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2020 BEST PIC III PAPER and BEST OVERALL PAPER WINNER - Do Open-Ended Design Projects Motivate First-Year Engineering Students?

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Abstract

This complete research paper examines students' situational motivation responses to open-ended design projects with varying degrees of autonomy control in a freshman Introduction to Engineering course. Four sections of the course were given different project themes with different constraints on scope and materials. The Situational Motivation Scale (SIMS) survey, an instrument to measure four types of motivation (intrinsic motivation, identified regulation, external regulation and amotivation) based on Self-Determination Theory (SDT), was administered weekly to the students enrolled in the four sections during the nine-week open-ended design project. A Basic Needs Satisfaction Scale (BNSS) survey was given at the end of the semester to measure the degree to which three basic psychological needs, autonomy, relatedness, and competence, were satisfied. Quantitative analysis reveals that the open-ended design project with the least constraints prompts more positive self-determination compared to the one with the most constraints. The provision of choice and control has a more prominent impact on female students' motivation than on male students. The perceived need satisfaction of competence may play a role in shaping students' motivational responses.

Introduction

Hands-on team-based open-ended design projects in freshman engineering courses have been shown to significantly improve student retention due to the benefits of active hands-on learning, self-directed acquisition of knowledge, development of skills and confidence necessary to succeed in engineering and a growing sense of community [1, 2]. These open-ended design projects range from highly structured [3] to theme-based [1, 2] to free choice [4, 5]. Combining entrepreneurial thinking and maker technology, student-driven free-choice open-ended design projects allow students to generate their own idea, take ownership of their design project, and results in significant gains in creativity and entrepreneurial intentions [6].

In a project-based first-year Introduction to Engineering course at Arizona State University, the design project was revamped in the fall semester of 2016 [7], following the KEEN (Kern Entrepreneurial Engineering Network) movement [8] of fostering an entrepreneurial mindset in young engineers. An open-ended design project was chosen to let students discover customer need, identify pain points, and design a solution. The student feedback was very positive. Most liked that they were given the ability to construct and solve their own design problem. They also liked the creative opportunity and inspiration to make better products. However, due to the very nature of free-choice project, different students engaged in different ways, with some creating sophisticated prototypes and others constructing simple solutions. For the past three years, the project definition was tweaked to varying degrees of freedom. For instance, from free-choice project (the only requirement is to positively impact the world) to theme-based project (such as relating the project to assistive technology, accessible and universal design), but there was no clear indication that one approach was better than the other.

Giving students the freedom to choose their own design project promotes autonomy, which is one of the three basic psychological needs from self-determination theory (SDT) [9-13].

However, given that most students taking the course are freshman in college and lack design experience, providing the students the complete freedom to choose an appropriate project with the right scope and proper difficulty level to ensure a meaningful learning experience is also a challenge. Therefore, exactly how instructors may best support student autonomy through provision of classroom choice and control is unclear. This paper will discuss an experiment investigating how open-ended design projects impact students' motivation. Specifically, how limiting choice in scope and materials in the open-ended design projects influence students' motivations.

Four sections of an Introduction to Engineering course in the fall semester of 2019 were all given open-ended design projects. Each section was given a problem statement with some common requirements but with different degrees of autonomy. The autonomy varied in scope and construction materials allowed. The open-ended design projects spanned nine weeks. Students went through activities such as pain point discovery, information collection and synthesis, problem definition, brainstorming solutions, design decision, project management, proposal presentation, construction and testing, final presentation and demonstration. Each week students were given a Situational Motivation Scale (SIMS) survey [14] to measure their motivation. A Basic Needs Satisfaction Scale survey [15, 16] was given at the end of the semester to measure the degree to which the basic psychological needs of autonomy, relatedness and competence were satisfied, which promotes positive forms of motivation.

The rest of the paper is organized as follows. First, self-determination theory and an introduction to the engineering open-ended design projects are briefly reviewed in the background section. Methodology and experimental setup are described next, followed by results and discussion. The paper ends with conclusions and future work.

