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Integrated project for sophomore-level engineering course contextualization

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Integrated project for sophomore-level engineering course contextualization

Abstract

Integrated curricula methodology has been investigated and recommended as a method to teach engineering. A group of engineering faculty at Cal State LA has designed and assessed an integrated student project that is the overarching theme of engineering curriculum contextualization at sophomore level. The project is part of the Sophomore Unified Core Curriculum for Engineering Education (SUCCEEd) program, funded by the National Science Foundation that seeks to integrate classes in the engineering core curriculum. The paper describes a house remodeling project that is used to integrate four lower division engineering core courses, namely, statics, programming, matrix algebra and CAD, and how it can be used to meet soft skills required by ABET. The manuscript concludes by including program assessment and recommendations based on what has been learned during project implementation.

Introduction

This article describes the overarching project of the Sophomore Unified Core Curriculum for Engineering Education (SUCCEEd) developed by faculty of the College of Engineering at California State University Los Angeles[1]. The project is the basis for the integration of engineering courses that were part of the SUCCEEd pilot that took place in the Fall of 2014. Integration is used as tool to reinforce learning and promote student success. An integration of subjects and reiteration of theories, prediction, practice, testing, optimization, assessment, and dissemination of information in a collaborative environment has been supported in the literature as a better way to learn engineering than the traditional, segregation by topic approach. A group of engineering faculty at Cal State LA sought to integrate classes in the engineering core curriculum as part of the Sophomore Unified Core Curriculum for Engineering Education (SUCCEEd) program, funded by the National Science Foundation. The investigators designed a house remodeling project to integrate four lower division engineering core courses, namely, statics, programming, matrix algebra and CAD, and to meet soft skills required by ABET.

California State University Los Angeles is located in East Los Angeles, in a county where 97.1% of residents are Hispanic, 26.8% live below the poverty line, and only 5.4% of adults over 25 hold a bachelor's degree[2]. Historically underrepresented minority groups (URM) and first-generation university students correspondingly comprise the majority (over 60%) of the student population within the College of Engineering, Computer Science, and Technology (ECST). The College of ECST offers ABET-accredited BS programs Civil, Electrical, and Mechanical Engineering in addition to its Computer Science and Technology programs. While enrollment of first-time freshmen in STEM majors increased from 232 in 2005 to 532 in 2011[3], low graduation rates still suggest a need for innovation of a transformative curriculum and pedagogy. Fifty-four percent of ECST students are admitted into CSULA needing remedial math. The 6-year graduation rate for our Fall 2001-2005 first-time Engineering freshmen cohorts still lies at 27.5%, although that is up from less than 20% for the Fall 1999-2003 cohorts.

Our Engineering students take their first program-specific engineering courses at the sophomore (200-level) level. The investigators researched the literature and discussed extensively their own observations of what seems to hinder our students' success. One main issue appeared to be that students are taught various subjects in a compartmentalized fashion, so they may feel overwhelmed at learning so many new concepts and find it difficult to persevere through challenging engineering content. Thus, we designed a new curriculum for the sophomore level courses, starting with Civil and Mechanical Engineering curricula, by which four courses were integrated through contextualization of content in a common themed project, namely remodeling of a house.

Background on Integrated Curriculum

Current pedagogical challenges encountered at many institutions of higher education, especially in minority serving institutions, have created an opportunity for testing innovative ideas in engineering education to obtain better learning outcomes. Many studies in the literature have documented that traditional teaching methodology is not the best approach to teach college students[4,5]. For instance, one of the flaws of the traditional educational system is separating knowledge into branches and presenting them to students stripped of their physical meaning. As a result, students can be unaware of the connections between different classes they are taking, and more importantly, they do not know why they have to learn the material that is presented to them. At California State University, Los Angeles, for example, most engineering students do not learn about the physical meaning of "moment of inertia" until their third or fourth year of college, if at all. These students go through Statics and Strength of Materials classes without knowing why so much time is spent on learning various aspects of moment of inertia.

