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# Designing the Design Experience - Identifying Factors of Student Motivation in Project-Based Learning and Project-Based Service-Learning

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# Designing the Design Experience: Identifying Factors of Student Motivation in Project-Based Learning and Project-Based Service-Learning

**Abstract**
Grounded in motivation theory, this research evaluates how the context of project-based service-learning (PBSL) affects aspects of student motivation in a required undergraduate mechanical engineering course - *Component Design*. Our research aims to answer: 1) How does the context of service in project-based learning affect student motivation? 2) What factors are most influential on student motivation to persist in project-based learning experiences?

*Component Design* is a required project-based course that introduces junior mechanical engineers to fundamental machine design concepts. In spring 2011, the control group participated in a conventional project-based learning (PBL) experience – to build an aesthetically pleasing vehicle that could be powered by a cordless electric drill. In spring 2012, the treatment group participated in a PBSL experience - fabricating adapted tricycles for children in the community with physical disabilities.

We found that both the PBL and PBSL contexts sustained student motivation for the course and the project. Students in both cohorts began the course with relatively high values of interest, value, and expectancy for success. Students in both cohorts ended the course with relatively high values (and in some cases significant gains) of interest, value, and feelings of success in the course and the project. Students from both cohorts also reported relatively high indicators of course and project engagement.

The results also indicated that for students in the PBL control group the most significant predictor of motivation was their confidence in non-technical skills while for students in the PBSL control group, the most significant predictor was initial value of the course and the project. Initial course and project interest, skill confidence, prior knowledge of course topics, and prior experience in design projects were also among the most important predictors of motivation in both project contexts. Gender was *not* found to be a significant predictor of any motivation indicators.

## Introduction
We know from motivation theory that enhanced motivation in students is positively correlated with engagement, feelings of success, interest, value, and strong learning outcomes.[1-3] We know less about the types of instructional strategies and curricular interventions that work to enhance student motivation in a typical engineering course. Grounded in motivation theory, the purpose of this research is to evaluate how the context of project-based service-learning (PBSL) affects student motivation in a required undergraduate mechanical engineering course.

### *Project-Based Service-Learning*
PBSL is a form of active learning where students work on projects that benefit a real community or client while obtaining a rich learning experience.[4] Many engineering educators are embracing alternative instructional strategies like PBSL in an attempt to respond to major shifts in the

engineering profession and practice. Today's world is a global market and a place of rapid technological change. Newly graduated engineers often find themselves working in teams with people very different from themselves, where they must be ready to engage in more entrepreneurship and integrative thinking.[1, 5-6]

One example of incorporating PBSL into engineering curriculum is SLICE (Service-Learning Integrated throughout the College of Engineering) at University of Massachusetts Lowell, where all engineering students are exposed to service-learning in every semester.[4] Another example is EPICS (Engineering Projects in Community Service) at Purdue University, where students earn academic credit for participation in multidisciplinary design teams that solve technology-based problems for local non-profit organizations.[6] Extracurricular programs like Engineers Without Borders,[7] Engineers for a Sustainable World,[8] and Engineering World Health[9] provide other opportunities for engineering students to participate in service-based engineering while providing a direct benefit to a target community – most often in a developing or underdeveloped community outside the U.S.

Although PBSL opportunities are expanding at educational institutions nationwide, much of the findings on their impacts are anecdotal.[10-11] Some faculty have begun to assess PBSL programs and have found that PBSL does, in fact, cultivate stronger learning outcomes, entrepreneurship, cultural awareness, and community-mindedness. However, comprehensive and rigorous assessment methods have not yet been implemented.[10] Also, given that the number of students participating in PBSL activities may be small or unrepresentative of the undergraduate engineering student population at large, it is difficult to draw conclusions that can be generalized about this promising instructional strategy.