Background

Self-Determination Theory

Self-determination theory (SDT) [9, 17] suggests that different types of motivations may be described on a continuum ranging from autonomous (internal) to controlled (external) motivations. Intrinsic motivation, which is at one extreme, is a deeply internalized state of engagement based on interest, enjoyment, satisfaction and passion. On the opposite side of the spectrum lies amotivation, which is a state of impersonal or non-intentional action due to learners finding no value and no desirable outcomes in a learning activity. Identified regulation and external regulation lie in between the two extremes. Identified regulation is a state in which actions are based on an internal sense of self and perceived value, importance, or usefulness of a task, whereas, external regulation is a state of compliance with external pressure, prompted by contingent reward or punishment avoidance.

SDT also postulates that individuals will adopt more internalized/autonomous forms of motivations, resulting in more optimal learning outcomes, when three basic psychological needs are satisfied: autonomy, a sense of choice and control; relatedness, a sense of positive and supportive connections to others; and competence, a sense of mastery and self-efficacy [18].

In a real-world setting, individuals express multiple forms of motivation to varying degrees in any given activity, instead of appearing as either autonomous/internalized or controlled/externalized. Examining the learner's motivation across the whole continuum of amotivation, external regulation, identified regulation and intrinsic motivation, i.e., characterizing it into a motivational response profile [19-21], can provide diagnostic information and practical insights into course design that supports more positive student motivational responses.

Open-ended Design Project in Introduction to Engineering Course

The open-ended design project is a part of an Introduction to Engineering course, which is a freshman level 2-credit 15-week lecture and lab course consisting of 50-minute lecture and 2-hour 50-minute lab each week. Most students take this course during their first semester in college. The course aims to provide students with an introduction to engineering, covering the broad topics of the engineering design process, engineering modeling and drawing, teamwork, technical communication, project management and an entrepreneurial mindset. In addition, technical knowledge such as computer-aided design including 3D printing and programming a microcontroller is introduced to help students with their two multidisciplinary design projects, i.e., a well-defined project during the first half of the semester and an open-ended project during the second half. The course is a required course for students majoring in aerospace engineering, chemical engineering, electrical engineering and mechanical engineering. Occasionally there are students from other majors such as computer science and materials science. Students work in multidisciplinary teams in both lecture and lab throughout the semester.

The open-ended design project starts around week 6 of the semester. The project schedule is shown in Table 1 with the topics for each week highlighted. The first two weeks are conducted during 50-minute lectures. These ideation sessions are meant to help students identify project ideas they prefer to work on. In the third week, the project goes into full gear with students having about three hours to work on their project during lab each week. Note that during the entire project period, regardless of lecture or lab, there is little lecturing by the instructor. Instead, students engage in team discussion and hands-on work during most of class time. The activities for each week will be explained in detail next.

<u>Project Week 1</u>

During the pain point investigation lecture, students work in teams of four to brainstorm pain points that either bother themselves or bother other people. They are free to choose their pain points but need to satisfy requirements in the project "Theme", which will be explained in detail in the next section. Through discussion, they narrow down their pain points to a top three. For each of the three pain points, they write down a need statement using the Point of View (P.O.V.) Madlib [22], i.e., [User] needs to [user's need] because [surprising insight]. Students then start to collect information regarding each pain point to answer questions related to customers, current solutions, technologies and trends.

<u>Project Week 2</u>

During the information synthesis and opportunity identification lecture, students use a decision matrix to help them choose the pain point they would like to work on for their project. Students are then given a primer on interview preparation and how to conduct an interview. Next they work with their team to come up with a list of interview questions. Their homework is to conduct at least four interviews outside of class with a potential customer who experiences the pain point and record their findings.

Table 1. Open-Ended Design Project Schedule

Project Week	Lecture	Lab
1	Pain Point Investigation and Information Collection (worksheet, group discussion)	---
2	Information Synthesis and Opportunity Identification (worksheet, group discussion)	---
3	---	Problem Definition, Brainstorming and Solution Prototyping (worksheet, group discussion, hands-on building)
4	---	Design Decision and Project Management (worksheet, group discussion)
5	---	Proposal Presentation (oral presentation)
6-8	---	Construction & Testing (hands-on building)
9	---	Project Presentation and Demonstration (video, oral presentation and demo)

Project Week 3

Starting this week, students get to work on their project during lab. This week focuses on three tasks. The first task is a refined, detailed problem definition. Students are asked to share their interview findings with their team. They then expand their P.O.V. need statement into a story describing how a semi-fictional character experienced the pain point, his/her frustration, and the big insight. Finally, they synthesize their findings into a complete problem statement with need, objective, and requirements. The second task is for students to brainstorm solutions, aiming for 50 solutions during a 20-minute brainstorm session. Lastly, students are given one hour to pick their top three ideas, quickly prototype them and exchange feedback with peers.

