

# Using Self Determination Theory Principles to Promote Engineering Students' Intrinsic Motivation to Learn\*

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Research based on Self Determination Theory (SDT) posits that autonomy, competence, and relatedness are important psychological needs for fostering intrinsic motivation. Although competence and autonomy are clearly defined in the literature, relatedness and its role in motivation are less clearly defined, as relatedness is often discussed in terms of project work, collaborative learning, and group experiences. This study seeks to describe the salience of students' motivation toward learning in a second-year engineering course (Computer Engineering I) that was redesigned to promote students' intrinsic motivation to learn. After completing the redesigned course, 17 students were interviewed about their experience throughout the semester. During interviews, students were asked to describe their experiences in the course and to discuss how those experiences affected their motivation. Interviews were coded to capture students' situational motivational orientations during the course and the psychological needs they mentioned in relation to their experience. The analysis of students' descriptions overwhelmingly pointed to relatedness as the most salient need in supporting their motivation in the course. Contrary to expectations based on the SDT literature for K-12 students, the analysis revealed a lesser salience of competence and autonomy for the college students in our study. Students' statements were coded least frequently as pertaining to autonomy out of the three psychological needs of SDT, even though the course designer's primary goal was to support students' autonomy. While autonomy support within classroom environments does affect students' motivation within the course context, relatedness, rather than autonomy, was most salient in our context. Engineering educators should explore how the social context of large engineering courses may create a deep need for supporting relatedness.

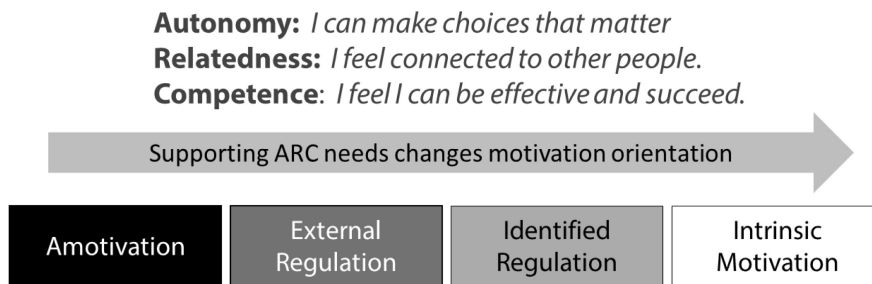
**Keywords:** self determination theory; relatedness; sophomore course; second year; thematic analysis

## 1. Introduction

Intrinsically motivated students learn more and retain that knowledge for longer [1], 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 [2]. SDT is based on three psychological needs: autonomy, competence, and relatedness [2]. *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 (Fig. 1): the individual increasingly internalizes their motivation until something intrinsic about the activity drives the individual [2–3]. This same drive can be harnessed in an academic context to improve student learning.

One of the authors of this paper redesigned an electrical and computer engineering course for sophomore students (Computer Engineering I) at the University of Illinois at Urbana-Champaign (a large, public research institution) to facilitate improved student motivation to learn. Drawing from SDT literature, the primary goal of the course redesign was to promote students' sense of autonomy by replacing mandatory midterm examinations and homework assignments with student-selected design projects. In these design projects, students were given progressively more autonomy as the semester progressed, with the level of autonomy of the final design project comparable to that of a senior capstone design course. Further, students



**Fig. 1.** Supporting students' psychological needs of autonomy, relatedness, and competence can change students' motivational orientation toward intrinsic motivation.

were given autonomy to choose which subset of homework problems to complete. The remainder of the course design was created to support students' sense of competence and relatedness within this new learning paradigm [4–5]. Rather than asking course staff to grade students' homework, as had been done in the past, each instructor or teaching assistant (TA) led weekly, team-based meetings during which the teams discussed their projects and questions students had about homework problems. These weekly meetings focused on supporting students through their struggles with the course content rather than assigning grades based on performance.

This study employs a thematic analysis of interviews with students to elucidate the student experience during this redesigned course. In particular, we focus on answering two research questions:

1. What are students' situational motivational orientations (i.e., motivations that vary by situation such as a single class meeting rather than by context such as a whole course [6]) in a sophomore engineering course with a motivation-supportive classroom environment?
2. How salient are the three psychological needs—autonomy, competence, and relatedness—to students during their experience in the course?