One of the main differences between PBSL and conventional project-based learning (PBL) is the addition of a community as a full partner. This added authenticity adds "real world complexity", causing the project outcomes to be less clear.[10] As described by Brescia, this challenges students to "use their functional skills related to technology along with their critical thinking and interpersonal skills to gain an understanding of the problems they must solve in their projects."[12] The integration of technical skills to dynamic environments challenges students to immediately apply and make sense of what they have learned in the classroom. This process has shown to promote four outcome areas, including: personal efficacy, awareness of the surrounding environment, personal value identification, and a greater engagement with the learning content.[13]

*Motivation Theory*
Motivation is a theoretical construct to explain the reason or reasons we engage in a particular behavior.[14] According to Brophy, students enter a "state" of motivation when their engagement in a particular activity is guided by the intention of acquiring the knowledge or mastering the skill that the activity is designed to teach.[15] Motivation produces thought, intention, and action; hence, it is of paramount concern to educators, who are constantly tasked with propelling students to learn, perform, and persist.

Fortunately, educators need not resign to the role of passive observers of students' motivational patterns. In fact, educators are active socialization agents capable of stimulating the general development of students' motivation to learn and its activation in particular situations.[15]

According to self-determination theory, people at their best have an innate inclination toward mastery, spontaneous interest, exploration, and curiosity. This *intrinsic motivation*, which is a type of motivation characterized by doing an activity for the inherent satisfaction of the activity itself, seems to be part of human nature; however, intrinsic motivation requires supportive conditions to persist.[16-17] Other motivation theories emphasize different (although related) conditions that support or thwart motivation. But, in general, supportive conditions include a person's feelings of autonomy, relatedness, and competence, accompanied by a sense of interest and value.

Student motivation to learn new information is also tied to student engagement in the learning process. Similar to motivation, the term *engagement* has been defined in several different ways. According to Barkley, students who are engaged in the learning process "really care about what they're learning; they want to learn" and they "exceed expectations and go beyond what is required." These statements reflect a view of engagement that is rooted in motivation theory. Barkley also describes student engagement with statements like "engaged students are trying to make meaning of what they are learning" and "engaged students are involved in the academic task at hand and are using higher-order thinking skills such as analyzing information or solving problems."[14] These statements relate engagement to *active learning*, which takes place when students are engaged in thinking tasks such as analysis, synthesis, and evaluation. Students are doing things and thinking about what they are doing.[18] Active learning can be facilitated by collaborative learning, undergraduate research, and problem-based learning activities, among other techniques.[19]

Essentially, student engagement is a product of motivation and active learning. The contexts of project-based learning and project-based service-learning fulfill the active learning portion of this relationship. However, before we can determine whether PBSL has an impact on student engagement, we must evaluate the extent to which PBSL affects student motivation to learn.

*Research Need*

As stated by Bielefeldt and Swan[10]: *"There is some indication that PBSL programs can help attract and retain a more diverse population of students in engineering. The popularity of these experiences with women and minorities is clear, but it is unclear if this leads to any overall benefits to recruiting or retention in engineering. There is virtually no quantitative assessment of the benefits of PBSL experiences to professional trajectory. It is not fully clear if companies view this as a way to attract and retain qualified engineers, value the unique skills developed in engineers with these experiences, etc. Therefore, the impacts in this area require further study."*

Hence, while there is evidence to support some of the benefits of PBSL, more rigorous research should be completed with control and treatment groups to elucidate some of the claims regarding its impacts. By more clearly understanding how PBSL impacts student motivation and engagement, practitioners can design more thoughtful project experiences. Lastly, from a research perspective, being able to identify factors of student motivation is useful in assessing project-based curriculum.

## Research Setting

This research is being carried out at the University of Colorado at Boulder over a span of two years. The research subjects are junior-level students in *Component Design*, a required Mechanical Engineering course that teaches fundamental design and analysis of mechanical components. A major aspect of the course is a semester-long design project that all students are required to complete in teams of five. In spring 2011, the control group (128 participants) engaged in a conventional PBL experience by designing and fabricating drill-powered vehicles. In spring 2012, the treatment group (127 participants) engaged in a PBSL experience by designing and fabricating adapted tricycles.