Project Week 4

During this week's lab, students first summarize the feedback they receive for their prototypes from the previous lab. Afterwards, they choose a list of criteria to evaluate their prototypes and construct a decision matrix to pick their top design solution. They then plan on how to implement their top solution by creating a bill of materials and developing a Gantt chart.

Project Week 5

This week's lab is for proposal presentation. Each student team gives a 5-min presentation to pitch their project. Students are asked to use the Need, Approach, Benefits, Competition (NABC) template [23] to show how their solutions are different from current solutions and how their solutions would create value for customers. They also show their prototype sketch, material list, and estimated cost to demonstrate their project is ready for construction.

Project Week 6-8

These are project construction and testing weeks. Students are asked to complete a lab agenda each week to help them plan out the lab time. They are also asked to write a testing plan to test their prototype.

Project Week 9

Project demonstration and presentation is during this week, which is the last week of the course. Each team first shows their pre-recorded 2-minute video in the form of a sales pitch. After the video, each team then gives a short presentation and a live demonstration of their project prototype.

Methodology and Experimental Setup

The open-ended design projects were deployed in four Introduction to Engineering sections of about 40 students each in the fall semester of 2019. All four sections were taught by the same instructor. All course materials and assessment were kept the same for all sections except that each section was given a different project theme. The goal is to see if the restrictions on scope and/or materials would have any impact on student motivation. There were 140 students in total who consented to participate in the research study.

To test different open-ended design projects with varying degree of autonomy, different project themes were created. The common requirement for all projects was to "design an automated solution using Arduino or other microcontrollers to add economic, environmental and/or societal value." Beyond this common requirement, each project was given a different scope and a different material requirement as shown in Table 2.

The rationale behind the different project themes is as follows. One complaint from students taking the course in previous years is that they had trouble choosing projects because the project definition was too broad [7]. Therefore, it would be interesting to see if limiting the scope of the project would alleviate this problem. The university's memorial union (MU) was chosen because of its on-campus location and the variety of business and facilities inside. It would be convenient for students to walk over to the MU and interview customers if needed. The second consideration is project quality. There were projects from previous years that were overly simple, lacked originality and sophistication [7]. A gadget called NKK Smart Display™ [24] was incorporated in the project in the hope to spark creativity, since it has the capability to display different images or even videos in response to events such as button clicks or sensor readings.

To measure students' motivation, they were given a Situational Motivation Scale (SIMS) survey at the end of lecture or lab during each of the nine project weeks (Table 1). Scores for "intrinsic motivation", "identified regulation", "external regulation" and "amotivation" were calculated. A metric called self-determination index (SDI) [25] is also calculated, which is a type of overall score of the motivational response. It is defined as SDI = 2·(intrinsic motivation) + 1·(identified regulation) – 1·(external regulation) – 2·(amotivation). This single number is used to represent students' overall motivation by weighing subscale constructs according to their position on the self-determination continuum. The range of possible SDI scores is from -18 to 18, with higher scores indicating greater self-determination. A Basic Needs Satisfaction Scale survey was given at the end of the semester, which measures the degree to which three basic psychological needs of autonomy, relatedness and competence are satisfied. There is also a free response question in each survey to capture anything students want to share.

Table 2: Open-Ended Design Project Themes

Themes	Scope	Materials	Comment
	Design an automated solution to add economic, environmental and/or societal value.	Use Arduino or other microcontrollers.	This is the common requirement for all projects.
1	Design for any space such as home, campus building including dorm, office, retail, restaurant, hospital, library, and factory.	Use any sensors and actuators as needed.	This theme is broad in scope and has no restrictions on materials.
2	Design for the university's memorial union.	Use any sensors and actuators as needed.	This theme has limit in scope but no restrictions on materials.
3	Design for any space such as home, campus building including dorm, office, retail, restaurant, hospital, library, and factory.	Use any sensors and actuators as needed but must use a Smart Display™.	This theme is broad in scope but has restriction on materials.
4	Design for the university's memorial union.	Use any sensors and actuators as needed but must use a Smart Display™.	This theme has restrictions on both scope and materials.

