

# APPLYING AN OPTIMIZATION MINDSET TO ENGINEERING EDUCATION: JUNIOR LEVEL COURSE PROJECT CASE STUDY

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## INTRODUCTION

What is the “best” way to educate students? There doesn’t seem to be a “one size fits all” answer. Thousands of educational theories have been proposed, each with its own unique benefits and drawbacks. In addition, the diverse and evolving needs/backgrounds of different students, subjects, and faculty members demand an ever-changing approach to teaching. We propose that using the principles of optimization and engineering design while creating course materials can enable instructors to develop an educational experience customized to their program, teaching style, and the needs of their students. In this paper we will present our experience applying this mindset to redesign a junior level chemical engineering project.

The key to any optimization problem is to clearly specify and understand the objective, the constraints, and the primary variables that affect the objective.<sup>[1]</sup> In this work the general objective of education is defined broadly as helping students develop skill sets that will enable success in their career and in life. We define success as engagement in the workplace and overall wellbeing (emotional, mental, social, and physical).<sup>[2]</sup> Analyzing the results of long-term studies,<sup>[2]</sup> we have identified the following three key attributes that contribute to student success:

- 1) Scholarship<sup>[3,4]</sup>
- 2) Citizenship<sup>[5-7]</sup>
- 3) Leadership<sup>[2,6]</sup>

The primary constraints of higher education are generally defined in this study as:

- 1) Time
- 2) Financial Resources
- 3) Student/Faculty Motivation

In this study we consider both the constraints and current best practices toward the objective of obtaining long-term student success as applied to an engineering course group project experience. Specifically, efforts to maximize the specific

outputs of student scholarship, leadership, and citizenship development within our constraints of student/faculty time, financial resources, and motivation are reported (detailed in Figure 1 later in this work).

This work is inspired by the senior author’s early group project experiences that developed scholarship but were not as engaging or helpful in integrating citizenship and leadership opportunities in a natural way. It is important to note that prior studies have reported multiple different approaches to group projects<sup>[8]</sup> with divergent efficacies due to the innate differences in instructors/students and in the definition of success. As such, we do not pretend to create an all-encompassing,



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ideal teaching and learning environment. However, we find great value in applying an optimization mindset (e.g. focusing on the constraints and objectives while working toward improvement) to help individual instructors as they continually work to improve the educational framework for their students.

## STUDY OBJECTIVES, APPROACHES, AND CONSTRAINTS

### Optimization Objectives and Approaches

In this study the first optimization output was scholarship, defined as the development of knowledge, attitudes, and skills. This definition is supported by a thorough study that tied program success to these three student attributes.<sup>[3]</sup> In this study scholarship was defined as helping students develop their long-term retention of key engineering competencies (knowledge) and increase their excitement and engagement (attitude) in problem solving (skills). Bloom's taxonomy proposes that the highest level of learning occurs when there is creation.<sup>[9, 10]</sup> Thus, to help students develop their long-term retention of core engineering competencies, we wanted to give them an opportunity to create. In addition, the process of teaching complex engineering concepts simply and concisely was integrated into the experience as teaching is reported to enhance long-term retention.<sup>[11]</sup> To foster excitement and engagement in the learning process, students were given greater autonomy to increase intrinsic motivation, as the two are reported as linked.<sup>[12]</sup> The holistic focus on citizenship and leadership in the context of a service learning opportunity also provided a chance to increase intrinsic motivation as service and leadership responsibilities have been linked to greater excitement and motivation.<sup>[5, 13-16]</sup> Finally, to increase problem solving skills, the integration of the engineering design cycle in student projects was encouraged.<sup>[17-19]</sup> To facilitate creation, autonomy, and use of the engineering design cycle, a project-based learning environment rather than problem-based learning environment was chosen.<sup>[20]</sup>

The second optimization output of this study was citizenship. Specifically, we sought to provide students the opportunity to serve their community and consider what is truly important and meaningful in life. In general, students intrinsically desire to serve others, as demonstrated by volunteer trends of students.<sup>[7]</sup> However, college education is naturally an intensive and self-focused time in life that doesn't always facilitate reaching beyond oneself. To address this, students were given the opportunity to serve the community through service learning.<sup>[21]</sup> Service learning has been shown to have significant positive effects on students, such as improving academic performance (including improved GPA, writing skills, and critical thinking skills), increasing self-efficacy, improving interpersonal skills, and encouraging participation in service after college.<sup>[5, 22]</sup> To facilitate service learning,

students presented engineering demonstrations/adventures at a BYU STEM program that annually brings in over one thousand K-12 students as part of National Engineers Week. In addition, final projects were posted online to allow K-12 teacher access to broaden access to educators (<http://bundy.byu.edu/outreach>).