On the other hand, the backbone of the so-called integrated curriculum "is about making connections"[6]. When the curriculum is integrated, students get an opportunity to connect different subjects to each other, learn the same concept from various points of views, and make associations between theoretical knowledge and the physical world. When the natural barriers between subjects are broken down, each subject adds a new dimension to the students' view. As a result, learning becomes more meaningful[7], abstract concepts gain physical meaning, and students become more engaged. As meaningful connections among different subjects are explored, a holistic view is formed, which reflects the world as students know instead of one described in abstract theories.

There is an overwhelming evidence for effectiveness of integrated teaching in the literature. Discussions on the importance of integration, reviews of most significant accomplishments to date and the corresponding conclusions, with further suggestions for future initiatives were reported by Froyd and Ohland[8]. A study of the long-term effect of adopting integrated curriculum on a group of students at Colorado School of Mines determined that the program had a strong positive effect on students' college careers[9]. A North Carolina State University, Raleigh investigation concluded that the students involved in an integrated curriculum program "outperformed their cohorts in demographically matched traditional classes, often by a wide margin"[10]. Similar results were observed by Olds and Miller[11], based on a two-year study of a group of "average" engineering students that were recruited for a first-year program that integrated curricula and fostered a learning community.

Integrating courses in SUCCEEd through contextualization

The four courses were contextualized in a hypothetical remodeling project of a small, single family residence. This scenario was chosen because it is familiar to students, it is a realistic application of class principles, and it lends itself well to integrating material from different courses. An overview of the house is shown in Figure 1. Students analyzed two house remodeling improvements in this project: installation of an air conditioning (AC) unit on the roof, and removal of an exterior wall to open up access to the yard. These two tasks are shown in Figure 2. In what follows, a chronological account is given of the exercises in the class related to the project.
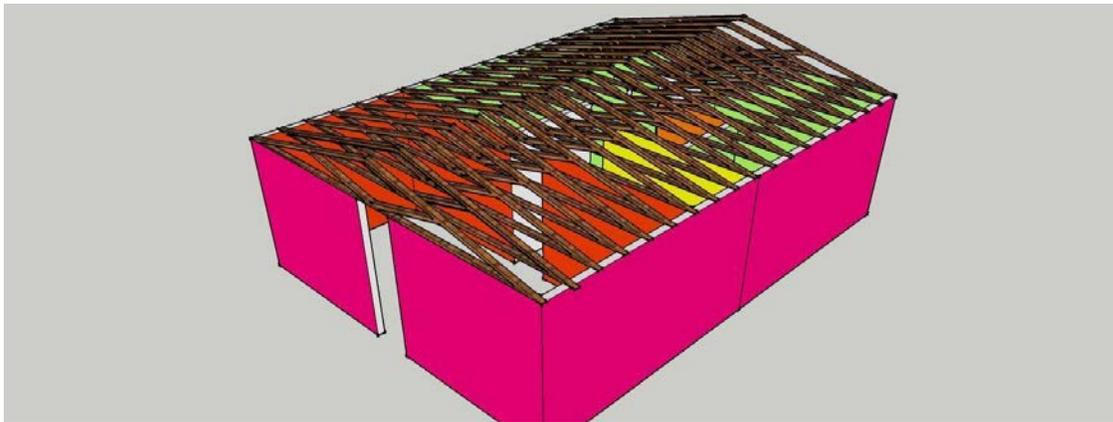
Figure 1: Single family residence used in the remodeling project. Architectural features like windows and roofing are not shown for clarity. The house is seen from a vantage point to the left and above the front door.
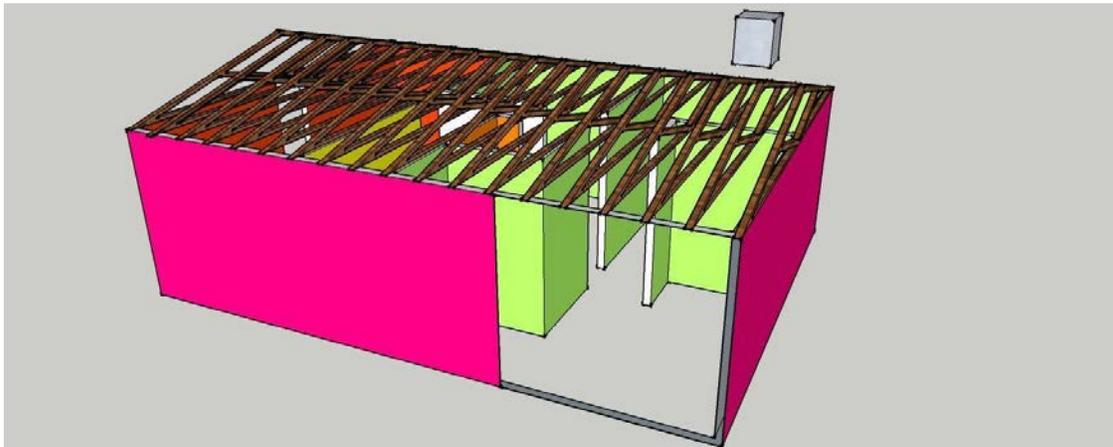