Results and Discussion

Overall Motivation

There are 857 Situational Motivation Scale (SIMS) survey responses received from 140 students during the nine-week project period. Subscale mean values from the full dataset are shown in Fig. 1. On average, students in this study show low amotivation, moderate external regulation, high identified regulation and relatively high intrinsic motivation. The mean self-determination index is 4.78±0.38 (with possible range from -18 to 18). The shape of the curve in Fig. 1 is in between two motivational response profiles, i.e., "strongly motivated" and "moderately autonomous" described in [20]. Students on average experience a sense of interest and enjoyment doing their projects, but also rely on external control and internal regulation to guide their actions.

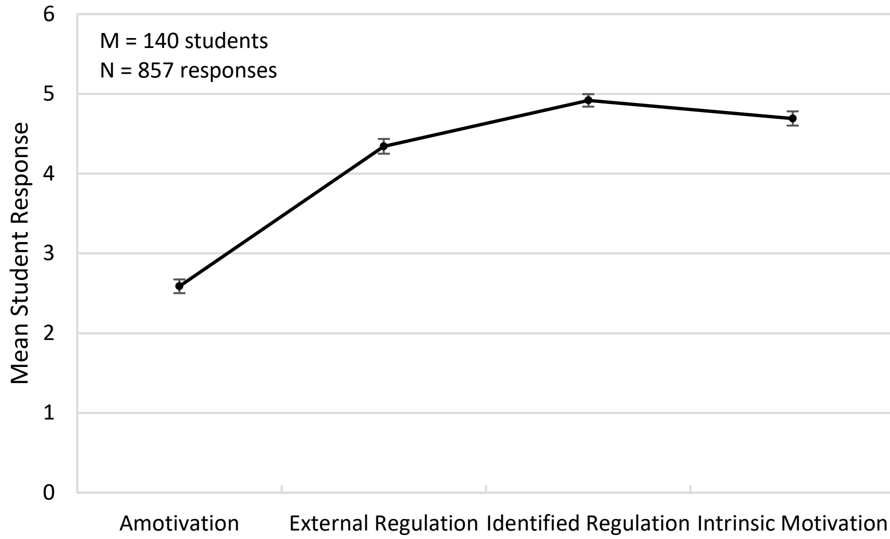

Figure 1. Situational motivation subscale responses from all students. Error bars show 95% confidence.

Motivation by Week

Figure 2 shows the weekly mean self-determination index from all students. The weekly activity is shown in Table 1. Although there is a large variation in each week's responses, the responses give a glimpse into the motivational journey students experienced throughout the project. Students start the project with high motivation. In the answer to the free response question in the survey, most find brainstorming project ideas with their team a fun experience. Many are excited about the idea of solving a real-world problem and adding value by using their creativity. Some worry about bringing a solution to life due to their little engineering experience so far. In week 2, there is a dip in motivation. Most students again find teamwork and discussion helpful. Some comment heated discussion within their team and difficulty reaching consensus. During week 3, there is an increase in motivation. Many say they enjoy the hands-on rapid prototyping activity. Week 4's planning activity such as coming up with a materials list gets some students excited. After week 5's proposal presentation, many students comment that they find sharing their ideas and seeing other students' ideas interesting. Week 6 is the first construction and testing week. There is a spike in student motivation. Many students share that they enjoy finally being able to begin building their project. During the Week 7's construction week, many report struggles, setbacks and trouble with coding, resulting in a decrease in motivation. Week 8 is the last construction and testing week. Some teams report their design starts functioning properly while others still struggle to get it to work. Week 9 is the presentation and demo day. Many reflect they enjoy growing together as a team, have fun building the project and learn a lot. Some complain about uncooperative team members and challenges of the project.