The third optimization output was developing the students' capacity for leadership, an essential characteristic for impactful workplace engineers<sup>[23]</sup> that has a positive effect on wellbeing.<sup>[2, 24]</sup> Divergent and innate student attributes and personality traits result in a wide range of leadership aptitudes and weaknesses within a student population. As such, an adaptive system is required to meet the needs of all students. It has been shown that individual goal setting is effective in enhancing personal development.<sup>[25]</sup> Thus, we implemented the setting of leadership goals, their post-project evaluation, and post-project goal resetting to encourage the continual focus on and enhancement of student leadership. We chose an autonomous team setting to further allow students to practice leadership skills and meet their goals. Team settings also provide an opportunity for cooperative learning, which is considered a successful learning strategy.<sup>[26]</sup> Researchers have reported that, despite the possible disadvantages of group projects (including the opportunity for students not to participate and the possibility that it is always the same students who take the leadership opportunities), group projects are an overall effective teaching method for project based learning.<sup>[27, 28]</sup>

### Optimization Variables/Constraints

The first constraint was time. Assuming the learning activity is one that has been shown to be effective for learning, increasing the time spent on that activity typically leads to increased retention.<sup>[29]</sup> However, there is a cost in student wellbeing if we "rob" time beyond that allotted to the course (typically 3-4 hrs per credit hour each week). The biggest barrier to having balance in life is overbooking oneself beyond time available.<sup>[30, 31]</sup> It has been shown that balance in life leads to success,<sup>[32]</sup> and excessive stress can have negative effects on wellbeing.<sup>[31, 33]</sup> Overbooking commonly leads to sleep deprivation, which is correlated with lower academic performance.<sup>[34]</sup> To help set students up for success, time spent on the project was limited to the course allotment by providing class time and reducing homework requirements. This prevented the temptation of creating a short-term learning gain in the course while reducing overall learning and gains in other courses or encouraging a lifestyle that is not conducive to long-term student success. In addition, the project was scheduled in the middle of the semester when other courses did not have a high demand on student time.

The second constraint was financial resources. Thus, financial demands were minimized to ~\$25/student group. A limited budget had the added benefit of necessitating increased

student ingenuity and resourcefulness while providing a context for expectations that helped overachieving students overcome temptations to allocate more time and resources to the project than intended.

The final defined constraint was the students' engagement and motivation. While external motivators (grades) are often the primary motivators in an educational setting, we desired to help the students find intrinsic motivation, as intrinsic motivation has been linked to greater educational success.<sup>[35]</sup> Minimizing external motivators while still having the presence to encourage completion of the project required a balance of how heavily weighted the assignment was and how the project would be graded. Maximizing internal motivation required designing a task that the students would be inherently motivated to complete. According to the National Research Council, intrinsic motivation to complete a task is a balance of the difficulty of the task (difficult enough to be engaging but not so difficult as to be frustrating), social opportunities (ability to contribute something to the benefit of others), and the ability to see the usefulness of the task (how it is of benefit to themselves or others).<sup>[36]</sup> To optimize intrinsic motivation, the presence of each of these three elements was included in the project structure and definition: (1) The ability to design and create something that communicated difficult concepts in simple ways allowed for balance in difficulty, (2) working in teams and serving the community provided meaningful social opportunities, and (3) application of learned principles to "real world" situations and the opportunity to provide community service using those same principles provided an increased capacity to see the usefulness of the task.