Figure 2: House viewed from the side showing the wall that is being removed and the AC unit in the location where it will be installed (but without any supports).

Fundamentals
The AC unit was introduced along with free body diagrams (FBDs). Students learned about engineering supports such as pins, rollers, and fixed supports. After four exercises with textbook

figures, they were asked to draw an FBD of one of the horizontal support beams shown in Figure 3. Once equilibrium was introduced students considered the reaction forces on the support beam under the general loading shown in Figure 4. These results were later used to develop shear force and bending moment diagrams for the support beam. Integration of the course material with the matrix algebra class allowed the treatment of vector arithmetic in the statics course to focus exclusively on the physical meaning of vectors. Although the integration with the CAD course was not always possible, in several opportunities course content was used to support the understanding of several aspects of the project. In the first class, for example, students produced a 3D sketch of a beam under various constraints and were asked to reflect on reaction forces, constraints and loads based on the various scenarios shown in Figure 5.
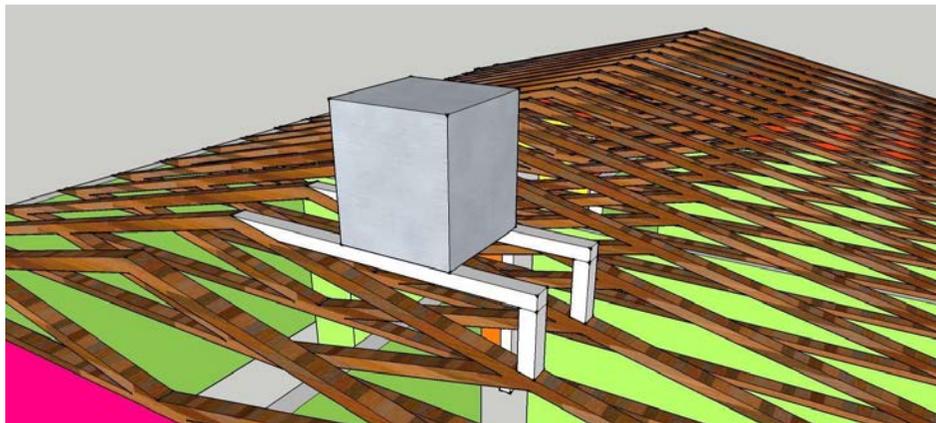

Figure 3: AC unit shown on the support frame. The support frame can be modeled by a pin at the left end and a single vertical reaction at the right end due to the rigid vertical strut. The AC unit was assumed to be supported at the four corners.
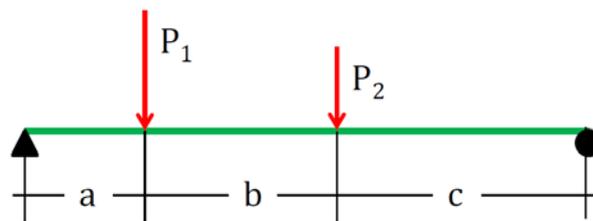