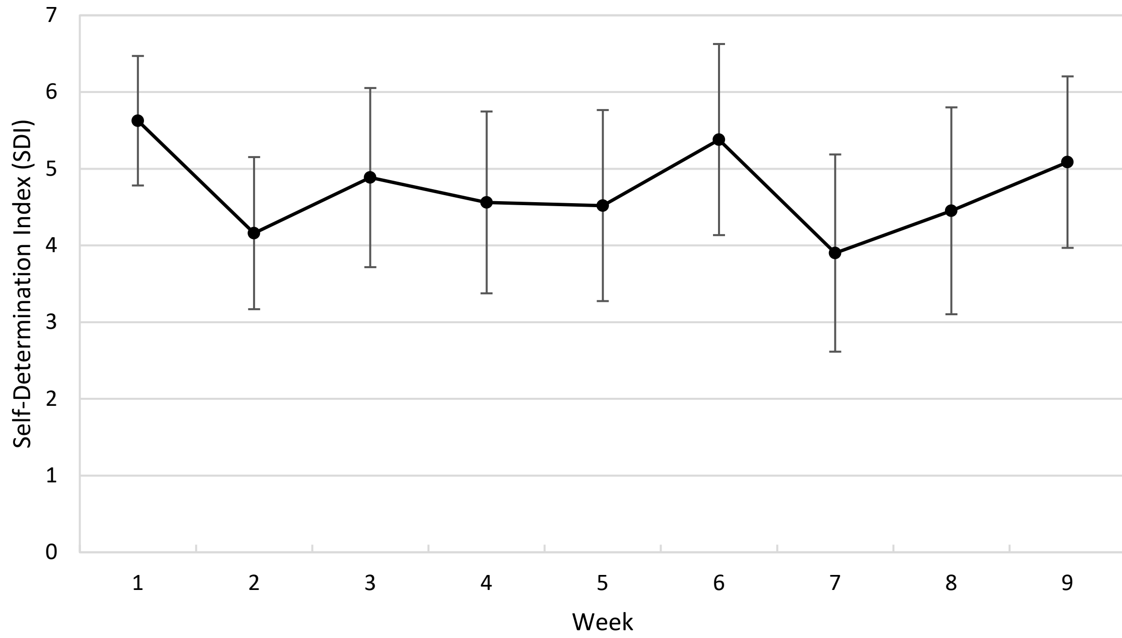

Figure 2. Mean self-determination index from all students spanning project weeks. Error bars show 95% confidence.

Motivation by Major

The introduction to engineering course enrolls students from different majors in the engineering school. Figure 3 shows the mean self-determination index across all majors. The variable M represents the number of unique students in each major that contributed to the survey and the variable N denotes the number of unique survey responses.

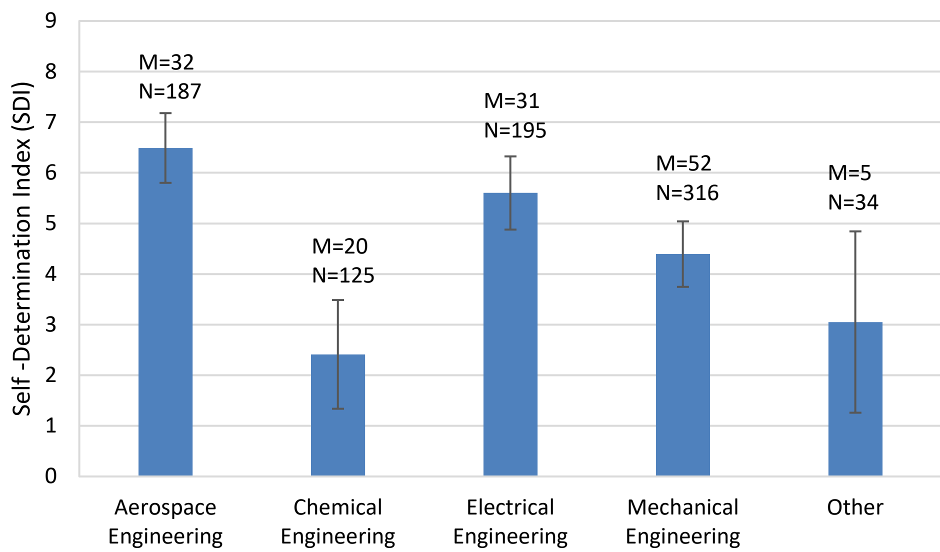

Figure 3. Mean self-determination index from different majors. Error bars show 95% confidence.