## 2. Background

Students' motivation toward learning can range from amotivation through various forms of extrinsic motivation up to intrinsic motivation, which is a preferred motivational orientation for learning [1]. While students may enter the classroom with any motivational orientation in relation to the course content and activities, SDT asserts that instructors can foster students' intrinsic motivation to learn by supporting students' psychological needs for autonomy, competence, and relatedness. [4–5, 7–9].

The type of motivation also has a hierarchical structure that varies by time scale or domain [10]. Motivation can be situational (e.g., a homework assignment or a group meeting), contextual (e.g., a

semester-long project, a course, or learning engineering), or global (e.g., a person's default motivational orientation). A person's motivational orientation may vary across these three levels in every situation and over time [10].

While engineering educators have previously advocated for the use of SDT in the context of engineers' motivation [11], it has not yet been used extensively with course-level analyses. Winters and Matusovich used SDT to investigate engineering graduate teaching assistants' perceptions of autonomy in teaching engineering courses [12]. They found that graduate teaching assistants' reported low perceptions of autonomy. In their longitudinal study of six engineering students, Winters, Matusovich, and Streveler found that students' feelings of autonomy-support decreased after the first year [13]. Students perceived positive relatedness throughout the four years except for the third year in the program. With regard to relatedness, studies of first-year and capstone engineering courses have shown that students' sense of belonging and caring can be supported through a problem-based learning design [14–15].

When applying SDT to instruction more generally, autonomy support receives primacy. In Deci and Ryan's early pedagogical research (e.g., [16–18]), they emphasized the importance of autonomy support and the detriment of controlling teaching behaviors. Similarly, more recent research such as that by Ryan and colleagues [7], Black and Deci [5], Reeve and colleagues (e.g., [19–21]), and Sierens and colleagues [8] continue to emphasize the importance of autonomy support for promoting intrinsic motivations for learning. Ultimately, the implications of SDT for teaching are framed in language that encourages instructors to move from controlling behaviors to autonomy-supportive behaviors to the extent that “autonomy support” is synonymous with “intrinsic-motivation support” [5, 8, 19]. Concretely, SDT researchers postulate that shifts toward intrinsic motivation 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 [4–5].

Autonomy support is also discussed as a core method for supporting students' sense of competence [16]. Particularly, by supporting students' sense of autonomy, instructors can help students better internalize their sense of competence [16]. Consequently, these first two needs are posited to be interrelated, if not dependent on one another in the process of motivational change [7, 22]. Instructors can further 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 [8, 21].

The third psychological need, relatedness, has received less explicit focus in the literature, often being discussed in conjunction with autonomy and competence, under the blanket term of the "psychological needs" necessary in order to promote intrinsic motivation, according to SDT [3, 23]. For example, a study by Filak and Sheldon found that satisfaction of all three psychological needs predicted positive teacher evaluations [24]. When relatedness is discussed it is often considered in the context of team-based learning such as project work, collaborative learning, and group experiences [14, 25–28]. For example, Xie and Ke found that collaborative elaboration interactions were most influenced by relatedness [26]. Jones and colleagues revealed that "group experiences" were seen by several students as "motivating opportunities" [14].

While these types of team-based learning experiences can have positive effects on students' motivation, instructors and researchers are cautioned against equating team-based learning to be synonymous with relatedness support [25]. Critically, team-based learning does not necessitate the involvement of a group at all and may be completed as an individual task, eliminating opportunities for relatedness [25]. A common anecdotal example that most engineering educators have experienced in their own team-based courses is the situation in which students on a team divvy up an engineering project assignment into parts, work on those parts individually, copy and paste their individual write-ups into a master document (often asynchronously via a document shared online), and turn in a final report almost without interacting with one another. Building from this example, relatedness support must encompass more than working toward a shared team grade or interacting with others. To truly foster a sense of relatedness, an experience

must support "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" [29]. In this sense, team-based learning is not, by itself, relatedness, but instead an opportunity for building relatedness.

Given the emphasis on autonomy- and competence-support in the literature, a pilot course redesign of Computer Engineering I (discussed briefly below) focused on giving students greater autonomy and control over their learning [30]. Additional considerations of relatedness-support in the context of team-based learning informed the course redesign discussed in this study, although the primary focus remained on providing autonomy support.

