of options such as calculators, number converters, message encoders, and even password hackers. For the second project, students were required to demonstrate a sequential logic design. A few predefined project options were suggested, but students were encouraged to generate their own project ideas based on their personal interests as they became more comfortable with their autonomy in the course. The third project provided the most autonomy by constraining only the context of the project: designing or modifying a computer architecture. This scaffolding of autonomy with progressively more autonomy throughout the semester allowed students to build competence with the course content and design process rather than overwhelming them with choices in the first week of the course.

The Fall 2012 redesigned course was co-taught by two different instructors. Instructor 1 delivered the lectures for the first half of the course using a "flipped" classroom model in which students watched video lectures before class and interactively solved problems in class with the instructor and peers. During the second half of the course, Instructor 2 taught with a more traditional lecture method. Video lectures were provided when available, but class time did not depend on students' watching the videos in advance.

During the first half of the course, the instructors created separate discussion session worksheets that focused on building students' competence with course content through collaborative solving of short, context-rich design problems. After the mid-semester student feedback, the instructors attempted to address student concerns about the amount of homework that was required for the course and gave students more autonomy to decide how to use the time in their discussion sessions. The discussion session worksheets were folded into the written homework assignments as *challenge problems*. To provide additional autonomy, students were expected to complete only a subset of challenge problems before their weekly consultation meetings.

4.4 Method

To better understand how this autonomy-supportive course design affected students' motivations to learn, we conducted post-course exit interviews. We analyzed the data from a constructivist perspective in which we treated each student's exposition as the constructed truth of their experience in the course (Guba & Lincoln, 1994). With our phenomenological approach, we sought commonalities among students' lived experiences in the course and attempted to distill the essence of the Fall 2012 redesigned course with respect to changes in students' motivational orientations (Finlay, 2009; Moustakas, 1994; Creswell, 2013). All research was performed with IRB approval (IRB Protocol #12046).

4.4.1 Data Collection

Post-course exit interviews were semi-structured and designed to take between 45 and 60 minutes. To allow students to decompress during the winter break and remove any concern that participation might affect the final course grade, interviews took place at the beginning of the semester following the Fall 2012 course offering. An email solicitation requesting volunteers for interviews was sent to all 216 students who had completed the Fall 2012 redesigned course with the goal of sampling until saturation. No sample exclusion criteria were defined or applied. Seventeen students volunteered to be interviewed. No students who volunteered were rejected for an interview. All 17 interviews were audio recorded. Of the 17 students, 2 were female (12%) and 15 were male (88%). This ratio is close to that of the ECE department in general with 1 female to every 10 males among undergraduate majors. Students were not asked to provide information about race or ethnicity, but some self identified during interviews. The students represented the full range of possible passing course grades (A to C): 11 students received above average grades, 2 students received average grades, and 4 students received below average grades. Each student was compensated $10 for volunteering their time.

Each interview began with a single request: "Take me through your experience in the course from the first week of classes to the final exam." This general request allowed students freedom to discuss whatever aspects of the course were most salient to them. After students described their experiences and motivation in relation to each aspect of the course they remembered as important, interviewers followed up with questions that highlighted aspects of the course that students had omitted, such as lectures, discussion sessions, weekly consultation meetings, design projects, homework assignments, the final exam, the primary instructors, the teaching assistants (TAs), or team experiences. Interviewers asked general questions to clarify why these aspects had been less memorable or important to students. For example, if a student did not mention the lectures during their response to the opening request, the interviewer might ask, "Could you discuss your experience in the course lectures?" or if the student spoke about interactions with their peers and the course instructors, but not the TAs, the interviewer might ask, "How would you describe your interactions with your discussion session TA?" By providing details about the neglected course aspects, students indicated the reasons each aspect was less important to their experience.

4.4.2 Data Analysis

The audio recordings of the interviews were transcribed and analyzed with a skeletal a priori coding scheme, to comport with our goal of understanding the student experience from the student perspective informed by SDT. No outside influences (historical, political, etc.) that might explain the meanings of students' responses were considered (Moustakas, 1994). The authors' preconceptions about SDT in relation to student motivation in the classroom and the importance of autonomy and competence were similarly acknowledged and set aside (or "bracketed") during analysis (Moustakas, 1994).

Three authors who were not involved in teaching the course or grading student work coded the interviews, to ensure that no bias based on student performance or participation in the course would be introduced into the analysis (Guba & Lincoln, 1994). First, we individually coded the interview transcripts with a skeletal a priori coding scheme focused on how students discussed their sense of autonomy, relatedness, and competence (Ryan & Deci, 2000) and when students exhibited any of four motivational orientations around their learning (described in SDT (Guay, Vallerand, & Blanchard, 2000). These four orientations emerged during open-ended coding of interviews with students about their experience with the Fall 2011 redesigned course (Trenshaw, Herman, Green, & Goldberg, 2013a): (1) amotivation (AM) characterized by no motivation or disengagement, (2) external regulation (ER) characterized by motivation from external sources such as grades or requirements, (3) identified regulation (IR) characterized by motivation from internalized values such as desired career or self-improvement, and (4) intrinsic motivation (IM) characterized by motivation from excitement, interest, or fun derived from the learning activity. This coding scheme included events that students discussed in their expositions as critical in changing their motivations. The codebook saturated after 10 interviews, but all 17 interviews were coded for completeness and no additional interviews were conducted.

We noted an undercurrent of relatedness throughout the codebook. To further investigate this undercurrent, we conducted a phenomenological analysis of each student's interview transcript. We looked for intersections between instances of statements about relatedness, competence, and autonomy and the codes for events noted as critical to motivation change in each interview. We created individual profiles of how students described each psychological need with respect to different motivation changing events. All individual profiles were compiled to build a portrayal of the essence of the student experience around motivation change in the course. The phenomenological analysis included three steps:

1. Horizontalization: In phenomenology, a *horizon* refers to the context of the phenomenological analysis. In our case, each event noted as critical to motivation constituted a horizon, and each horizon that a student mentioned was highlighted in each interview transcript.