The figure shows aerospace, electrical, and mechanical engineering students experience more positive motivations compared to chemical engineering students. In the free response questions, chemical engineering students complain that the open-ended design project that emphasizes automation does not relate to their major.

Motivation by Project Theme

Situational motivation subscale mean values for the four project themes are shown in Fig. 4. The mean motivational response profiles are similar, although quantitative analyses from one-way ANOVA test and independent samples t-tests show statistical difference among the themes in Table 3.

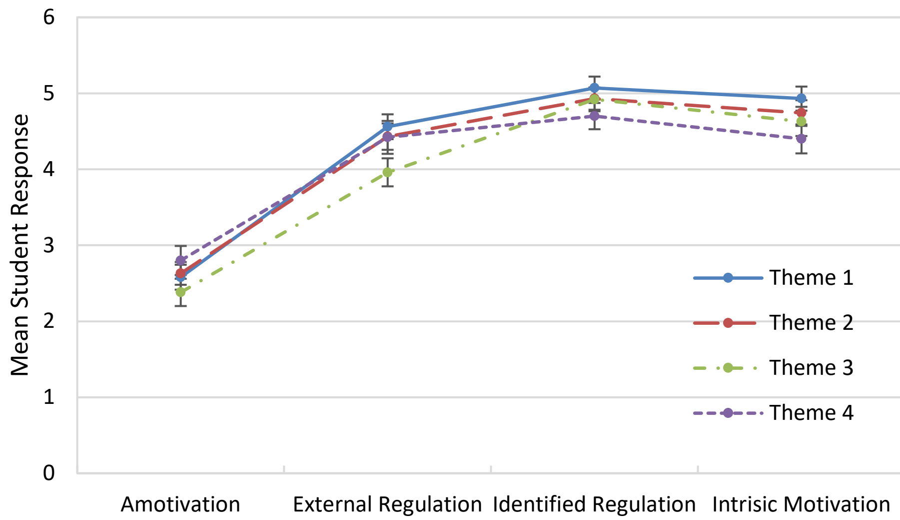

Figure 4. Situational motivation subscale responses across different project themes. Error bars show 95% confidence.

Table 3. Comparisons of SIMS subscale measures for the four project themes in Table 2. Between groups p-values are from independent samples t-tests. IM = Intrinsic Motivation, IR = Identified Regulation, ER = External Regulation, AM = Amotivation, ns = not significant.

	Theme 1 M=35 N=245		Theme 2 M=33 N=207		Theme 3 M=35 N=222		Theme 4 M=37 N=183		Between Groups p-value					
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**1-2**	**1-3**	**1-4**	**2-3**	**2-4**	**3-4**
IM	4.93	1.26	4.74	1.24	4.63	1.46	4.4	1.31	ns	0.02	0.00	ns	0.01	ns
IR	5.07	1.20	4.93	1.07	4.92	1.19	4.70	1.19	ns	ns	0.00	ns	0.05	ns
ER	4.56	1.30	4.43	1.27	3.96	1.40	4.42	1.49	ns	0.00	ns	0.00	ns	0.00
AM	2.58	1.31	2.63	1.10	2.38	1.36	2.8	1.32	ns	ns	ns	0.04	ns	0.00
SDI	5.20	5.00	4.72	5.22	5.47	6.34	3.47	5.91	ns	ns	0.00	ns	0.03	0.00

Specifically, the last row of Table 3 shows there is statistical difference in the mean self-determination index between any of Theme 1 (5.20), Theme 2 (4.72), Theme 3 (5.47) and Theme 4 (3.47). In other words, constraints on both scope and materials on the open-ended design project lead to lower student motivation compared to no constraints or only one constraint. This result confirms that more choice and control promote more positive motivation [10-13].

Motivation by Gender

Figure 5 shows the mean self-determination index from students with different genders across the four project themes. It is interesting to observe the four themes have relatively little impact on male students compared to a much larger impact on female students. The figure also shows that female students from the first three themes demonstrate higher self-determination compared to male students. Female students from Theme 4 experience negative SDI value, and it is most likely due to bad team dynamics based on their free form responses in the surveys.

