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Sophomore Unified Core Curriculum for Engineering Education (SUCCEEd) at Cal State LA

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Abstract

The SUCCEEd program at California State University-Los Angles (Cal State LA) was designed within an integrated curriculum context to overcome the low success rate with respect to graduation and professional licensing, a common problem in engineering programs at minority serving institutions. The curriculum design has been driven by outcomes established to help Engineering majors acquire a strong foundation in core competencies; i.e., in: (1) analysis, (2) applications, (3) design and modeling, (4) communication, and (5) professionalism. The curriculum has also been designed to provide cohesiveness between the different courses in a given term so that students can focus on common topics from the perspective of each of the five competency-areas and see the interconnectedness of the material they are learning in all five classes. Although, the integrated curriculum approach was developed in the late-80s, it has not been widely adopted due to various obstacles at the individual, departmental, and institutional levels. Many of these obstacles are common to strategies that require major transformation in an engineering program. The manuscript reports on the programmatic and administrative challenges encountered at Cal State LA, and the strategies used to overcome them during the implementation of the integrated curriculum pilot program. The pilot study focused on integrating/contextualizing nine quarter units of lower division engineering courses (i.e.: statics, programming, matrix algebra, and computer-aided design). The paper concludes by reporting on preliminary assessment data.

Background

As is the case with most minority serving engineering colleges, the College of Engineering, Computer Science and Technology (ECST) at California State University-Los Angeles (Cal State LA), has a long history of providing freshman-year remedial programs to assist students with their academic challenges. These programs have significantly reduced the time students spend in remedial English and mathematics courses and have increased the first-year retention rates. Nevertheless, these first-year improvements do not often reflect on the overall retention and graduation rates. In fact, contrary to what might be assumed, strong first-year support programs, which have received the bulk of the attention in the literature, can degrade sophomore performance for a variety of reasons[1,2]. These observations have led to the suggestion that sophomore-specific programs are necessary to support rising students[3]. In many cases, the vanishing effect of first-year programs on later years has been attributed to the fact that students transition from a very supportive environment in their first year, to having no support in the following years when they are expected to develop a strong foundation for upper division engineering courses. Without proper preparation in these foundational years, students are not able to keep up with their classes and end up transferring to non-engineering majors or, in many cases, dropping out. There are several individual and institutional factors that have been associated to the inability of students to complete an engineering degree[4]. Herein, we are focusing on what seems to be one of the main causes of failure: lack of preparedness[5,6]. The core of the problem seems to be in the fact that the academic foundation that should have been developed over the years in K-12, is not at the level that is expected from incoming freshmen. This raises the question: how can engineering students receive adequate training if they are not college-ready? One has to keep in mind that one-year programs are likely unable to help students catch up on all K-12 skills and knowledge. The task seems even more formidable considering that study habits and academic attitudes are usually formed and solidified during K-12.

Clearly there is no single remedy for the problem. Study habits, general attitude towards education, and academic preparedness need to be addressed. A solution for the latter issue may be obtained by integrating programs that are academically challenging. At the same time, providing support through tutoring, team building, and mentoring may create an environment that promotes change in the academic mindset (i.e.: attitude towards learning and study habits)[7]. With this in mind a group of engineering professors started working on the development of the Sophomore Unified Core Curriculum for Engineering Education (SUCCEEd) Program, which is currently funded by the National Science Foundation (NSF).

The Dawn of SUCCEEd

We began by formulating the outcomes of a new engineering core to clearly define what sophomores need to know before moving forward with higher-level engineering studies. Traditionally, engineering programs in the USA have focused on a linear progression of content that must be covered to ensure that students receive a well-grounded core education. However, recent evidence suggests that a focus on program outcomes—rather than content—can lead to the design of a more effective curriculum[8,9]. This approach has been endorsed by The American Association of Colleges and Universities and is integrated in our ABET accreditation process. Once the outcomes were agreed upon, we identified a preliminary set of core competencies that correlated with the desired outcomes and objectives while ensuring a robust sophomore experience. Details on this process are provided below. We also looked at the various pedagogical innovations that were being used in the college and in other STEM programs, and identified the following set of guiding principles: (i) integrated curriculum, (ii) time-on-task, and (iii) community building and support, to establish the core values and the corresponding framework for the program.