2. Clustering and theme development: The clustering process removes redundant horizons from further analysis, leaving only unique horizons for each unit of analysis. In our case, a unit of analysis was an interview transcript. A *core experience* is a collection of all the unique horizons in a unit of analysis viewed as a single unit. For example, a core experience for an individual interview might include relatedness generated from teamwork and competence reduced by a lack of relatedness with course instructors. We clustered unique horizons into the core experience for each participant and developed

themes from each core experience.

3. Core experience synthesis: Themes from each core experience were synthesized into a combined expression of the essence of the phenomenon (motivation change in an autonomy-supportive course redesign). In our case, this essence emerged as students' sense of relatedness.

4.4.3 Trustworthiness

During the interview analysis, three authors compared and discussed codes for each interview until we agreed unanimously on all codes to reduce individual variation in perceptions about students' statements. After clustering and theme development, we asked two peers with knowledge of the course redesign project and of relevant qualitative methods who were uninvolved in the study to debrief with us on our themes from each interview. This peer debriefing allowed us to uncover any interpretive leaps we made during theme development and further refine our themes.

Member checking was carried out by sharing a complete draft of the manuscript with the interviewed students and asking whether it accurately reflected their experiences in the course. All students approved the presentation of their quotations and interpretations as accurately portraying their experiences in the course. No students requested any changes to the manuscript.

4.4.4 Limitations

Our study was limited to interviews with self-selected students at a large, public university in the Midwest. Because we did not reject any students and did not take a random sample of the students in the course, a self-selection bias may have existed within the interviewed students. Our sample was representative of the gender and grade distribution in the course, but the sample may have consisted only of students who simply desired $10, who could travel conveniently to campus for the interview, who had strong opinions (positive or negative) about the course, or other unforeseen factors that could affect the results of the study.

The institutional context of our study may limit the generalizability of our results. Because the university studied is a large, public institution with an above average population of international students, the students may have significantly different motivations from students at a small, private institution with fewer international students. International students come from different cultural and societal contexts in which family values, socioeconomic status, educational background, and many other aspects may either positively or negatively affect the motivation to attend an American university or choose a particular major. The diversity of students' cultural backgrounds may reduce students' sense of relatedness with their peers. Further, the redesigned course is situated in a curriculum that traditionally emphasizes individual performance and deliverables. The department relies on large lecture courses to serve students during the first and second years of study. These types of courses provide few opportunities for faculty-student and student-student interactions. These limitations should be considered when applying the conclusions of this study to other dissimilar populations.

The format of the interview protocol focused specifically on covering all aspects of the course and may have skewed student responses toward discussing their relationships in the course. Three of the nine aspects that all students were asked to describe were primary instructors, TAs, and team experiences, all of which focus specifically on relationships and thus had a high likelihood of prompting students to discuss relatedness in some way. No questions such as "Describe some of the choices (autonomy) you made during the semester." or "Were there any events that made you feel as though you could succeed (competence) in the course?" were asked, but a common question format about team experiences might have been "Tell me more about working with your team members (relatedness)." which almost certainly would result in a description of relatedness (or lack thereof) from the student. The other aspects (lectures, discussion sessions, weekly consultation meetings, design projects, homework assignments, and the final examination) were more general and could prompt a variety of responses, although course assignments would be more likely to prompt responses involving competence. While some questions about project selection or choice in completing homework might invoke students' senses of autonomy, none of the questions dealt exclusively with autonomy. This questioning protocol may have contributed to the final code frequency distribution observed from interviews. However, most students discussed relatedness issues before the interviewer prompted them to do so. This lack of prompting students to discuss their relationships in the course limits the potential impact of questions directly targeting relatedness on the final code count.

4.5 Results

Of the three psychological needs identified by Self-Determination Theory (SDT), students discussed relatedness most often in their statements related to motivation. Autonomy appeared approximately one-sixth as often as relatedness, contrary to the expected hierarchy of the psychological needs (autonomy, competence, and then relatedness). To provide perspective on the overall code frequency, Figure 4.1 displays the relative frequencies of relatedness, competence, and autonomy codes. For comparison, Figure 4.2 displays our predicted proportions based on the literature.

Three themes focused on relatedness emerged from the data: **team projects promote relatedness**, **relatedness provides a safe space for learning**, and **without relatedness, motivation declines**. These three themes were the most prevalent themes in students' core experiences and are presented below. Additional themes related to competence and autonomy also emerged, but these themes were much less frequent (appearing in three or fewer core experiences) or tied into relatedness (for example, the **without relatedness, motivation declines** theme is linked with competence). The less prevalent themes were not considered as part of the essence of the student experience as prescribed by our phenomenological approach and are not presented.

To illustrate occurrences of relatedness in the context of various horizons within the phenomenon, we present unaltered quotations from students' interviews. These quotations are presented in block quotations. Students were given number identifiers based on the order in which they participated in interviews.