### 3. Context

To investigate the outcomes of redesigning a course to support students' intrinsic motivation to learn, we chose Computer Engineering I as the context for our study. Computer Engineering I is a large course on digital logic and computer architecture required for all second-year electrical and computer engineering (ECE) majors at the University of Illinois at Urbana-Champaign. 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 these discussion sessions over multiple semesters. Historically, due to the large class size, all instructors require that students complete all homework and laboratory assignments and all examinations, offering students little, if any, autonomy in their learning activities.

#### 3.1 Fall 2011 course redesign

In the Fall of 2011, we conducted a pilot study of the redesigned course, focusing on providing students with increased autonomy. Details of the Fall 2011 course design are discussed in other publications [30–34]. 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 [31, 34]. As measured by the Digital Logic Concept Inventory [35], cognitive outcomes for students in the Fall

2011 offering were equivalent to, or better than, those of students in the traditional offerings of the course [30].

### 3.2 Fall 2012 course redesign

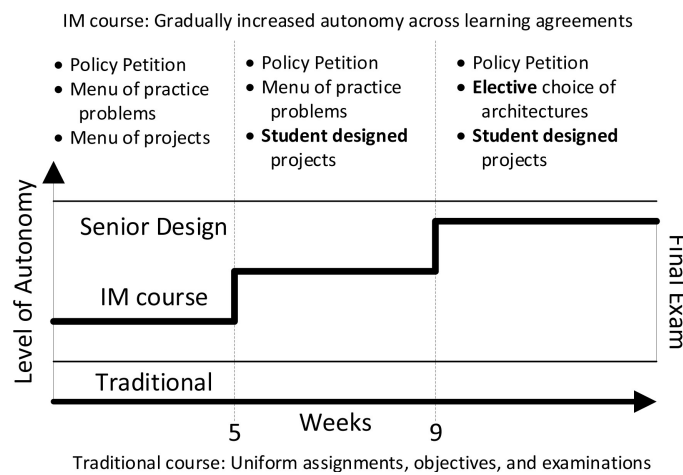
In this paper, we analyze the outcomes of the redesign of Computer Engineering I that was offered in the Fall of 2012. A summary of the course structure and which aspects were designed to support which psychological needs is provided in Table 1. Based on the results of the Fall 2011 pilot, the Fall 2012 course focused on increasing students' autonomy by centering the course around a series of design projects. 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 password hackers. For the second project, students were required to demonstrate a sequential logic design. A few pre-defined 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, 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 (See Fig. 2). Project grading included both team and individual assessments as well as peer evaluation

to provide students with a sense of autonomy with their teams' course grades in addition to the autonomy from project choice.

To further support students' autonomy, course staff created additional homework sets and problems so that students could have choices in which homework and laboratory assignments to complete. For example, students could choose 75 out of 125 online practice problems and five out of seven laboratory exercises to let them focus on the particular skills they wanted to develop in the context of the course.

To support students' sense of competence in this high-autonomy environment, we added *weekly consultation meetings* to the Fall 2012 course in lieu of grading written homework assignments. During weekly consultation meetings, students met in their project teams of four to six students with an instructor or TA to discuss their written homework and design projects. To support autonomy and relatedness, student teams were composed to match students together with other students who had similar self-identified learning goals. Team construction also provided relatedness support by constructing teams so that women and minorities were not isolated on a team [36]. To mitigate the effect of negative team dynamics on students' success in the course, students were given the option to dissolve their teams and be assigned to new teams midway through the semester, but the vast majority (> 90%) of students remained in the same team during the entire semester. This option to dissolve teams was an additional method for increasing student autonomy. This extended duration of contact in team-based learning was unique in the department.

The Fall 2012 redesigned course was co-taught by



**Fig. 2.** Students' autonomy was gradually increased over the course of the semester relative to traditional lecture-based offerings. Increased levels of choice and autonomy are highlighted in bold. The hypothetical level of autonomy in a Senior Design course is included for reference. The semester ended with a mandatory final exam.