Figure 4: Sketch of an AC support beam showing the AC unit placed at an arbitrary location and with non-symmetric loads due to the AC unit.
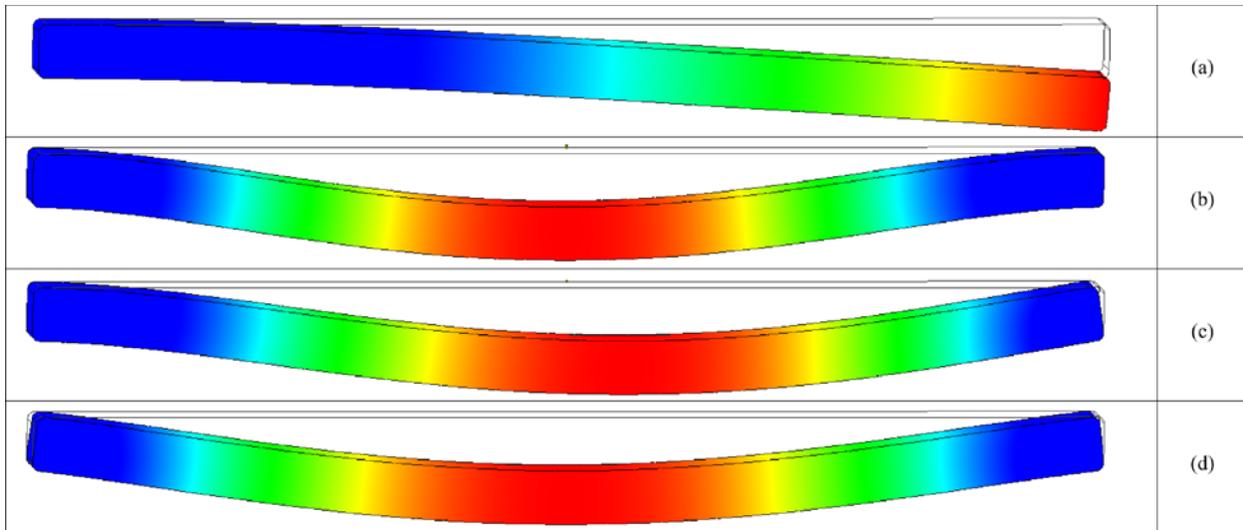
Figure 5. 3D Model of beam displacement under specific boundary conditions: (a) cantilever; (b) fixed at both boundaries; (c) fixed (left) and pinned (right) boundaries; and (d) simply-supported.

Roof Truss Analysis and Solving Systems of Equations

The roof truss supporting the AC unit was considered at two different levels of detail. First, when the method of joints was introduced, the roof truss was analyzed assuming a symmetric AC placed symmetrically on the support beam. This meant that each roof truss was loaded with one quarter of the AC's weight at the two supporting joints (joints 4 and 5 in Figure 6). At the end of the truss unit, students were divided into seven groups (one for each joint). They considered the most general case in which each joint could be loaded vertically and horizontally if there was no restraint present. The results were placed on the board. In this way, students derived a system of equations with 14 equations (2 per joint) and 14 unknowns (11 member forces and 3 reactions). This tied into the linear algebra class in which they studied the theory behind of systems equations, in particular the different techniques to solve both analytically and numerically (when the number of equations in the system became large), the resulting mathematical model, and in the programming class as described next.
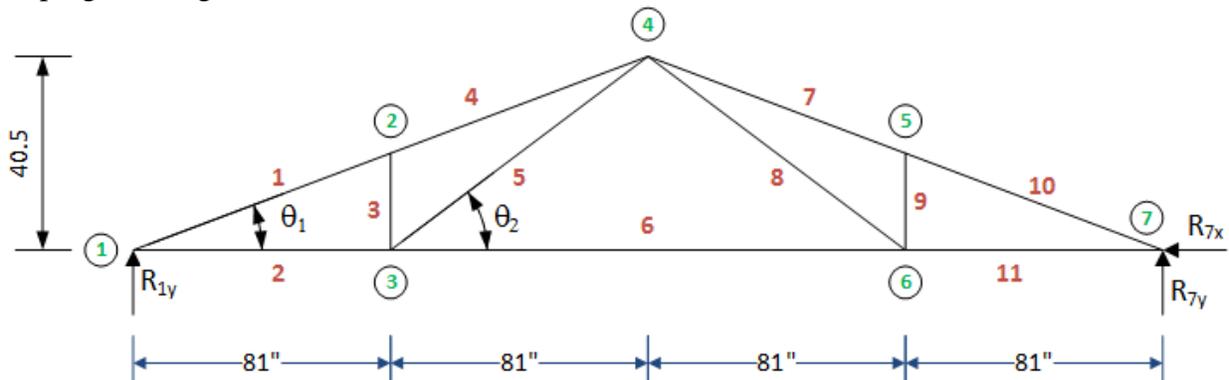