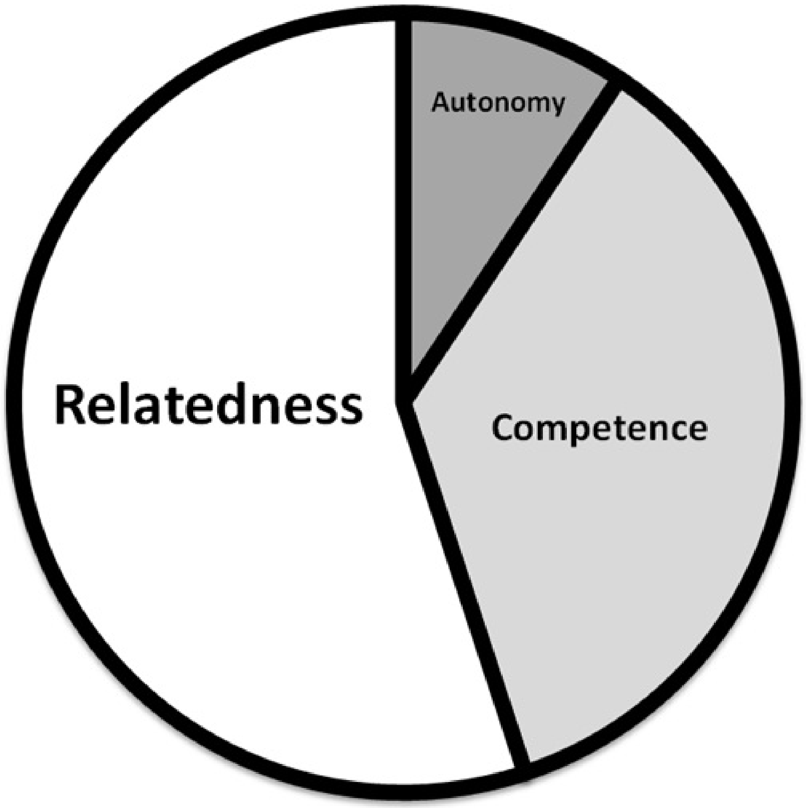

Figure 4.1: Graphical representation of autonomy, competence, and relatedness by frequency of code. Actual frequency counts of codes are as follows: 147 instances of relatedness, 95 instances of competence, and 25 instances of autonomy.

4.5.1 Team Projects Promote Relatedness

Students frequently compared learning in team-based projects with traditional examinations. During these comparisons, students emphasized how projects promoted feelings of relatedness. In particular, students described the relationships that they built during their project work and the teamwork skills they gained through those relationships rather than the course content they learned or the grades they received. They further highlighted how many of these relationships and teamwork experiences were noticeably absent from their more traditional examination-based courses. More important, students commonly expressed a deeper identification or relatedness with the course content and other learning outcomes in the context of the projects.

> I got to meet quite a few other people that I do not think I would have met

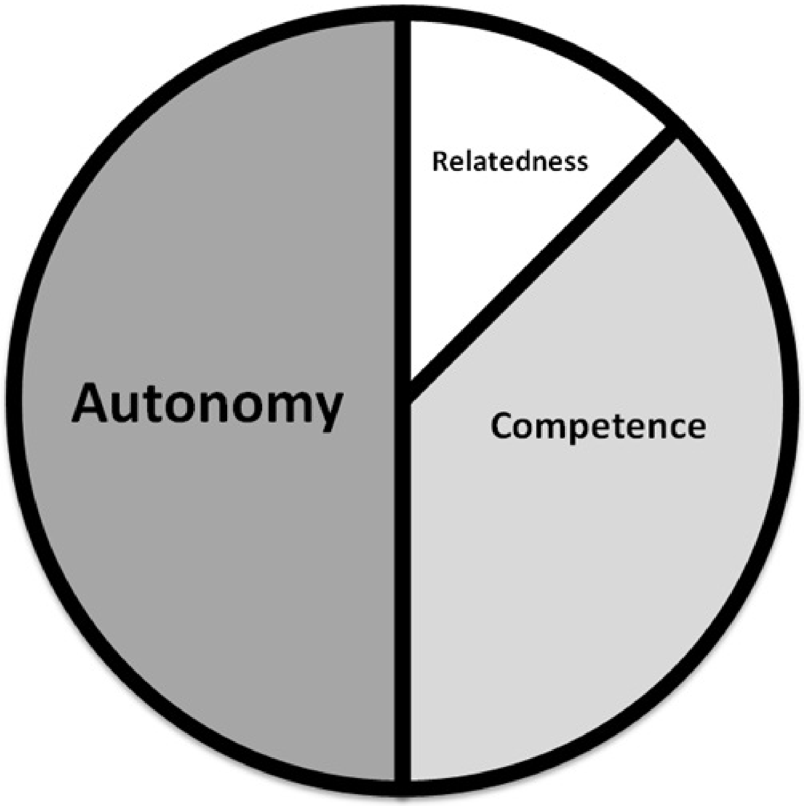

Figure 4.2: Expected representation of autonomy, competence, and relatedness based on literature.

otherwise. And, **I made a lot of new friendships**. That was a social aspect, but then from the unique people ... I also learned a lot of things. I mean from each person that I've met they have a different skill set. They had different ways of attacking their studying. I was able to basically find different study groups and see how they were approaching the subject, how they were understanding the material. And, I was able to work as a group towards understanding the homework and exams, preparing, everything. And, **I feel as if this was just a general exam [based course], I wouldn't have met these other different people. I wouldn't have seen these other perspectives.** So, I felt that the project and the group and the TA was definitely a great way to teach the subject. - Student 17 (emphasis added)

I was surprised when they said the exams were eliminated and I didn't have

> any particular feelings if ... that was a good or bad thing ‘cause I didn’t really know or had a project based course. In the beginning it was a little different working in teams because not a lot of my classes have assigned group work. They want you to do everything by yourself.... **It was kinda nice to have [group work] because you don’t normally get that in any other classes.** But in terms of learning the material I would say you don’t learn particular exam based questions, but **you learn different types of material, cooperating in groups, designing, which is not really exam based**. - Student 14 (emphasis added)

Based on the foundation of relatedness that students felt through team projects, they reported feeling that they had learned more lasting knowledge about the course content or more valuable skills for their future careers compared with the students who did not experience the autonomy-supportive course redesign. Students who mentioned knowledge gains from team projects were more likely to have more internalized forms of motivation such as identified regulation (IR) and intrinsic motivation (IM). These internalized motivations were characterized by a focus on improving oneself (IR) or on learning for its intrinsic value (IM). Codes pertaining to these motivational orientations are highlighted in braces. An example of IM is shown below.

> I would have to say that the knowledge gained in that class would have been really dry and boring without [the redesigned course], so now it’s more relevant to me and the **fact that I have those projects, I’ll always remember that knowledge from that memory {IM}**. So, it’s really, it was a great experience {IM}. - Student 4 (emphasis added)

Two examples of IR are shown below. The first example shows that the student has internalized the course content as important, and the second example shows IR in the context of career preparation and interviews for jobs.