Integrated Curriculum

An integration of subjects and reiteration of theories, prediction, practice, testing, optimization, assessment, and dissemination of information in a collaborative environment has been reported to support learning[10].

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[11,12]. For instance, one of the flaws of the traditional educational system is separating knowledge into branches and presenting them to students often stripped of their physical meaning. As a result, students frequently become unaware of the connections between the different courses in the curriculum, and more importantly, they do not know why they have to learn the material that is presented to them in these courses. At Cal State LA, 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 the courses of Statics and Strength of Materials 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"[13]. When the curriculum is integrated, students get an opportunity to connect different topics to each other, learn the same concept from various points of view, and make associations between theoretical knowledge and the physical world. When the natural barriers between topics are broken down, each subject adds a new dimension to the students' perspective. As a result, learning becomes more meaningful[14], abstract concepts gain physical significance, and students become more engaged. As the essential connections among different topics are explored, a holistic view is formed, which reflects the world as known by the students, instead of the one abstractly described by the theory.

Substantial evidence on the effectiveness of integrated teaching exists in the literature. For instance, a discussion on the relevance of integration, including a detailed review of the most significant accomplishments to date with further suggestions for future initiatives, was reported by Froyd and Ohland[15]. An investigation about the long-term effects of adopting integrated curriculum was conducted at the Colorado School of Mines, concluding that the program had a very positive effect on the college-careers of the group of students that were selected[16]. Another study at North Carolina State University-Raleigh established that the students involved in an integrated curriculum program "outperformed their cohorts in demographically matched traditional classes, often by a wide margin"[17]. Similar results were observed and reported by Olds and Miller[16], based on a two-year investigation of a group of "average" engineering students who were recruited for a first-year program that was based on integrated-curriculum and also fostered a learning community.

Community Building

A sense of belonging plays a critical role in the academic success of students and their persistence in dealing with challenges inherent to the typical academic environment. However, a sense of affinity to their new habitat is not automatically instilled in all students entering the university. While some students are eager to embrace their new situation and to assimilate themselves to the university life, most students tend to remain at the margins unless they are actively introduced to various organizations that may potentially facilitate assimilation. This detachment phenomenon is more frequently found in urban universities[18], where difficulties such as traveling distance among home, workplace and university hinders community-building, which is essential for the academic success of students.

Several studies have concentrated on the role that a supportive environment has in nurturing a community of students to promote success in college[19]. This factor is particularly important for underrepresented students in engineering and first-generation college students (those who generally lack familial history with college experience). Specifically, the focus has been on the influence that supportive habitats have on academic attitudes, motivation, engagement, goal setting, graduation, grades and test scores of college students. As mentioned by Schaps[19], some of the evidence found seems to be correlational, resulting from "descriptive studies that assess the relationship between aspects of the school environment as they naturally vary and student outcomes." Some of "the evidence is causal, coming from evaluations of programs or 'interventions', that are intended to alter the school environment in desired ways."[19] However, regardless of the type of study, the common conclusion is that establishing learning communities promotes a professional culture at schools that may enhance the assimilation of the majority of students to their environments[20]. In general, students who have a sense of belonging to their school attain higher academic achievements compared to students who feel isolated.

As being defined by Bellah et al.[21] "A community is a group of people who are socially interdependent, who participate together in discussion and decision making, and who share certain practices that both define the community and are nurtured by it." When students are brought together into a community, a "community of practice" is formed in such a way that learning takes place through activities—including discussions—shared by the students[22]. Exchange of information among students is beneficial to all. The one who has something to share has an opportunity to test his/her level of understanding through the follow up questions and consequently gains a deeper understanding; benefit to the one with whom the information is shared is obvious. This is a fundamental reason for the inclusion of a strategy within the SUCCEEd program (a so-called "pillar") for creating a community of learners among the students.