Figure 6: Supporting truss showing member and joint numbering used in the statics class.

The mini-project assignment was designed to give students an opportunity to apply their understanding of programming skills (function calls, loops, logical and conditional statements, and output display functions) to the analysis of a roof truss on which the AC unit is hypothetically being installed. During the first half of the 10-week quarter, exercises included writing Matlab code to sum and decompose vectors, practice array construction and indexing, plot functions, and implement basic I/O commands. The class also began to set up the system of internal and reaction force equations for the truss in Matlab and did an exercise on finding the linear dependence of the system of equations to further practice matrix manipulation. While the students were learning how to find the inverse of a 2x2 matrix by hand in Linear Algebra, they were learning how to do matrix inversion and how to solve matrix equations in Matlab to solve N-member trusses. Then by week 6, students had added function calls, logical operators, and if statements to their arsenal of programming capabilities and the students were given their first mini-project assignment. The objective of the project was to determine whether a truss with given member capacities and factor of safety has sufficient strength, both in the unloaded condition and with the AC unit installed. The students were asked to write a MATLAB program that allowed the user to input key design parameters and then alerted the user to the safety of the design and also displayed a graphical representation of the roof truss labelled with each member's internal forces. The program was required to:

- Allow users to vary the position and weight of the AC unit.
- Calculate truss member forces of truss.
- Generate a graphical representation of the roof truss displaying the axial forces of each member.
- Determine whether the truss meets strength requirements, and outputs this to the user in an easy-to-understand output.

An unintended difficulty at this stage related to member and joint numbering. The joint and member numbering in statics was from left to right (Figure 6) whereas the numbering in programming was from the center out to take advantage of symmetry (Figure 7). It was decided to retain the different numbering as an example of the difficulties that arise in practice between different teams of engineers.
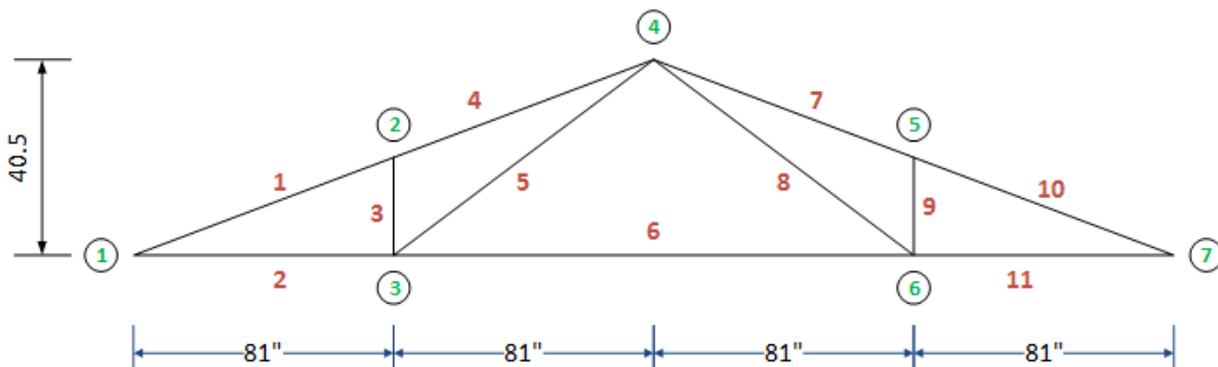

Figure 7: Supporting truss showing member and joint numbering used in the programming class.