> I think I learned just as much, I think I could’ve remember more of the small things, and not as much of the major things if there were exams I had to study

for, the structure of the way it was, **I think I learned the main things, the more important things, the things you wanted us to keep and remember afterwards, so that I think stays in here [*points to head*] {IR}**. - Student 9 (emphasis added)

Overall, I loved the course and I loved doing projects and I know it really helped me, like when I was talking to recruiters and I had interviews, to actually talk about the projects I did ... because it's like when you take a test or when you take [a traditional course], you can tell them about ... your programs you wrote, but so can the 400 other kids that took that class that are also maybe interviewing {IR}. But this one **you have your own unique choice of a project that you can talk to them about and impress them with**, so that was really nice and I enjoyed not having tests that I had to just keep studying for only to waste my time or do poorly or not be able to apply the knowledge that I had learned {IR}. - Student 1 (emphasis added)

4.5.2 Relatedness Provides a Safe Space for Learning

Although the weekly consultation meeting was conceived as a way to manage and sustain students' autonomy in the course, students emphasized their sense of relatedness with peers, teaching assistants (TAs), and instructors during these weekly interactions. According to students, this context of increased relatedness provided an effective environment for building competence. The essence of the student experience included support from members of each subset of the learning community (peers, TAs, and instructors) and the varying roles each relationship played in the learning process. The autonomy-supportive course redesign allowed students to work in the same team over the entire semester and build strong relationships with their peers.

I didn't know anyone in the class since all my friends had already taken it. ... I think you had the option of choosing one person to work with, but I didn't really know anyone, so I just didn't. I just had all these people put in the same group

> as me. So, **that was kind of nice, just being introduced to new people and just having to work with new people.... We worked pretty well together so we just stayed together for all three projects**, and there were six of us.... Everything worked out really well. - Student 13 (emphasis added)

This duration of contact created a "safe space" that allowed students to challenge themselves and each other by pursuing more ambitious goals than they would have in a shorter project or in a traditional course. Students built a sense of competence by discovering their own strengths and weaknesses through collaboration and the low risk context of their project teams. Students further established their own sense of competence through the competencies of their peers and their instructors during the weekly consultation meetings. Team members filled in the gaps in one another's competencies and contributed to the success and accomplishments of the team as a whole.

> Our first project was really interesting because **everyone was pushing each other around trying to figure out what everyone was good at** and it helped in the sense that you learned how to work with them as a team and it wasn't just one project and you're done. It was during the entire semester and **you got to know everyone's strengths and weaknesses and you got to work off of that** as opposed to being done at one point and not ever touching it again. - Student 16 (emphasis added)

> [The weekly consultation meeting] was where a lot of the kind of big realizations about our project happened because we have, you have the whiteboard, you have people who have a lot more experience with the stuff than you do. And you have everybody kind of like staring at the problem and figuring out what to do and it's, they were really super effective honestly. - Student 2

The "safe space" was strengthened through students' relationships with their instructors during weekly consultation meetings. TAs and instructors became "mentors" instead of "graders" and guided students through their homework and project questions. Based on this reciprocal relationship, students commented on feeling connected to TAs and instructors beyond concern for their course grades and toward a collaborative effort in their learning.

> Like if your TA is really gung-ho about the good material they want to teach people, not so much like, "I'm here just to do it and check in homework and stuff like that." **Like [the TA is] more of a mentor than a grader per se. That can definitely be really helpful ... because the TA is kind of part of the group in that sense.** - Student 6 (emphasis added)

> [Instructor 1] as a project leader was good.... He definitely likes to hear other people's ideas, and if you say something, like your idea, that's probably totally wrong, **he doesn't say, "That's wrong," he's like, "Why do you think that?" It's really nice, very encouraging.** - Student 15 (emphasis added)

Aside from the weekly consultation meetings, students also described the importance of relatedness and its creation of a "safe space" for learning in the traditionally distant space of lecture. Students particularly expressed the importance of feeing cared for.

> The lectures with [Instructor 1] were awesome. He was very energetic, very interactive. He would do things like, he talked some, and we would have little handouts, and he would be like, "All right now, try this." .... Once he gave you something, you worked on it for a little bit, and if you had a question you raised your hand and said, "Hey, I don't understand this part right here." He would say, "Well hey, try this and I'll make sure I bring that up in a couple of minutes when I go over this." [This technique] gave him a chance to see what stuff people weren't getting from the part that he had already done and what he needed to explain a little more.... **It always seemed like he really, really wanted to be there and cared about what people were actually learning.** - Student 5 (emphasis added)

4.5.3 Without Relatedness, Motivation Declines

When students experienced a lack of relatedness during course activities, students' motivational orientation shifted toward extrinsic motivation or amotivation, and their sense of competence declined. Students' sense of competence suffered when they perceived that TAs and instructors did not care about their learning. Poor feedback and communication led to losses in students' sense of relatedness and competence. In the following quotations, both students take motivational cues from the TAs. For Student 15, since the TA did not seem to care about the problem set, the student was not motivated to learn from the problem set. For student 1, since the TA took only a cursory look at the problem set paper, the student did not get the feedback necessary to build competence.

> **[The TA] didn't really care if we did the problem sets or anything**.... I mean he was helpful when we had questions, but he was just kind of like, "Did you do it?" and we were like, "Yeah." **And he didn't really want to go over it, so we didn't want to go over it.** - Student 15 (emphasis added)

> **[Compared to the "good" TA], there was really no in depth back-and-forth between us and [our first TA]** as far as the project point. Whether it was too easy, too hard, more challenging aspects of a specific project **to make it more of a learning event**, we didn't really have any of that. And, [concerning] the homeworks, there was really no teaching in that. - Student 5 (emphasis added)

> ... you would just give [the TA] your problem set and he would just look over it, flip it, "Okay, good," and then give it back to you and **there was no, like, "Maybe you got it right, maybe you got it wrong."** And then ... you would get a grade [online]. And there was no [feedback]. - Student 1 (emphasis added)

When students felt disconnected from the TAs and instructors, their motivational orientations remained more extrinsic in nature. These disconnects were discussed most often with regard to unalleviated concerns over course structures and grading rubrics. These concerns generally centered on assignments that the students completed individually (without the "safe space" created by their project teams) such as the final examination or their online homework assignments. For the student below, concerns about the final examination grade went unvoiced because the student perceived the instructor to be unavailable as a resource.