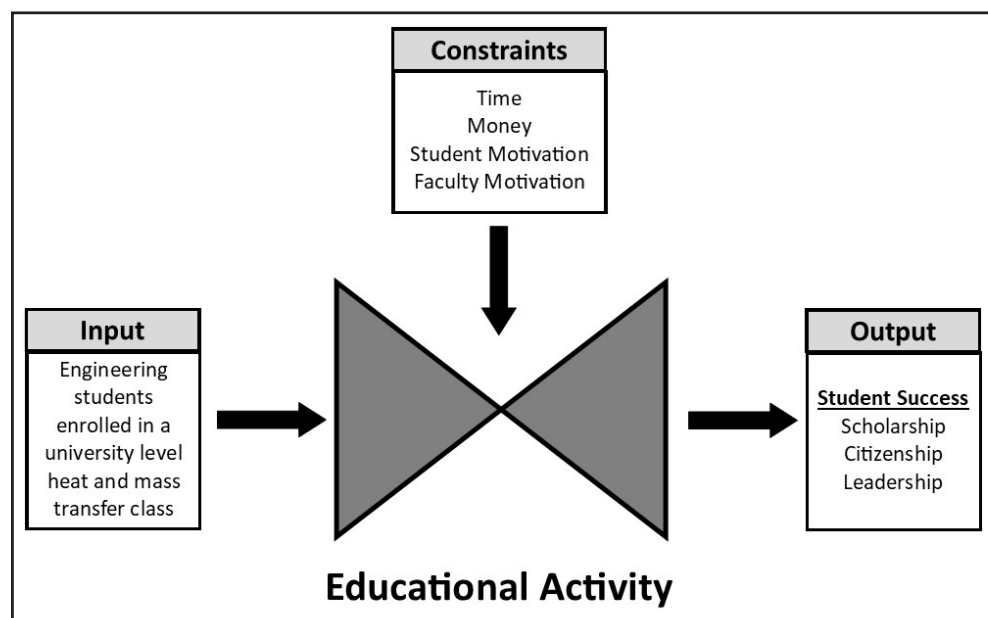
## PROJECT DESIGN/METHOD

Combining the above defined variables and constraints toward our educational objective resulted in an optimization "function" for educational enhancement (Figure 1). Consideration of each component of this function led us to assess the impact of an engineering group project that was focused on service learning, leadership development, and academic depth while not "robbing" time from other student activities, requiring minimal financial resources, and engaging student intrinsic motivation.

Specifically, in a Junior level Heat and Mass Transfer course, students were invited to work in teams and limited to 10-15 hours (per individual) during the semester to create a demonstration or hands-on "learning adventure" to teach K-12 students principles of heat and mass transfer. Students were encouraged to achieve K-12 student engagement using as many senses as possible. The engineering students would then share their curriculum with over a thousand K-12 students and provide instructions for teachers to implement the demonstrations in their classrooms. To reduce extrinsic motivation, the project contributed only a small percentage of the overall class grade (less than 10%). Additionally, topic selection was left open to any concept of heat or mass transfer if the university's risk management team approved the project for safety. Teamwork and leadership training are integrated into prior chemical engineering courses, making the requirement that students focus on these soft concepts during the project organic. The project was completed by approximately 250 Junior level chemical engineering students at Brigham Young

University over a three-year period from 2011-2013 (see Figure 2).

During the course of the study, approximately 130 of the 250 students provided feedback via a survey taken upon completion of the project. Because abstract characteristics are difficult to measure (including those of knowledge, citizenship, leadership, and motivation), a set of 14 "indicators" was selected. Each indicator was expressed as a statement and, upon completion of the project, a survey was given to each student with a series of these indicator statements to evaluate different parts of the project. The students were asked to rate each statement



**Figure 1.** Engineering Education Mindset: Flow diagram illustrating this study's optimization input, outputs, and constraints.





**Figure 2.** Heat and mass transfer “learning adventures” being taught by Junior level chemical engineering students to K-12 students.

on a scale from 1 to 8, the numbers representing the following: 8 – very strongly agree, 7 – strongly agree, 6 – agree, 5 – somewhat agree, 4 – somewhat disagree, 3 – disagree, 2 – strongly disagree, 1 – very strongly disagree. The indicator statements and survey results are listed by series in Figures 3-7).

## RESULTS AND DISCUSSION

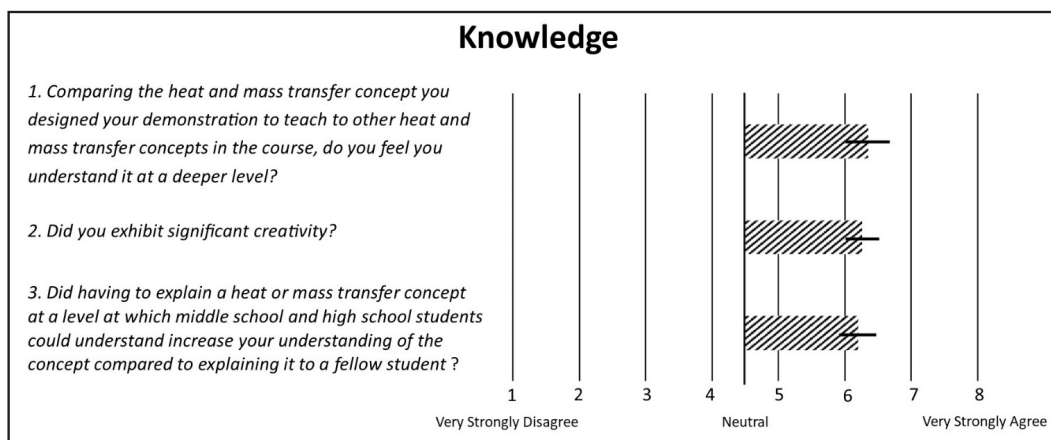
The long-term ramifications of such an experience are extremely difficult to ascertain at this stage; however, by applying approaches that have been shown through long-term studies to have long-term impacts on student career and well-being success,<sup>[2, 5, 6]</sup> it is our hope that we increase, to some degree, a student’s probability for success. As detailed below, students responded very positively to the experience created by the optimization mindset described in the previous section.