*Course Structure*

In spring 2011 and spring 2012, the course met two times per week for a 75-minute lecture with an additional weekly two-hour lab time. Lecture time consisted of a combination of mini-lectures, self-directed group workshop problems and videos to support the technical content. Homework was due weekly and included originally developed *real world* design problems. The semester-long project comprised 40% of each student's final course grade (in lieu of a final exam). Each team had a dedicated peer mentor, a senior Mechanical Engineering student who had previously taken Component Design, who helped his or her team run team meetings, prepare meeting agendas, answer design questions, and progress through the various stages of the design loop. Student teams also had access to the mechanical engineering machine shop with a dedicated staff member to assist with various fabrication tasks.

The stated learning objectives of both the drill-powered vehicle project and the adapted tricycle project were to:

- Learn professional skills essential for engineering, including project management, working in a team, and technical design report writing
- Plan and implement the stages of the design loop
- Learn how to practically apply course concepts
- Learn how to research information that is not explicitly given in a formal classroom setting

*PBL: Drill-powered Vehicle Project*

The challenge presented to the students was to design and build an aesthetically pleasing vehicle that could be powered by a standard cordless electric drill and driven by one of the team members. Other project requirements included:

- Height of the drill-powered vehicle and driver could be no more than 3’6”
- Driver had to complete a given obstacle course
- Select the chassis, the components, and the appropriate drill for the project – all within a $200 budget

Friendly competition was a major element of the project. The obstacle course, or run-off, served as the culminating event, where each team was evaluated on their vehicle’s functionality, height requirement, vehicle performance (course completion time and power-to-weight ratio), and vehicle safety. The run-off, held in the main quad outside the Engineering Center, was lively and well attended by approximately 75 additional students and faculty from engineering and other disciplines.

*PBSL: Adapted Tricycle Project*
The challenge presented to the students was to design and build adapted tricycles for children and young adults in the community who have physical disabilities. Each of these clients was assigned to five different teams who competed against each other to produce the best design for their client. To initiate the project, each student team conducted a needs assessment with their client's family and the client's physical therapist to identify their client's more specific needs, including the nature of the disability, range of motion and strength, movement patterns, and goals for mobility. Other project requirements included:

- Ensure safety and comfort
- Meet weight and size constraints
- Select the tricycle frame, gearing system, and all other components within a $300 budget (higher budget allotted for this project to make safety a priority)
- Deliver a functional prototype to the client

Similar to the drill-powered vehicles project, the culminating event of the adapted tricycle project was a design exposition where the teams presented their tricycles to faculty design judges and their clients. After test riding each tricycle, the clients selected their favorite design. With the help of several local non-profit organizations in the community, the remaining bikes were placed with other families.

Figure 1: Drill-powered Vehicle Run-off


Figure 2: Adapted Tricycle Design Exposition

**Methods**
*Study Design*
Assessment methods were chosen to account for the relationships among the input or *predictor variables*, the process (instructional context: PBL vs. PBSL), and the output or *response variables*. Figure 3 is a visual presentation of the predictor and response variables and their relationship to the learning context.