In contrast against how students with high levels of relatedness focused on learning experiences they saw as valuable, students with this lack of relatedness focused on external factors such as grades or requirements in the course. These external regulation (ER) statements are highlighted in braces.

> As far as I know, I had most of the points going in, maybe a couple points lost, but I had some other stuff that tied in, so I would have had an A if there was no exam {ER}. I ended up getting, I think, B+ in the course which was very disappointing {ER}.... Before going into the exam, I think I needed a very manageable percentage on the exam through my calculations {ER}. And it was very disappointing over the winter break to see that I didn't get an A {ER}. **Compared to other courses where I might have saw it coming, this one kind of blindsided me**.... I felt with [Instructor 1] being a visiting professor and with like other things ... **it would have been hard to communicate with the people managing the course to investigate into [the final exam] grade** if there was something, outside of my own performance, that accidentally affected my grade {ER}. So yeah, I didn't investigate into it {AM}. - Student 11 (emphasis added)

This focus on grades associated with a lack of relatedness also played a role in reducing some students' sense of competence. Students who focused on extrinsic rewards for their learning chose not to complete assignments because they were concerned about the difficulty of the assignments or because they did not need all assignments to achieve their target course grades. These students also reported feeling that they had learned less from the course. After discussing a TA who "didn't really care" about student learning (low sense of relatedness), Student 15 also expressed frustration with the system of grading in the course and avoided challenging material perceived as "too hard" in favor of percentage counting.

> **[There was a] bizarre grading system in this whole class {ER}.** [*laughs*] It was like some things you didn't have to do and some things you did.... Since you didn't have to do all [of the online quizzes], I saw that there were really hard

> ones this week so I was like, "Nmm, I'm just not going to do them. Because I don't have to do all of them, so these will be the ones I skip." And then I didn't really learn that stuff. So, not that I want future people to have to have those all required, they should probably all count for something {ER}. Otherwise, **there are things that I just didn't learn because some of the things looked a little too hard**, and I was having a million other assignments to do so that was lowest priority {ER}. Because you know it's not like your grade is, like you have 30% homework, 20% midterms, and 30% final, or whatever {ER}. You have like 5%, 5%, 5%, so nothing {ER}. You're like, "Well, I can scratch off a percent here. I don't need to do this because I don't need that percent," and it adds up because you just keep thinking they're all little pieces so they don't really matter {ER}. - Student 15 (emphasis added)

4.6 Discussion

While prior research on student motivation for learning based on SDT has emphasized autonomy as the central need in promoting intrinsic motivation, our study surprisingly highlighted that relatedness was the central need in promoting students' intrinsic motivation in an electrical and computer engineering course. Because the importance of autonomy support for learning was established by studying how children learn (Niemiec & Ryan, 2009; Grolnick & Ryan, 1987; Ryan & Grolnick, 1986; Connell & Ryan, 1984; Deci, Speigel, Ryan, Koestner, & Kauffman, 1982; Deci, Schwartz, Sheinman, & Ryan, 1981), rather than how college students learn, we hypothesize that environmental differences may cause the variance in how students respond to the meeting of their autonomy, relatedness, and competence needs.

In primary and secondary education, students live at home with their families, attend class with primarily the same students for several years, and attend classes taught by the same teachers for several years. This highly relational context may abundantly meet students' relatedness needs. In contrast, this study was conducted at a large, public, residential university where students may not have these strong relationship networks. As our students revealed in their comparisons between traditional examination courses and the redesigned course, students came into the course feeling isolated from their peers. They did not know anyone else in the course, they were told to complete assignments individually, or they felt isolated in large lecture classes.

Given this difference in context and difference in findings, we argue that the centrality of autonomy support is not directly transferable to promoting engineering students' intrinsic motivation to learn at the college level. Instead of a fixed hierarchy of importance among the needs as frequently described in the literature, the needs may have interdependencies that cause their importance to manifest differently in different contexts. To extend our assertion beyond the literature, we propose two models that combine our results with the classic emphasis on autonomy support found in SDT. These models seek to expand the prior work in SDT to better explain the role of the three psychological needs across learning contexts. The proposed models provide alternate interpretations of our data and suggest different implications for instruction. The first model is a hierarchical pyramid analogy whereas the second model relies on a structural stability analogy.

4.6.1 Hierarchical Model

The first model draws inspiration from Maslow's Hierarchy of Needs, which argues that higher order needs can be met only by first meeting lower order needs (Maslow, 1954). In this model, relatedness serves as the lowest order need, but is essential for meeting the other needs of competence and autonomy. Relatedness provides a supportive social framework that can allow competency needs to be met. Once students feel competent with a particular concept or in a particular course, they can take ownership of the autonomy provided to them in that context.

This model reinterprets prior SDT findings by arguing that autonomy and competence appeared to be more important for promoting students' intrinsic motivation to learn in prior studies because those studies occurred in contexts that were adequately satisfying students' relatedness needs. Because students' relatedness needs were being met, improvements in students' motivation was expressed through the higher order needs. In contrast, students in our study needed to have their relatedness needs satisfied before they could have their competence and autonomy needs met.

The conception of this model (shown in Figure 4.3) is supported primarily by the theme **relatedness provides a safe place for learning**. From this theme, we saw that students frequently described how the relatedness they built through the team projects gave them a platform on which they built their sense of competence to succeed in the course. Students described how they challenged themselves and their peers because they trusted that the instructors and their peers would provide the necessary support and mentorship for success. Similarly, the **without relatedness, motivation declines** theme indicates that students lost their sense of competence concurrently with losing a sense of relatedness with instructors or peers.