Time-on-task

Most students can succeed as engineers if they work hard, focus, and dedicate themselves to the task at hand. However, students who are not accustomed to the rigors of advanced courses in precollege or academically-rigorous college-content, struggle when dealing with most engineering courses. As previously described, first generation students, which is the case for the majority of the students in the SUCCEEd program, struggle with time on task. Accordingly, pedagogical and contextual practices must be set in place to support them[23,24].

Based on these principles, we were able to identify the following robust objectives for the core program:

> *At the end of the core, students will receive a firm grounding in the fundamentals of engineering and will be able to design and/or solve engineering problems using theoretical, experimental, and numerical approaches, while appreciating the applicability and limitations of these approaches. Students will be able to think critically, analyze data, and generate appropriate data if needed. They will also be able to communicate their results and findings both orally and in writing. Above all, they will be prepared to successfully complete their engineering education.*

These objectives were distilled down to specific student learning outcomes (SLOs) that are shown in the figure below. By focusing on the objectives and SLOs of the core program, we were able to avoid focusing on the traditional linear progression of core content and have begun developing interconnections between topics and content in the core, therefore integrating various approaches to solving engineering problems.

Student Learning Outcomes (SLOs)

At the conclusions of the core program, students will be able to:

- apply knowledge of mathematics, science, and engineering (ABET a)
- demonstrate the ability to conduct experiments, as well as to analyze and interpret data (ABET b)
- work independently and on multidisciplinary teams (ABET d)
- identify, formulate, and solve elementary engineering problems
- understand of professional and ethical responsibility (ABET f)
- communicate effectively (ABET g)
- use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET k)
- manage human and other project resources
- demonstrate competency in quantitative and scientific reasoning
- demonstrate a depth of understanding of principal modes of inquiry in engineering
- access and evaluate a variety of information sources

It is important to note here that students will achieve these SLOs at a level appropriate to their standing in college. One cannot assume that a sophomore student will demonstrate the same level of competency in, for example, quantitative and scientific reasoning (SLO #9) as a senior or a graduate student. Part of the process in developing this curriculum will be to identify an appropriate level of achievement for the competencies and to develop appropriate assessment rubrics.

Table 1. Sample of preliminary core competencies of the core program

Engineering Analysis - These labs focus on teaching basic analysis skills with applications to a broad range of engineering problems.		
• dimensional analysis • free body diagrams • equilibrium of rigid bodies • basic properties of materials	• moments of inertia • equivalent systems of forces • basics of electrical circuit analysis	• conservation of momentum • conservation of energy • linear systems and convolution
Engineering Applications - These labs allow the students to apply the fundamental knowledge obtained in the analyses courses to practical problems in engineering.		
• data acquisition • data analysis and interpretation • statistical significance testing	• forming, testing hypotheses • propagation of errors • electronic signal measurements (e.g., oscilloscope, logic analyzer, multimeter)	• regression analysis • characterizing material properties (e.g., shear stress/strain measurements, tensile tests, flexure test, compression tests)
Engineering Design and Modeling - These labs focus on teaching students the fundamentals and applications of engineering design and modeling.		
• dimensioning and tolerancing • ANSI Y14.5 Standards • basic programming • basic CAD	• developing algorithms • modeling basic engineering systems • data assimilation and interpretation	• roots of equations • interpolation • systems of linear equations • design with constraints
Engineering Communication - These labs provide opportunities for students to communicate their findings in the other laboratories through a series of written and oral exercises.		
• email etiquette • writing business letters • making presentations • writing reports	• editing • reading/evaluating literature • basic communication theory • Gantt Charts	• researching and referencing • writing abstracts/summaries • pitching your project
Engineering Professionalism - This laboratory allows students to explore applications of ethics and systems of moral principles and environmental stewardship in engineering practice		
• Ethics in Engineering	• FE and PE registration	• history of engineering

The SLOs were further subdivided into core competencies (a sample of competencies is provided in Table 1), which were formulated in the context of the following two constraints: (1) the competencies must support the SLOs, and (2) the competencies must prepare students for higher-level engineering studies (i.e., all prerequisites for pursuant courses are met). Initially, the interest at Cal State LA has been on the core shared by the three existing engineering departments, namely, civil, electrical and computer, and mechanical engineering, though implementation with closely-related engineering fields should be straightforward.