**Table 1.** List of course activities and the psychological needs they were intended to meet

Need	Autonomy	Relatedness	Competence
Activity	<ul style="list-style-type: none"> <li>• Course policy petition</li> <li>• Menu of online and written homework assignments</li> <li>• Menu of laboratory assignments</li> <li>• Student-directed projects</li> </ul>	<ul style="list-style-type: none"> <li>• Team-based projects</li> <li>• Collaborative learning in discussion sessions</li> <li>• Weekly consultation meetings</li> </ul>	<ul style="list-style-type: none"> <li>• Challenge vs practice problems</li> <li>• Weekly consultation meetings</li> <li>• Flipped lectures</li> <li>• Laboratory assignments</li> </ul>

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. Instructor 2 provided video lectures 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. Method

To better understand how this motivation-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 [37]. With our thematic analysis, we sought descriptive narratives of students’ lived experiences in the Fall 2012 redesigned course with respect to their motivation to learn [38]. Consistent with thematic analysis, the authors were familiar with the data by being part of both data collection and data analysis [39]. All research was performed with IRB approval (UIUC IRB Protocol #12046).

##### 4.1 Data collection

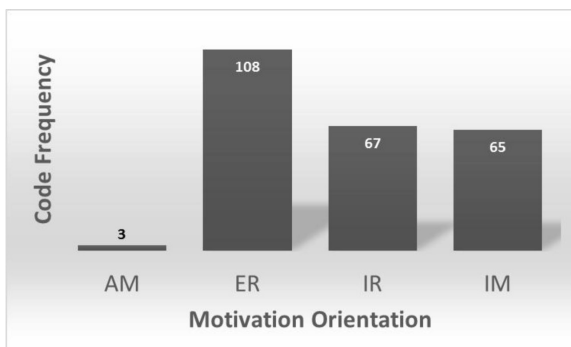
Post-course exit interviews were semi-structured and designed to take between 45 and 60 minutes. To allow students to decompress during the winter

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. 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). Each student was compensated \$10 for volunteering their time.

Two of the authors, who were later involved in data analysis, carried out the interviews. 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 to discuss whatever aspects of the course were most salient to them. At the conclusion of the interviews, the interviewers followed up with questions that highlighted aspects of the course that students had omitted, such as lectures, discussion sessions, or the primary instructors. 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 salient to their experience. The interviewers went through a pilot interview together prior to interviewing students to ensure that they would be asking the same kinds of questions related to the semi-structured interview protocol.

#### 4.2 Data analysis

Consistent with our overall goal to understand the student experience in the motivation-supportive classroom through the lens of SDT, we conducted theory-driven coding with an a priori coding scheme [39]. SDT was chosen as a framework for interview analysis because the course redesign was itself based on SDT. The audio recordings of the interviews were transcribed and three authors who were not involved in teaching the course or grading student work coded the interviews. This distance from grading ensured that no bias based on student performance or participation in the course would be introduced into the analysis, improving trustworthiness [37]. First, to ensure familiarity with the data, we reviewed the interviews before coding them. Second, we individually coded the interview transcripts with an a priori coding scheme focused on how students discussed their sense of autonomy, relatedness, and competence [2] and when students exhibited any of four motivational orientations around their learning (described in SDT [6]). These four orientations emerged during open-ended coding of interviews with students about their experience with the Fall 2011 redesigned course [40]: (1) amotivation (AM) characterized by no motivation or disengagement, (2) external



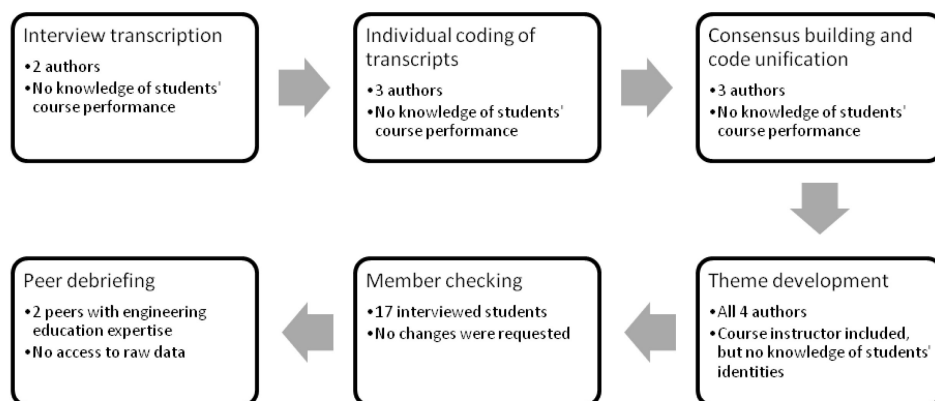
**Fig. 3.** Frequencies of AM, ER, IR, and IM codes. Frequency counts of codes are as follows: 3 instances of AM, 108 instances of ER, 67 instances of IR, and 65 instances of IM.