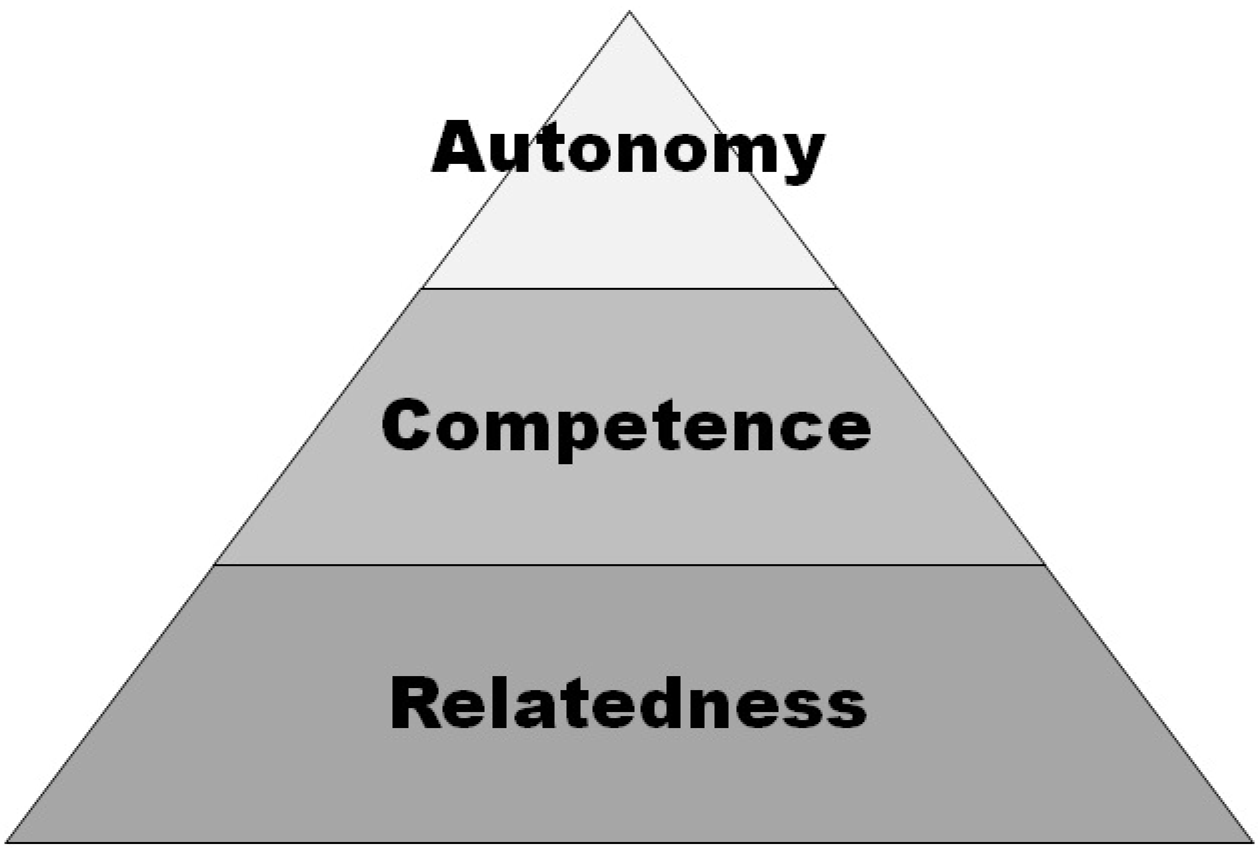

Figure 4.3: Autonomy, competence, and relatedness as pieces in a structural hierarchy where relatedness creates a foundation on which students build competence around learning, and competence allows for students to take full advantage of autonomy.

Similarly, meeting autonomy needs seems to depend on meeting competence needs. Our prior studies with similar students who participated in an autonomy-supportive course redesign revealed that many students found the autonomy supportive environment intimidating and overwhelming (Trenshaw et al., 2013a). Although students were offered significant autonomy, they became amotivated or extrinsically motivated until they gained a sense of competence. As students felt competent to succeed, they became possessive of their autonomy, claiming that all courses should provide them with the autonomy to decide how to learn (Trenshaw et al., 2013a).

4.6.2 Structural Stability Model

The second model draws inspiration from the classic block stacking game Jenga®, in which each "floor" of the tower comprises three blocks; each new floor is stacked on top of the previous floor in a crisscrossed pattern. Players must remove blocks from various locations in the base of the structure while maintaining the stability of the overall structure. If too many blocks are removed in certain configurations, the tower topples.

In this model (shown in Figure 4.4), we suggest that the blocks constituting each floor are analogous to the three needs of SDT. All three needs are vital to maintaining student motivation in a specific context. Each floor of the tower can be thought of as a learning activity (for example, a lecture, a group meeting, or a presentation), and a block is added to the tower for each need that is met in that situation. A student's motivation in a learning context (for example, a course or an engineering discipline) is then constructed into a motivational tower. This analogy aligns with the hierarchical model of SDT which posits that students' motivational orientations in a context are built slowly through the support of students' motivational orientations over a series of situations (Vallerand, 2000).

However, rather than trying to remove blocks, the goal of an instructor is to add the blocks that students are missing. As discussed earlier, the students entering the redesigned course had transferred from high relatedness learning contexts in primary and secondary school into a low relatedness learning context at the university. In this context, students entered the course with a tower severely lacking in relatedness blocks, which created a less stable structure for their motivation. The **team projects promote relatedness** theme