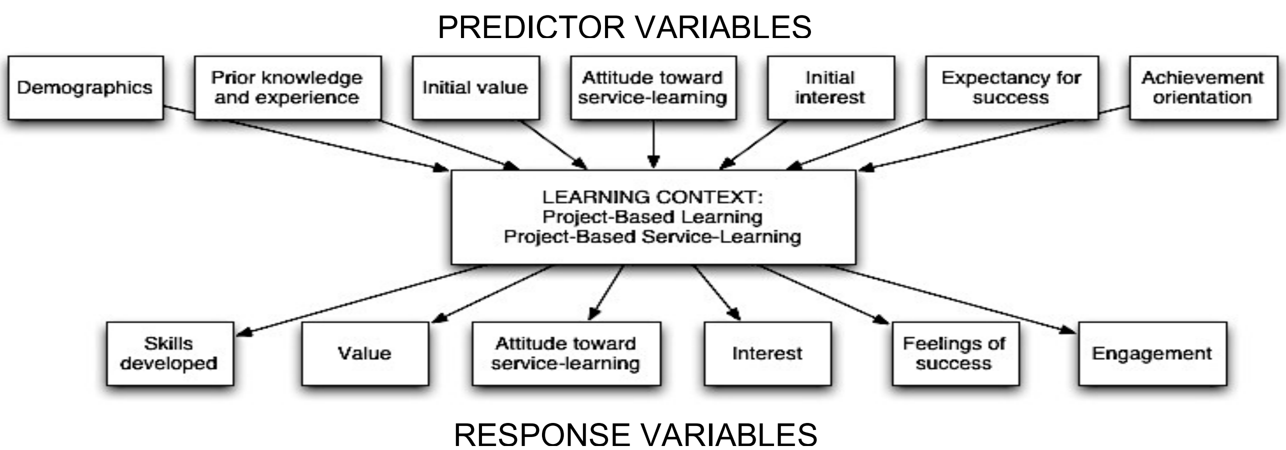


Figure 3: Predictor Variables, Learning Context, and Response Variables

Pre-course and post-course surveys were used to collect data to form the predictor and response variables. The surveys aimed to gather data about student baseline characteristics, changes in interest and value for both the course and the project, confidence in non-technical skills (i.e. technical writing, working with people who are not engineers, ability to meet the needs of a client, etc.), confidence in technical skills specific to Component Design, interest in service-learning, feelings of success in the course and project, and engagement.

The surveys were home-grown with a mix of original questions and questions adapted from previous achievement motivation research studies.[20-21] All of the students in the course were required to complete the surveys for a portion of their course grade. A description of the surveys is shown in Table 1.

Table 1: Survey Description and Timeline

| | Survey Administered | Data Collected |
|---|---|---|
| Pre-course survey | January 2011<br>(PBL Control group)<br><br>January 2012<br>(PBSL Treatment group) | Student demographics, prior knowledge and experience, initial value and interest, attitude toward service-learning, expectancy for success, achievement orientation, technical and non-technical skills (self-rated) |
| Post-course survey | May 2011<br>(PBL Control group)<br><br>May 2012<br>(PBSL Treatment group) | Indicators of motivation: sustained interest and value, feelings of success, attitude toward service-learning, feelings of engagement, and technical and non-technical skills gained (self-rated) |

*Data Analysis*

Each input and output variable was assessed on four point or five point Likert-type scales. The process of assessing gains and changes for each variable was carried out via Wilcoxon Rank-Sum, a non-parametric statistical hypothesis test for assessing whether one of two samples of independent observations tends to have larger values than the other and is appropriate for data that is not normally distributed. Tables 4 and 5 in the Appendix contain a more detailed description of the input and output variables.

Random forest analysis was used to estimate the importance of each input variable in predicting student motivation. The random forest algorithm provides an estimate of the importance of a variable by looking at how much the prediction error increases when a subset of the data is permuted while the rest is left unchanged.[22] For example, we may hypothesize that service learning is an important predictor of student engagement in the project. Every student can be partially categorized by this pair of variables. The random forest algorithm *scrambles* these variables in such a way so that one student's level of initial interest in service-learning is used to predict another student's level of engagement. If this process causes the predictor error to increase, it is an indication that initial interest in service-learning is an important predictor of student engagement.

**Preliminary Results**
Table 2 shows the mean and standard deviation for each of the response and predictor variables and the results of the Wilcoxon rank-sum hypothesis testing.