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 a desired career or self-improvement, and (4) intrinsic motivation (IM) characterized by motivation from excitement, interest, or fun derived from the learning activity. Two other motivational orientations, introjected regulation and integrated regulation, are included in SDT. These two motivational orientations, while theoretically distinct, were subsumed into IR as variations on “self-improvement” for the purposes of this study. This simplification of the motivational orientations in SDT has been similarly executed and validated in other SDT studies focused on situational motivation [6]. The frequency of motivational orientations from the codebook is shown in Fig. 3.

After the initial individual coding, the same three authors came together for consensus building and code unification. During consensus building, we developed a set of unified codes for each transcript and discussed any discrepancies between our individual coding schemes until we reached a consensus on which code to apply. We applied the unified codes to identify patterns in interview transcripts. Through code unification and pattern building, we arrived at three themes that represent and emerged from the data relevant to students' motivation in the course [41]. These themes were presented to another author uninvolved in theme development for further refinement. This author was involved in teaching the course and gave verification that the themes were an accurate representation of the experience from an instructor's perspective. We provide an outline of our interview analysis process in Fig. 4. The themes developed using this method are reported in the Results section below.

#### 4.3 Trustworthiness

During the interview analysis, three authors compared and discussed codes for each interview until



**Fig. 4.** Data collection and analysis processes from interview transcription to peer debriefing.

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 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 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 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.

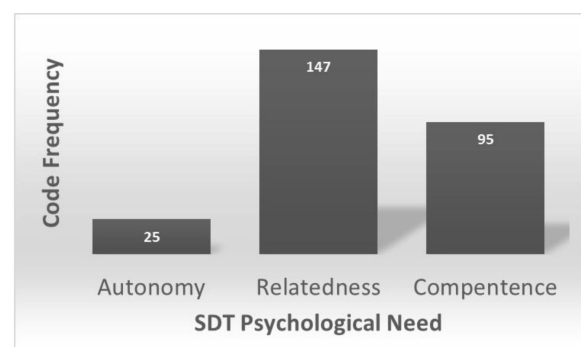
The institutional context of our study may limit the generalizability of our results. Because the university studied is a large, public institution with an above average population of international students, the students may have significantly different motivations from students at a small, private institution 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 a university in the United States 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. A common question format about team experiences might have been "Tell me more about working with your team members (relatedness)" which would likely result in a description of relatedness (or lack thereof) from the student. 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.

## 5. Results

Of the three psychological needs identified by Self-Determination Theory (SDT), students discussed relatedness most often in their statements. Autonomy appeared approximately one-sixth as often as relatedness, contrary to the expected order of frequencies of the psychological needs based on the course redesign (autonomy, competence, and then relatedness). To provide perspective on the overall code frequency, Fig. 5 displays the relative frequencies of relatedness, competence, and autonomy codes.

Three themes emerged from the data: *team projects promote relatedness*; *relatedness provides space for competence building*, and *without relatedness and competence, motivation declines*. These three themes are presented below. To illustrate the themes, we present unaltered quotations from students' interviews. These quotations are presented in block-indented text. Students were given numerical iden-



**Fig. 5.** Frequency of codes associated with each of the psychological needs: 147 instances of relatedness, 95 instances of competence, and 25 instances of autonomy.

tifiers based on the order in which they participated in the interviews.

### 5.1 Team projects promote relatedness

Students frequently compared learning in team-based projects to learning 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 importantly, 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 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 because 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 kind of 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 their perception of the students who did not experience the motivation-supportive course redesign.

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*. So, it's really, it was a great experience. —Student 4 (emphasis added)

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]. —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. 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. —Student 1 (emphasis added)

### 5.2 Relatedness provides space for competence building

The support from members of each subset of the learning community (i.e., peers, teaching assistants, and instructors) and the varying roles each relationship played in the learning process led to competence building for students. Although the weekly consultation meetings were conceived as a way to manage and sustain students' autonomy in the course, they were key to the way the students built relationships and received support from peers, teaching assistants (TAs), and instructors. According to students, this context of increased relatedness provided an effective space for building competence.