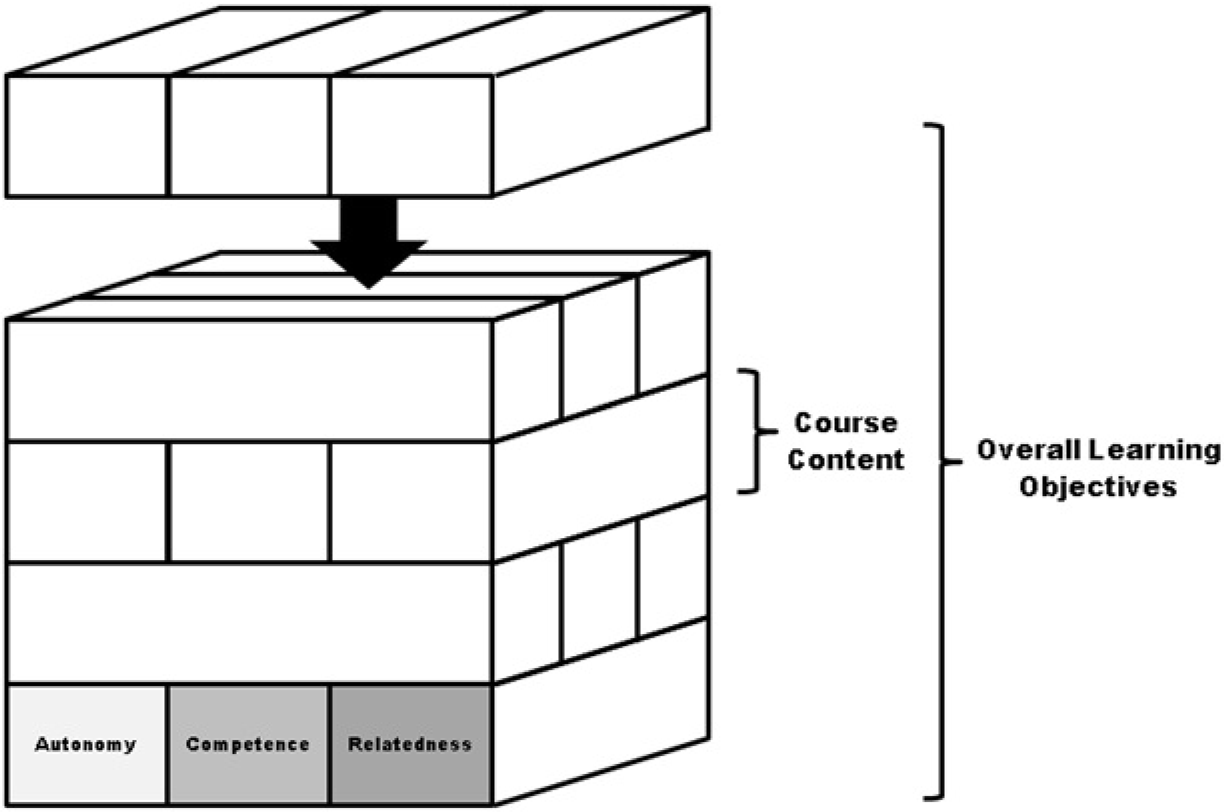

Figure 4.4: Autonomy, competence, and relatedness as pieces in a structural hierarchy where learning is possible, although less stable, without all three at any one step in the hierarchy. For example, in the course under study, course content might represent learning the concept of a register or an arithmetic logic unit (ALU) and the overall learning objective would represent understanding an entire computer architecture from its component parts.

demonstrated that students specifically contrasted their low relatedness courses with the high relatedness redesigned course. Working in team projects added relatedness blocks that stabilized their motivation.

The seeming hierarchical dependence of the needs as described in the first model may be better understood by first perceiving which need is the least met for the college students. In a course design that emphasized supporting students' autonomy, students did not have a felt need for autonomy. Further, post-secondary studies are often perceived as the prime opportunity for adolescents to "discover themselves" and create an environment that generally satisfies students' autonomy needs. In this study, because the students felt a greater need for relatedness in their low-relatedness context, they did not feel their needs for competence and autonomy as acutely, until there was adequate support for their relatedness needs. Adding relatedness blocks removed certain instabilities in the structure, but revealed other instabilities caused by lacking competence or autonomy blocks. In contrast, prior SDT studies have occurred in high relatedness contexts that revealed the controlling behaviors of teachers and parents (Reeve & Halusic, 2009; Reeve, 2009), likely creating greater autonomy needs in these younger students.

Similarly, few students had ever experienced project-based learning before. This lack of experience may have eroded their sense of competence. Consequently, after the most pressing need of relatedness was adequately filled, students' most salient need was gaining a sense of competence. Desires for autonomy would surface only after the other needs were met.

4.6.3 Implications for Practice

The hierarchical model suggests a more prescriptive approach to teaching practice, course design, and curriculum design. For curriculum design, course sequences should first establish relatedness support for students, then build students' sense of competence, and finally give students autonomy. This model would suggest an urgent need for collaborative or cooperative forms of learning early and often in the curriculum with more autonomous forms of learning (such as student-driven capstone projects) later in the curriculum. On the course level, faculty should focus first on developing classroom climates and cultures that are interactive and welcoming and build layer upon layer to improve students' motivation.

The structural stability model requires a more reflexive approach, adapting course design and curricula to fill gaps in the current structure. This model would suggest beginning with a needs analysis or assessment of the existing structure to identify what needs are the least met among the students. Design decisions would then respond to the needs assessment by supplying additional relatedness-supportive, competence-supportive, and autonomy-supportive interventions as needed.

4.7 A Reexamination of the Effectiveness of Active Learning Pedagogies

Calls to adopt interactive engagement and active learning pedagogies often appeal to the cognitive benefits for students. Classic arguments appeal to constructs such as Bloom's taxonomy to claim that active learning improves learning because students are engaging in higher order learning tasks or engaging in cognitive processes that lead to deeper processing of the information. However, these arguments may incorrectly be treating secondary causes and effects as primary ones (Herman, 2012).

Currently, active, collaborative, and problem-based learning strategies are the closest teaching methods to what might be part of a relatedness-supportive classroom environment. Not only does active learning involve techniques that engage students more directly with instructors (for example, electronic response systems where instructors can incorporate students' ideas into the lecture) and with peers (for example, think-pair-share activities where students discuss with one another before reporting back to the class a whole), but active learning also creates a channel through which instructors can show that they care about student learning (Hall, Waltz, Brodeur, Soderholm, & Nasr, 2002). Further, the more students feel that instructors are engaged in supporting their students' intellectual progress (through incorporating active learning experiences with the expressed purpose of improving student learning, for example), the more students report perceiving themselves as confident, competent, and successful (Vogt, 2008). This perception of relatedness between instructors and students was the most prominent outcome of using active learning in engineering classrooms specifically, even above the cognitive outcomes usually focused on by active learning researchers (Hall, Waltz, Brodeur, Soderholm, & Nasr, 2002; Chen, Lattuca, & Hamilton, 2008).