Table 2: Summary of hypothesis testing

| | **2011 Pre-course statistics N=92** | **2011 Post-course statistics N=92** | **2012 Pre-course statistics N=117** | **2012 Post-course statistics N=117** | **Results of Hypothesis Testing** **** denotes statistical significance at the 0.10 level*** ***** denotes statistical significance at the 0.05 level*** |
|---|---|---|---|---|---|
| **Interest: course** *(1=none, 5 = high)* | M = 4.39<br>SD = 0.634 | M = 4.55<br>SD = 0.634 | M = 4.34<br>SD = 0.629 | M = 4.42<br>SD = 0.921 | 2011 pre-post: p = 0.028**<br>2012 pre-post: p = 0.011**<br>2011/2012 pre-pre: p = 0.470<br>2011/2012 post-post: p = 0.621 |
| **Interest: project** *(1=none, 5 = high)* | M = 4.60<br>SD = 0.678 | M = 4.59<br>SD = 0.647 | M=4.52<br>SD=0.643 | M=4.56<br>SD=0.904 | 2011 pre-post: p = 0.901<br>2012 pre-post: p=0.010**<br>2011/2012 pre-pre: p=0.073*<br>2011/2012 post-post: p=0.504 |
| **Value: course** *(1=none, 5 = high)* | M = 4.86<br>SD = 0.406 | M = 4.72<br>SD = 0.432 | M=4.78<br>SD=0.475 | M=4.40<br>SD=0.859 | 2011 pre-post: p = 0.000**<br>2012 pre-post: 0.000**<br>2011/2012 pre-pre: p =0.134<br>2011/2012 post-post: p =0.007** |
| **Value: project** *(1=none, 5 = high)* | M = 4.79<br>SD = 0.481 | M = 4.68<br>SD = 0.487 | M=4.70<br>SD=0.606 | M=4.57<br>SD=0.912 | 2011 pre-post: p = 0.006**<br>2012 pre-post: p = 0.267<br>2011/2012 pre-pre: p = 0.252<br>2011/2012 post-post: p = 0.501 |
| **Confidence in technical skills** *(1=none, 5 = high)* | M = 2.82<br>SD = 0.752 | M = 4.23<br>SD = 0.454 | M=2.79<br>SD=0.651 | M=4.15<br>SD=0.546 | 2011 pre-post: p = 0.000**<br>2012 pre-post: p = 0.000**<br>2011/2012 pre-pre: p = 0.725<br>2011/2012 post-post: p = 0.444 |
| **Confidence in non-technical skills** *(1=none, 5 = high)* | M = 3.84<br>SD = 0.532 | M = 4.10<br>SD = 0.545 | M=3.80<br>SD=0.505 | M=4.01<br>SD=0.514 | 2011 pre-post: p = 0.002**<br>2012 pre-post: p = 0.002**<br>2011/2012 pre-pre: p = 0.691<br>2011/2012 post-post: p = 0.232 |
| **Expectancy for Success: Course** *(1=none, 5 = high)* | M=4.37<br>SD= 0.704 | | M=4.43<br>SD=0.606 | | 2011/2012 pre-pre: p = 0.700 |
| **Expectancy for Success: Project** *(1=none, 5 = high)* | M=4.53<br>SD=0.565 | | M=4.44<br>SD=0.607 | | 2011/2012 pre-pre: p = 0.298 |
| **Indicators of Engagement** *(1=least, 4 = greatest)* | | M=2.85<br>SD=0.563 | | M=2.83<br>SD=0.577 | 2011/2012 post-post: p = 0.861 |
| **Feelings of Success: Course** *(1=none, 5 = high)* | | M= 4.43<br>SD=0.663 | | M=4.25<br>SD=0.709 | 2011/2012 post-post: p = 0.077* |
| **Feelings of Success: Project** *(1=none, 5 = high)* | | M= 4.47<br>SD=0.982 | | M=4.67<br>SD=0.509 | 2011/2012 post-post: p = 0.390 |
| **Interest in Service-Learning** *(1=none, 5 = high)* | M = 3.85<br>SD = 0.954 | M = 3.96<br>SD = 0.903 | M=3.93<br>SD=0.831 | M=4.37<br>SD=0.822 | 2011 pre-post: p = 0.461<br>2012 pre-post: p = 0.000**<br>2011/2012 pre-pre: p = 0.680<br>2011/2012 post-post: p = 0.000** |

Table 2 illustrates the following trends:

- INTEREST: a significant increase in pre to post interest in the course in both 2011 (p=0.028) and 2012 (p=0.011). Concerning the project, there was a pre to post interest gain in the project in 2012 but not in 2011. There were no significant differences between the cohorts in pre or post levels of interest in the project or the course.