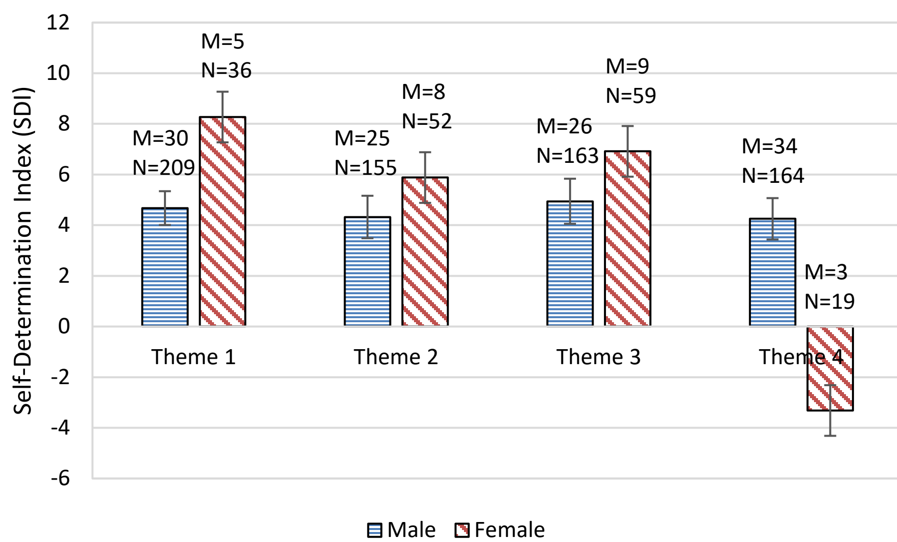

Figure 5. Mean self-determination index from different genders across different project themes. Error bars show 95% confidence.

Motivation by Ethnicity

Figure 6 shows the mean self-determination index from students with different ethnicities across the four project themes. Non-white students include Hispanic, Asian, Black, Native American and Middle Eastern students. Figure 6 does not show a clear pattern across the four project themes except that non-white students demonstrate more positive self-determination compared to white students in three out of four themes.

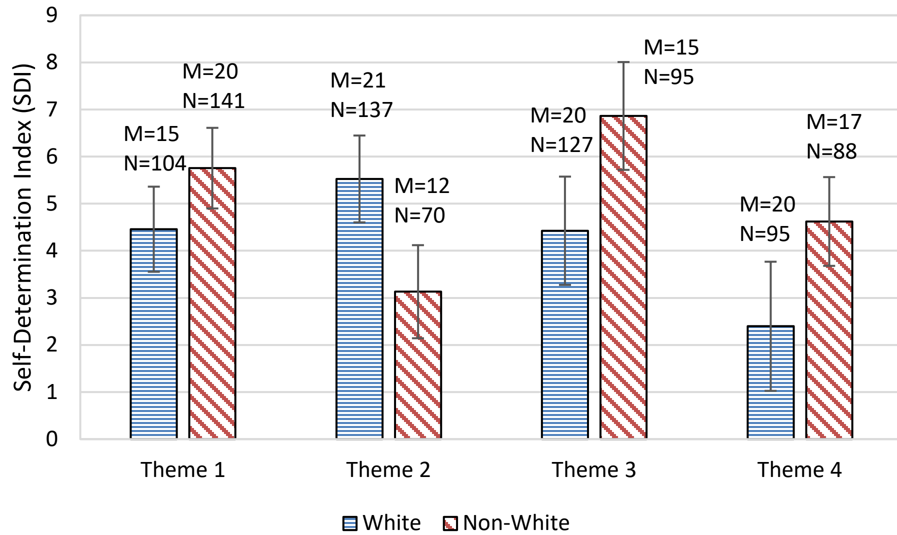

Figure 6. Mean self-determination index from different ethnicities across different project themes. Error bars show 95% confidence.

Basic Needs Satisfaction

The Basic Needs Satisfaction Scale (BNSS) survey was given at the end of the semester. The survey measures students' perceived level of autonomy, relatedness and competence, which are the three basic psychological needs that must be satisfied to support internalized motivations. Figure 7 shows the mean student response from different project themes.