When evaluating student perception of knowledge, students agreed that the engineering concepts demonstrated in their project were understood at a deeper level than other concepts of the course (Figure 3, Question 1). Students also reported that the project fostered creativity (Figure 3, Question 2), which is an important part of engineering education<sup>[9, 10]</sup>. In addition, students felt that explaining the concept at a level middle school students could understand increased understanding beyond just explaining to a fellow student (Figure 3, Question 3).

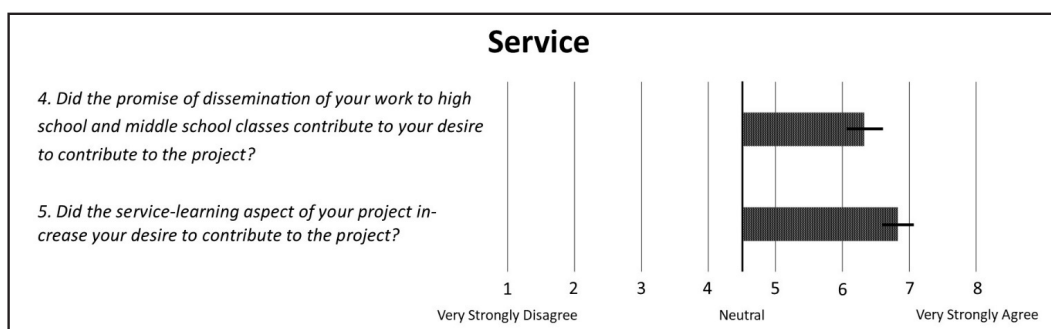
Results from the survey also indicate that service learning was a good model to increase student motivation. Students felt that the service learning aspect of the project increased their desire to contribute (Figure 4, Question 4). The survey also indicated that the promise of dissemination of work to high school and middle school classes increased the student’s desire to contribute to the project (Figure 4, Question 5).

Students felt less strongly about the leadership benefits of the experience. They felt that setting leadership goals during the project was an effective way to improve leadership skills (Figure 5, Question 8), and meeting with and discussing leadership goals with other students was an effective way to improve leadership skills (Figure 5, Question 7). They also reported that two months after the project, the students remembered the goals they worked on and new goals they set (Figure 5, Question 6). The responses averages were between “agree” and “somewhat agree,” which leaves room for improvement in our optimization of developing an environment to strengthen leadership skills. Since the completion of this study, the senior author has sought to remind students more often of their leadership goals and remind students that this is an opportunity to develop leadership skills that will help them in their career that will begin in ~18 months.

The constraints of the experience were also assessed. When considering the timing of the project, students were



**Figure 3.** The average of the students' responses to the knowledge output survey questions is reported by the bars. Please note that the bars initiate at the neutral score of 4.5 and terminate at the average response value. The black line centered on the average response represents the 95% confidence interval.



**Figure 4.** The average of the students' responses to the service output survey questions is reported by the bars. Please note that the bars initiate at the neutral score of 4.5 and terminate at the average response value. The black line centered on the average response represents the 95% confidence interval.

also neutral on whether the mid-semester timing of the project limited the scope of project ideas (Figure 6, Question 9). Students were also fairly neutral in their preference for moving the project earlier or later in the semester, with a slight preference for the time selected (Figure 6, Question 10). Overall, students reported spending an average of eight hours during the semester on the project, with a mode of ten hours, which was our original objective. Most importantly, students reported that the project was an effective use of their time (Figure 6, Question 11).