Shear and Bending Moment in the Support Beam

For the second mini-project of the programming course, the students analyzed the support beam for the AC unit. The location of the AC unit was completely arbitrary (see Figure 8). Shear and bending moment profiles were calculated along the length of the beam for varying positions of the AC unit. Students created a movie of these profiles using a for loop and the pause command. This project was also used to help students to practice file input/output (I/O) functions. Students were asked to read a binary file containing the nominal and actual dimensions of various beams available to them to use for the support beam, and then, using allowable capacities, determine whether the maximum shear and bending moments would still fall within capacity of each beam. Students were required to write a program which again employed function calls to:

- Calculate and plot shear forces along the length of the beam.
- Calculate and plot bending moments along the length of the beam.
- Show these shear and bending moment profiles for various positions of the AC unit along the length of the beam.
- Generate a 3D plot of shear force profiles and of bending moment profiles at the various AC unit positions.
- Determine whether the selected cross section meets strength requirements for the given AC location, and outputs the analysis results to the user in an easy-to-understand file which contains the nominal beam size, the maximum shear force at any position along the beam and for any AC unit location, the maximum bending moment at any position along the beam and for any AC unit location, and an indicator of whether the beam would meet strength requirements. As an example, one line in the file, and the header are depicted in Figure 9.
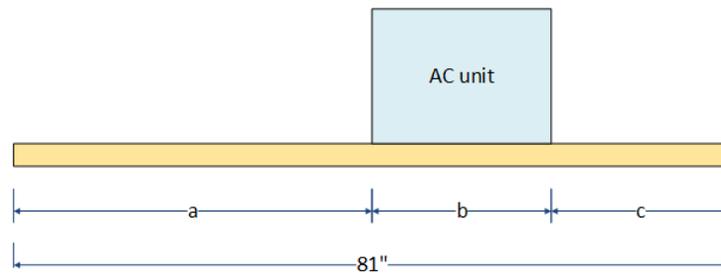

Figure 8. AC unit support beam used in parametric analysis of shear and bending moment

Size	Vmax	Mmax	Safe(Shear)	Safe(Bending)
2 x 4	73.4	1523.4	1	0

Figure 9. Sample output file of shear/bending analysis program developed by students

Frame Analysis, Distributed Load, and Centroids

The wall removal was considered in the unit on frames and machines. The supporting frame is shown in Figure 10. As a simple first approximation, students solved for reactions on the frame assuming that all the load from the roof trusses was placed at the center of the horizontal span. Although this is incorrect, it allowed for the introduction of the project early in the unit on

frames and machines without the need for complicated equilibrium equations or advanced topics such as distributed loads.
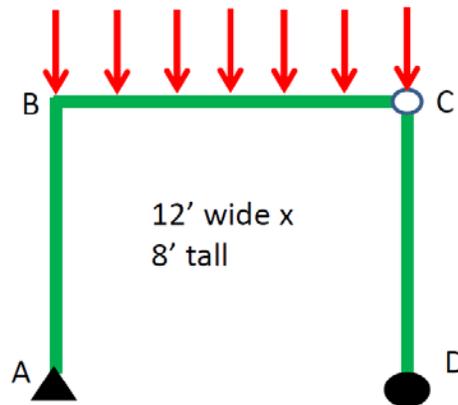

Figure 10: Sketch of the frame used to replace the removed wall.