In particular, cooperative and problem-based learning result in greater affective and cognitive gains when instructors make clear to students their support and reasoning for the use of cooperative learning techniques and implement the learning experience effectively (Oakley, Felder, Brent, & Elhajj, 2004; Prince & Felder, 2006; Rosenbaum, 1996). Simply putting students into teams and expecting that they will learn teamwork skills is an incomplete view of team related pedagogies. Without the proper course structures and instructor support in place, implementing student teams in the classroom becomes a negative experience for everyone involved. This frequent lack of support is one of the reasons that many studies disagree on the effectiveness of team related learning techniques (Alpay, Ahearn, Graham, & Bull, 2008; Oakley, Felder, Brent, & Elhajj, 2004; Prince & Felder, 2006). Students want to experience authentic problems and to solve important problems, but they also need to understand that the goal of these activities is not only to learn the material, but also to gain teamwork skills and reflect on their growth in their role as a member of a team (Oakley et al., 2004; Alpay et al., 2008). When gaining a sense of relatedness and community around finding solutions to important modern problems becomes the purpose of collaborative and problem-based learning, students can truly take ownership of their learning in these experiences (Alpay et al., 2008). When students' needs for relatedness are not fostered, their motivation for learning in team-based experiences suffers from negative team dynamics and breeds the idea that teamwork is detrimental to their academic success (Alpay et al., 2008).

Emerging theories such as "hot cognition" suggest that motivation is important in moderating cognition and learning (Sinatra, 2005; Pintrich, Marx, & Boyle, 1993). These theories indicate that the goal of improving students' learning through active learning pedagogies may be more effectively conceived as improving students' motivations to learn. Because active learning pedagogies do provide degrees of support for each of the three psychological needs of SDT, their full potential may be unlocked by a deeper understanding of how to expand on current pedagogies through support of the psychological needs. In the context of relatedness support, we suggest that the pathways to successful instruction may lie in interactions that communicate genuine caring rather than simply better technique.

4.8 Conclusion

We conducted a phenomenological study of an electrical and computer engineering course for second-year students; the course was designed to support intrinsic motivation by providing significant autonomy support. We found that relatedness was unexpectedly most salient to students, and their sense of relatedness defined the essence of their motivational changes in the course. This finding contradicts the generally accepted hierarchy of needs in SDT where autonomy and competence are thought to be more vital to motivation than relatedness (Ryan et al., 2011; Sierens et al., 2009; Ryan & Deci, 2008; Black & Deci, 2000; Deci & Vansteenkiste, 2004). This contradictory observation highlights a gap in our understanding of the interdependence of the three needs.

More research is needed to elucidate how autonomy, competence, and relatedness interact in shaping an individual's motivational orientation, situationally, contextually, and globally. We suggest two productive directions for future research: 1) qualitatively exploring the relative importance of the three psychological needs of SDT in a variety of learning contexts and 2) developing quantitative instruments that measure students' motivational orientations and felt needs in a course, particularly in contrast with the needs provided by their general learning context. These future research studies should test the generally accepted model of the centrality of autonomy-supportiveness in learning against other potential models such as those proposed in the discussion section. Further, this type of research can better inform teaching practice and its consideration of contextually-dependent principles versus more globally applicable ones.

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CHAPTER 5

CONCLUSIONS

As presented in Chapters 2, 3, and 4, I conducted three studies of how team-based project experiences can improve affective outcomes for engineering students. In Chapter 2, I evaluated a program that integrated team design projects into required courses in a chemical engineering curriculum with high student to faculty ratios. As program outcomes, students perceived increased confidence in their teamwork skills, communication skills, leadership skills, and design skills. In Chapter 3, I took a narrative inquiry approach to investigate how students experienced a discussion section redesigned to support intrinsic motivation to learn in a required course in electrical and computer engineering. Fostering trust between students and their peers, teaching assistants, and professors moved students' motivational orientations toward intrinsic motivation without sacrificing their learning gains. In Chapter 4, I performed a phenomenological analysis of students' experience in a full course redesigned to be autonomy-supportive. The essence of the student experience was a sense of relatedness in the context of the course. Through that sense of relatedness, students expressed motivational orientations more toward intrinsic (rather than extrinsic) in nature and perceived improved learning gains.

In all three studies, relatedness stemming from team-based learning experiences surfaced as important to students. To support students' sense of relatedness, instructors should structure courses such that students can build a community with one another around their learning and feel that instructors care about them as learners. This commitment to community building should extend both inside and outside the classroom through pedagogies such as active learning during lectures and assignments that require students to interact outside of class time, for example. Simply grouping students into teams for assignments is not enough. The duration of contact, clarity of course structures, and availability of resources all play a role in creating the "safe space" necessary for a sense of relatedness to grow in students. By understanding that students' sense of relatedness and their intrinsic motivation can be potential course outcomes, instructors can refocus their pedagogies and not only improve students' learning, but also students' general attitudes toward education.

All three studies in this dissertation were hampered by a paucity of instruments for measuring students' affective outcomes. Confidence, trust, motivation, and even satisfaction are complex, multifaceted psychological constructs that human beings often find difficult to articulate clearly, much less in a manner that can be quantitatively compared across individuals. Further, existing instruments were often developed for a single study and never used again, measure the construct only in the context of a single event instead of an entire course (Guay, Vallerand, & Blanchard, 2000), or do not provide the resolution necessary to measure component factors of a particular construct (Williams & Deci, 1996; Jones, 2009). There is a need for the development of instruments firmly based in accepted theoretical frameworks of constructs like trust and motivation that stand up to rigorous statistical testing, are found to be reliable for the populations and contexts under study, and have the resolution to separate out the factors contributing to the construct (autonomy, competence, and relatedness from Self Determination Theory, for example). Widespread use of such instruments would yield previously unavailable insights into the student experience in the context of a course and limit the amount of redundant research in instrument development.

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