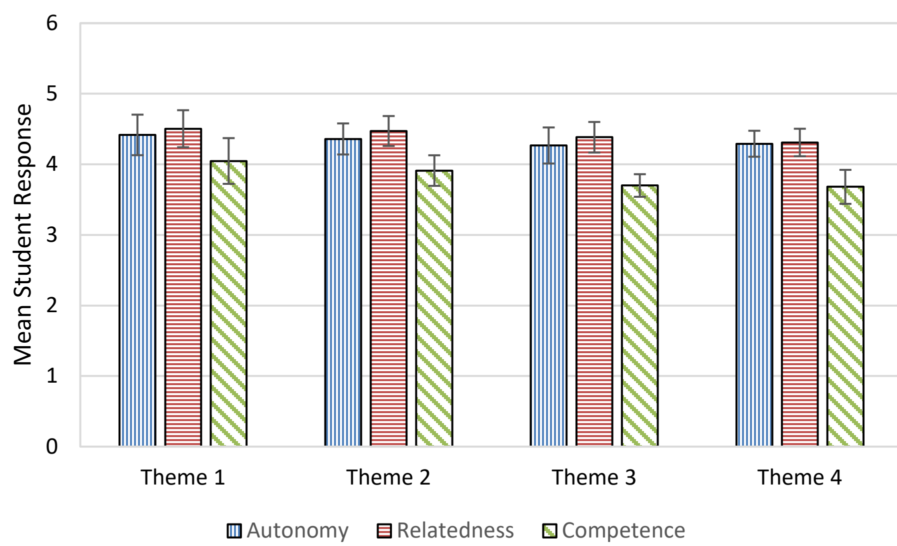

Figure 7. Basic needs satisfaction scale survey from different course sections with different project themes. Error bars show 95% confidence.

Table 4 shows the mean and standard deviation of student response from different project themes for easy comparison. A one-way ANOVA test was performed on each of the three basic need subscales among different themes and no statistically significant difference is found. However, based on the data collected, it is interesting to observe that students perceive very little difference in the autonomy subscale even though they are given different project restrictions. It is likely because all four themes, albeit differences in constraints, are still open-ended projects and students get to choose their project topic. The relatedness subscale is also similar across all themes since students engage in similar teamwork throughout the semester. The biggest difference is observed in the competence subscale. It is most likely because the SmartDisplay™ [24] required in Theme 3 and 4 is more difficult to learn how to program. This could be a factor negatively impacting the internalized motivation of the Theme 3 and 4 students.

Table 4. Comparisons of BNSS subscale measures for the four project themes in Table 2.

	Theme 1 M=N=26		**Theme 2 M=N=32**		**Theme 3 M=N=20**		**Theme 4 M=N=28**	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Autonomy	4.42	0.75	4.36	0.64	4.27	0.58	4.29	0.49
Relatedness	4.50	0.68	4.47	0.61	4.38	0.49	4.31	0.52
Competence	4.03	0.84	3.91	0.63	3.7	0.37	3.69	0.64

Conclusion and Future Work

The survey findings show that students doing the team-based hands-on open-ended design projects in the Introduction to Engineering course are "motivated" and "moderately autonomous". This confirms the research findings in [17] that active and student-centered learning associated with non-traditional pedagogy prompts more positive motivational responses compared to lecture-based traditional pedagogy.

This research also finds that out of the four configurations of the open-ended design projects, the free-choice one with the least constraints in scope and materials promotes more positive motivational responses compared to the one with the most constraints. This again confirms that autonomy engages more positive self-determination. Another interesting finding is that the different provisions of choice and control seem to have more dramatic impact on women than on men. In addition, competency may also play a role in determining the motivational responses of students.

The survey results also help to identify potential curriculum improvement in the future. For example, the open-ended design projects focusing on automation do not seem to motivate chemical engineering students. How to come up with remedies to reach this population is an urgent next step. The weekly motivation survey shows a dip during Week 2. How to modify activity during that week to keep students engaged is another future improvement. Given that the SIMS curve in Fig. 2 shows higher average amotivation and external regulation values compared to the "truly autonomous" profile in [20], identifying strategies to further motivate students is also an important future work.

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