- VALUE: a significant decrease in pre to post value of the course in both years (p=0.000, 2011 and p=0.000, 2012) as well as a significant difference between post-course levels of value (p=0.007, with students in 2012 reporting lower value). In terms of the project, there was also a significant pre to post decrease in value of the project in 2011 (p=0.006) but not in 2012 (p=0.267). There was no significant difference between the years for pre-course levels of value for the course or the project.
- SKILL CONFIDENCE: a significant increase in both technical (p=0.000, 2011 and p=0.000, 2012) and non-technical (p=0.002, 2011 and p=0.002, 2012) skill confidence for both years. There were no significant differences between the cohorts in terms of pre-course or post-course skill confidences.
- EXPECTANCIES FOR SUCCESS: no significant differences between the two cohorts in terms of the course or the project.
- FEELINGS OF SUCCESS: a significant difference in students' post-course feelings of success in the course between the two cohorts (p=0.077, students in 2011 reported greater feelings of success in the course). There was not a significant difference between the cohorts in students' post-course feelings of success in the project.
- ENGAGEMENT: no significant difference between the two cohorts in terms of indicators of engagement.
- INTEREST IN SERVICE-LEARNING: no significant difference in initial interest in service-learning between the two cohorts However, there was a significant increase (p=0.000) in the pre to post interest in service-learning for the 2012 cohort.

Table 3 shows the variable importance results from the random forest analysis. Overall, the most important variable for predicting motivation in the PBL control group was *non-technical skills* (appearing as a significant predictor four times in Table 3). For the PBSL treatment group, the most important variable for predicting motivation was a tie between *initial value* of the course and *initial value* of the project (both appearing as significant predictors four times in Table 3). Table 3 also shows similarities between the cohorts in terms of variable importance. For example, *initial project value* appeared as a significant predictor of *engagement* for both cohorts, *non-technical skills* appeared as a significant predictor of *feelings of success* in the course, and so on.

Table 3: Variable Importance (PBL Control Group and PBSL Treatment Group)

| Response variable | Top three predictors for each response variable 2011 | Top three predictors for each response variable 2012 |
|---|---|---|
| **Engagement** | **1. Initial project value**<br>2. Initial course interest<br>3. Achievement orientation | 1. Non-technical skills<br>**2. Initial project value**<br>3. Initial course value |
| **Feelings of success in course** | 1. Initial project experience<br>**2. Non-technical skills**<br>3. Technical skills | **1. Non-technical skills**<br>2. Initial course experience<br>3. Initial course interest |
| **Feelings of success in project** | **1. Technical skills**<br>2. Non-technical skills<br>**3. Initial project experience** | 1. Underrepresented minority<br>**2. Technical skills**<br>**3. Initial project experience** |
| **Final interest in course** | 1. Non-technical skills<br>2. Initial project value<br>3. Initial course experience | 1. Initial course value<br>2. Initial course interest<br>3. Achievement orientation |
| **Final interest in project** | 1. Initial course experience<br>**2. Initial project interest**<br>3. Non-technical skills | **1. Initial project interest**<br>2. Initial course value<br>3. Initial project value |
| **Final value of course** | **1. Initial project value**<br>2. Initial project experience<br>3. Non-technical skills | 1. Initial course value<br>**2. Initial project value**<br>3. Initial project interest |
| **Final value of project** | 1. Initial interest project<br>2. Initial course experience<br>3. Initial course interest | 1. Initial project value<br>2. Technical skills<br>3. Achievement orientation |

## Conclusions

Overall, we found both project contexts to be effective at maintaining student motivation for the course and the project. Students in both cohorts began the course with relatively high values (and no statistically significant differences between these initial values) of interest, value, and expectancies for success. Students in both cohorts ended the course with relatively high values (and in some cases significant gains) of interest, value, and feelings of success in the course and the project. Students from both cohorts also reported relatively high (and statistically equivalent) indicators of course and project engagement.