Distributed load and centroids were introduced near the end of the statics course. Student understanding of these concepts was further developed in an exercise in the programming course. Students were taught numerical (trapezoidal) integration and used this to numerically compute centroids of a curve which they defined as a MATLAB sub-function. These concepts were first incorporated into the project, not with the frame in Figure 10 but by assuming that the truss forces were carried by a simply supported beam between points B and C. This allowed students to calculate shear force and bending moment diagrams in two different ways. First they considered point loads acting underneath each truss; second they considered an equivalent distributed load. Through this exercise, students were able to justify treating the loads as a distributed load in subsequent examples.

Finally, as a culminating exercise, students analyzed the frame in Figure 10 under two load cases: a distributed load due to supported trusses, and a lateral load representing a seismic load. Students calculated support reactions and bending moment diagrams for all members in both cases. Then, to provide an air of realism, students applied a factor of safety and compared the internal forces (bending moments and shear forces) to capacities in the Steel Construction Manual[12]. This part of the project was vastly simplified as compared to the design process used in design of steel structures; indeed there were even inaccuracies. The objective, however, was to focus on the statics calculation while providing students with a sense of the real-world applications of the principles.

Lessons Learned and Future Work

Strengths
A major strength of this approach is that it helped students see different aspects of the same problem. For instance, the roof truss example allowed students to explore physical concepts in statics, vector and matrix algebra fundamentals in Matrix Algebra, and computational applications in programming. Moving the theoretical vector content out of statics allowed for more time working with physical concepts. Having a familiar example in Programming allowed

students to focus on building a simulation tool instead of spending time first having to understand the physical principle they were trying to model. At the same time, the programming exercise allowed students more time to understand the physical principles taught in statics. Importantly, participants in the SUCCEEd program increased in their understanding of statics principles. Scores on pre- and post-course concept inventories were Mean = 4.40 (Standard Deviation = 3.10) before the course and Mean = 6.40 (Standard Deviation = 4.16) after their first quarter of SUCCEEd.

We queried the students about the impact that the program had on them after their first quarter. They reported that the structure and interconnectedness of the curriculum helped them. Some of their qualitative comments about the integrated nature of the curriculum include: *"I think the most beneficial aspect of SUCCEEd was the fact that all of the classes where able to tie in together and saw how some of the material was needed to accomplish a task in another"; "The curriculum for each class was tied in with all of our other classes and was awesome"; and "The repetition of concepts was really helpful to use them throughout the Course".* These comments are illustrative of the impact of interconnecting different aspects of engineering in one contextualized project. We are hopeful that this impact will increase across quarters in the program.

Faculty also benefitted from the program. Faculty met weekly to discuss progress and curriculum development. We discussed how to best fit our content together and to share observations about students. In addition to the curricular benefits just discussed, the weekly meetings also allowed faculty to develop a sense of community that is rare in academia.

Areas of Improvement
Since this was the first implementation, despite significant planning during the summer, it was difficult to align all aspects of the four courses. There was significant, real time trial and error during the first implementation. Now that we have taught the sequence once, we can improve the sequencing and alignment of the different assignments.

In addition, students reported feeling burnt out at the end of the sequence. Part of the cause can be addressed by the sequencing of content and assignments during the term. In the first implementation, the latter part of the quarter had too many simultaneous assignments. A more difficult challenge is programmatic. Taking four core engineering courses at one time is a very heavy load. Most of our students were taking a physics and/or calculus course on top of that. We need to figure out a better way to help students manage their course load, but the issue is really at a larger programmatic level in which some of the courses are more demanding than the unit load students receive credit for.

Future Implementations
We will continue the program in the spring quarter with Strength of Materials (Mechanics of Materials), Strength of Materials Laboratory, Numerical Methods, and Statistics. Both of the project tasks will be revisited while covering stresses and forces in rods, beams, columns, and beam columns in Strength of Materials. The Numerical Methods class will make use of the project by creating parametric simulation modules. Statistics will be integrated with the Strength of Materials Laboratory, which will also be sequenced with the Strength of Materials lecture course.

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