The space for building competence 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)

We could throw ideas at [the TA], and he would give us some feedback on what's realistic and what's not. *On*



*the homeworks, he was really good at explaining things that I didn't understand. I would be like, "Hey, I didn't understand what this was really asking and I want to see if you can explain what it's asking." Then, I knew how to solve it. —Student 5 (emphasis added)*

The motivation-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 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*

When instructors engaged face-to-face with project teams, students recognized and appreciated their encouragement first hand.

*[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 relatedness and its creation of a space for learning in the traditionally distant space of lecture. Students particularly expressed the importance of feeling 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)*

### 5.3 Without relatedness and competence, motivation declines

When students experienced a lack of relatedness during course activities, their situational motivational orientations were more likely to be extrinsic motivation or amotivation. Further, a reduced sense of relatedness was connected with a reduced sense of competence. 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' senses 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)*

*. . . 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 situational motivational orientations were 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 indivi-

dually (without the relatedness 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. This student's reduced sense of relatedness revealed a greater focus on external incentives such as grades and requirements. These types of comments were less prevalent among students with a stronger sense of relatedness. These external regulation (ER) statements are marked 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. [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 {ER}. Because I don't have to do all of them, so these will be the ones I skip {ER}." 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)

## 6. Discussion

As a preface to the discussion of our results, we provide a summary table for quick reference to the three main themes described in the Results section above (See Table 2).

Prior research based on SDT has emphasized autonomy in promoting students' intrinsic motivation to learn, calling for autonomy-supportive pedagogies. In contrast, our study highlighted that relatedness was most salient to Computer Engineering I students. Because the importance of autonomy support was established by studying how children learn [16–18, 23, 42–43], rather than how college students learn, we hypothesize that environmental differences may explain this variance.

In primary and secondary education, students live at home with their families, attend class with mostly 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 university where students may not have these strong relationship networks. Our students revealed that in traditional courses they did not know anyone else, they were told to complete

**Table 2.** Summary of themes identified from interviews.

Theme	Summary
Team projects promote relatedness	Students' narratives focused on describing the relationships that they built through the team projects and consequently how those relationships deepened their learning and appreciation of the technical content.
Relatedness provides space for competence building	Students' feelings of connectedness with peers and instructors transformed instructors from graders into mentors and peers into valued partners in learning. These relationships motivated students to challenge themselves as it became safe to fail and try again during the process of learning.
Without relatedness and competence, motivation declines	Students felt a loss of relatedness with peers and instructors when they did not express interest in their work. Students felt a loss of competence because of unfamiliar grading schemes. These felt losses prompted extrinsic and amotivation orientations.

assignments individually, or they felt isolated in large lecture halls. Further, university students experience greater autonomy than K-12 students, being away from parental oversight, choosing their majors, and choosing their courses.

Given these differences, we argue that the centrality of autonomy supportiveness may not translate directly into large-enrollment undergraduate engineering courses. We are not saying that autonomy is not important, but that relatedness may be more salient to the intrinsic motivation to learn of certain populations of students. More generally, tactics for promoting students' intrinsic motivation to learn may vary in effectiveness based on students' social environments outside the classroom. Critically, we question whether faculty teaching large lecture courses should focus on implementing autonomy-supportive pedagogies or whether they should focus on thinking more holistically about students' social environments.

Because the language of "autonomy support" may not concisely capture how to promote students' intrinsic motivation to learn, we propose a new conceptualization to capture the complexity of students' motivation in undergraduate engineering courses. In this conceptualization, we describe the process of promoting students' intrinsic motivation as a structure that an instructor attempts to build and stabilize. This conceptualization combines the salience of relatedness from our results with the classic emphasis on autonomy support, respecting prior research while exploring potential contextual limitations.

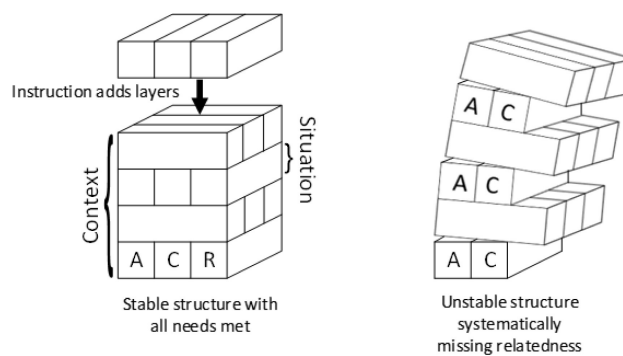
### 6.1 The structural stability conceptualization

This conceptualization draws inspiration from the classic block stacking game Jenga<sup>®</sup>, in which each "floor" of the tower is comprised of three blocks; each new floor is stacked on top of the previous floor in a crisscrossed pattern (See left diagram in Fig. 6). When all three blocks on a floor are present, that

floor is stable, but when one or more blocks is removed from a floor, the block becomes increasingly unstable. If too many blocks are removed, the tower topples (See right diagram in Fig. 6).