We were surprised to see decreases in students' value. It's important to note that students in both cohorts began the semester with extremely high levels of value for the course and the project; hence there was greater potential for value to decrease than to increase. However, it is encouraging that both project contexts were effective in helping students strengthen certain technical and non-technical skills. Lastly, both cohorts began the course with statistically equivalent levels of interest for service-learning. The 2011 cohort did not show a statistically significant gain in interest; however the 2012 cohort's interest in service-learning did increase significantly.

By comparing and contrasting the projects in terms of students' interest, value, skill development, feelings of success, and preference, we were able to draw important conclusions about the impact of PBSL on student motivation. Perhaps our most insightful finding is that the service context, when considered in isolation, did not seem to have a significant impact on student motivation as compared to the conventional project context. This finding suggests that the *design* of a project-based learning experience itself may have a greater impact on motivation than the project context. We would expect a well-designed PBL experience to have a thoughtful driving question (one that is relevant to students and that serves as a vehicle for learning the course concepts), opportunities for students to develop a variety of skills, and that is facilitated by the professor in a way that provides students with a balance of structured guidance and autonomy.

**Future Work**

The last phase of this research will include a qualitative analysis of focus group data. Three 60-minute focus groups were held with students from both the PBL control group and the PBSL treatment group one week after the culmination of each semester's project. Approximately six students per group were in attendance, and participation in the groups was voluntary. The aim of the qualitative analysis will be to more deeply understand aspects of both the course and the project that were most and least valuable to the students, how students' interest in Component Design changed over the course of the semester, the specific technical and non-technical skills that were gained from the project, how the project impacted students' excitement, and the types of challenges students encountered while working on a team.

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## Appendix

Table 4: Description of Predictor Variables

| Predictor Variables | Description |
|---|---|
| Achievement orientation | The motive behind a student's desire to excel. Conceptualized as a relative stable personality trait[23] |
| Attitude toward service-learning | Student's level agreement that community service and academic coursework should be combined |
| Expectancy for success in course | Student's confidence in successfully learning the course material |
| Expectancy for success in project | Student's confidence in succeeding in the course project |
| Gender | Gender of student |
| Initial course experience | Student's previous experience with Component Design course topics |
| Initial project experience | Student's previous experience with Mechanical Engineering design projects |
| Initial course interest | Incoming interest for Component Design course topics |
| Initial project interest | Incoming interest for Mechanical Engineering design projects |
| Initial interest in service-learning | Incoming interest in combining community service with academic coursework |
| Initial course value | Perceived value of Component Design course topics |
| Initial project value | Perceived value of Component Design course project |
| Non-technical skills | Student's self-rated level of non-technical skills such as technical writing, ability to identify needs of a client, ability to work with non-engineers, etc. |
| Technical skills | Student's self-rated level of technical skills specific to Component Design |
| Underrepresented minority | Student identifies as African American, Hispanic, or Native American |

Table 5: Description of Response Variables

| Response Variables | Description |
|---|---|
| Engagement | Students' perception of how often they participated in class discussions, interacted with the professor, helped a peer understand course material, etc. |
| Feelings of success in course | Students' feelings of successfully learning the course material |
| Feelings of success in project | Students' feelings of successfully completing the course project |
| Final interest in course | Sustained interest in Component Design course topics |
| Final interest in project | Sustained interest in Mechanical Engineering design projects |
| Final value of course | Sustained value of Component Design course topics |
| Final value of project | Sustained value of Component Design course project |