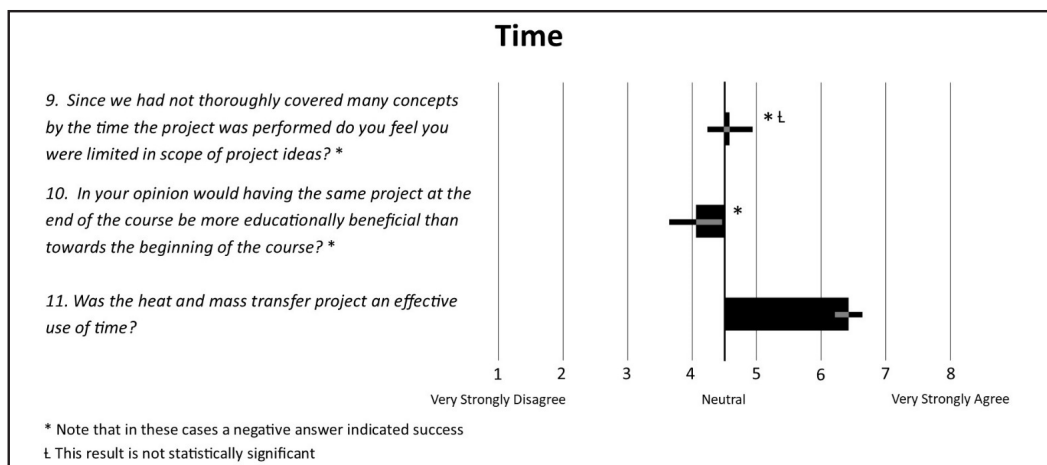
Finally, the results for increasing students' perceived motivation and engagement were also encouraging. Students reported that they were not overly concerned about their grades during the project (Figure 7, Question 13), which was a goal of the project to help facilitate intrinsic motivation. Additionally, students strongly agreed that they had autonomy when performing the project and that the project was more enjoyable compared to projects in other courses (Figure 7, Questions 12 and 14).

## CONCLUSIONS AND RECOMMENDATIONS

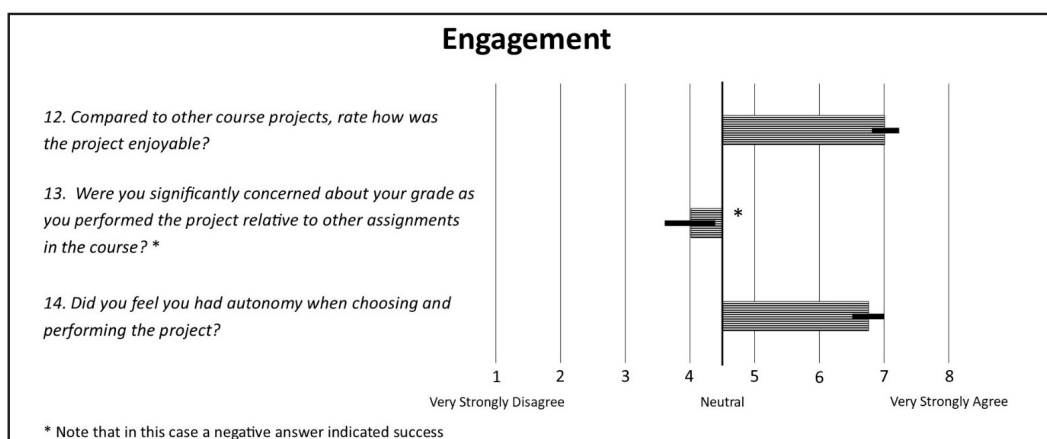
Based on student responses, applying an optimization mindset enabled a successful project experience that enhanced retention, citizenship, and leadership while operating inside higher education's constraints of time, financial resources, and participant motivation. Our results from this initial study appear to support the hypothesis that a group project focused on service learning would result in positive development in indicator areas for success. Research by the authors is continuing in this area, and the senior author is currently applying the same service learning project approach to other classes, including graduate classes. In all cases, preliminary indicators suggest these projects have been well-received by students. We propose that the use of similar optimization mindsets in education can be widely applied to improve engineering educational practices without undue hardship and stress on students. The beauty of an optimization mindset is that it adapts and bends to meet the needs of specific individuals,



**Figure 5.** The average of the students' responses to the leadership output survey questions is reported by the bars. Please note that the bars initiate at the neutral score of 4.5 and terminate at the average response value. The black line centered on the average response represents the 95% confidence interval.



**Figure 6.** The average of the students' responses to the time constraint survey questions is reported by the bars. Please note that the bars initiate at the neutral score of 4.5 and terminate at the average response value. The black line centered on the average response represents the 95% confidence interval.



**Figure 7.** The average of the students' responses to the engagement constraint survey questions is reported by the bars. Note that the bars initiate at the neutral score of 4.5 and terminate at the average response value. The black line centered on the average response represents the 95% confidence interval.



students and faculty. It also shows the students that professors practice what we teach and apply optimization principles and the engineering design-build-test-learn cycle to our efforts in the classroom.

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