In this conceptualization, we suggest that the blocks constituting each floor are analogous to the three needs of SDT (see base floor of Fig. 6). 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. Floors of the tower that meet all three needs provide a stable structure, whereas floors that are missing needs create instability. The aggregate stability of the structure can then be thought of as the likelihood that the student will be intrinsically motivated to learn in a context (e.g., a course or an engineering discipline). This analogy aligns with the hierarchical model of SDT, which posits that students' motivational orientations in a context (such as in a course or a curriculum) are built slowly through the support of students' motivational orientations over a series of situations (learning activities) [10].

In this analogy, we suspect that students come into a learning environment with various blocks missing. For example, K-12 students are more likely to be missing autonomy blocks whereas undergraduate engineering students in large enrollment courses are more likely to be missing relatedness blocks. In this analogy, the salience of a need being met would be correlated with the relative lack of that need in the structure: the more a need is missing, the more meeting that need becomes salient to the student. The theme *team projects promote relatedness* specifically revealed that students contrasted their more common experience in low relatedness courses with the unique experience in the high relatedness redesigned course. With this overall lack of relatedness in their engineering course experience, team projects might have added desperately needed relatedness blocks to stabilize their



**Fig. 6.** Autonomy (A), competence (C), and relatedness (R) are three building blocks needed to build a structure of intrinsic motivation. Each new situational experience adds a new layer to the structure to determine a student's motivation in a context. When a need is systematically unmet such as relatedness, the structure becomes unstable.

intrinsic motivation to learn. As a direct comparison, SDT studies in K-12 environments focus on students learning in high relatedness, low autonomy settings. Consequently, increasing autonomy-supportive behaviors of teachers and parents would be more salient to these students [19–20].

### 6.2 Implications for practice

The traditional SDT emphasis on autonomy support may unintentionally lead instructors to focus solely on increasing students' autonomy rather than to think more holistically about students' social contexts and the complexity of their motivations. We believe that our structural stability conceptualization instead encourages faculty to take a reflective stance in their course designs, adapting course design and curricula to fill gaps in students' current situational motivation structure rather than immediately pursuing autonomy support. Conversely, our finding about the relative salience of relatedness is unlikely to be generalizable across engineering students as institutions with smaller class sizes may more naturally meet students' relatedness needs than institutions with large enrollments. Our model suggests beginning with a needs analysis or assessment of the existing structure to identify what needs are the least met among the students. Design decisions should respond to the needs assessment, supplying additional relatedness-supportive, competence-supportive, and autonomy-supportive interventions as needed. We describe one such approach in other publications [44].

### 6.3 Future work

The proposed structural stability model is based on a single qualitative study at a single institution. While we are confident in the relative salience of relatedness for the students in this study, future research should explore whether similar disparities in salience exist in other contexts. A next step in this research could include a large quantitative study at different institutions to verify whether different psychological needs are indeed met differently in different learning contexts. With this data, we could then explore and measure whether the same intervention or course design in different contexts affects students' motivation in a way that aligns with our proposed model. Do students from different contexts reliably perceive different salience in the satisfaction of their psychological needs based on what needs were previously not being met? Answering this question may also have significant implications for motivating and retaining underrepresented populations in engineering who often feel as though they do not belong (i.e., they have a low sense of relatedness).

## 7. Conclusions

We studied a redesigned version of Computer Engineering I to foster intrinsic motivation by providing autonomy, competence, and relatedness support. We found that relatedness was unexpectedly most salient to students. This finding contrasts with prior SDT-focused research in which autonomy- and competence-support are presented as more vital to motivation than relatedness. This contrasting observation highlights a gap in our understanding of the interdependence of the three psychological needs and students' experiences of these needs. We proposed that researchers and instructors should consider moving from trying to be “autonomy-supportive” to assessing their students' unmet needs in a structural stability conceptualization of engineering courses and curricula. More research is needed to explore the validity of this analogy.

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