Original Program Framework

As envisioned, the SUCCEEd program was designed to achieve the SLOs and the program objectives in a one-year period, and it was originally organized around the following laboratories/clinics:

1. *Engineering Analysis:* 6 hours/week (taken quarterly)
2. *Engineering Applications:* 3 hours/week (taken quarterly)
3. *Engineering Design & Modeling:* 6 hours/week (taken quarterly)
4. *Engineering Communication:* 3 hours/week (taken quarterly)
5. *Engineering Professionalism:* 3 hours/week (taken once)
6. *Independent Study:* 6 hours/week (taken quarterly)

The original year-long 22-unit sequence (i.e., 7 unit load for first two quarters and an 8 unit load in the third quarter), would replace traditional engineering core courses including, but not limited to: statistics/probability, statics, strength of materials lecture and lab, circuits, design, communication, programming and numerical methods. Each clinic was designed to support the learning process in the other clinics to enable students to analyze, model, build and test, write and talk about the same topic as they move through the labs. There was also a built-in mechanism (through the "independent study" labs) for students to peer-mentor each other, catch-up if necessary, and receive expert feedback and coaching by faculty and teaching assistants.

The level of integration of the original framework created barriers for the implementation of the SUCCEEd program, which had to be modified before the pilot could run in the fall of 2014. In terms of scheduling, the two possibilities were: (i) to create special topic courses that could later be used to substitute for required courses or (ii) to block-schedule the courses being replaced by the program. If the former option was to be adopted, transcripts would show a number of special topics courses in lieu of the actual engineering courses, which could negatively impact students. There were also concerns from university faculty and administration related to meeting the accreditation criteria. These potential problems would be solved by adopting the latter option, which would not impact transcripts or accreditation. However, due to the nature of the program, competencies of the different courses could potentially be distributed over the three academic quarters, which would make assigning course grades at the end of each quarter virtually impossible. In addition, there were no mechanisms in place to give credit to students wanting to leave the program. Thus, the team agreed that the core values and objectives of the program could still be met in a one year-program via semi-independent quarters. There were several benefits to running the program in the aforementioned format: (a) the new scheme does not have an impact on scheduling or grade assignment; (b) students have the option to leave the program at the end of each quarter and, at the same time, new students can join it at any quarter as long as pre-requisites are met; (c) contextualizing materials over a quarter is also less demanding than doing the same for the whole year; and (d) instructors do not need to commit to the program for a full year. To this point in time, we have had no problems with administration or faculty in the college with implementation of SUCCEEd; on the contrary, they have been very supportive of the program. Since Cal State LA is in the process of transitioning from a quarter-based program into a semester-based program, all indications are that we will accomplish a relatively smooth transition of the SUCCEEd program into the new semester-based system.

The pilot took place in the fall of 2014 and consisted of four courses, namely, Statics, Matrix Algebra, Numerical Methods I and Introduction to CAD. These courses were block-scheduled (Table 2) on Mondays, Wednesdays and Fridays, allowing students to take other sophomore-level courses on Tuesdays and Thursdays. In addition, students were required to participate in the "independent study" labs, where they had the opportunity to review the material, work on assignments and projects and study with support from their peers and a student mentor/tutor.

Table 2. SUCCEEd program pilot schedule – Fall/2014

Time / Weekday	M	T	W	Th	F
9:00 -9:50AM	Statics		Statics		CAD
10 -11:40AM	Matrix Algebra		Matrix Algebra		
11:50AM - 1:30PM	Lunch Break		Lunch Break		
1:30PM – 4:10PM	Num. Methods I		Num. Methods I		
4:20PM – 6:00PM	Independent Study		Independent Study		

SUCCEEd Program Pilot

SUCCEEd was open to all engineering students that met the prerequisites of the courses in the program. Information sessions on the program were held during the spring and summer quarters of 2014, and interested students were assigned permits to add the SUCCEEd sections of the respective courses. We noticed that several students who were interested could not join the program since they had already taken at least one of the courses offered in it. Thus, only ten students participated in the pilot (in the future we plan to hold the information sessions earlier so that students can plan accordingly).

During the first class, students were introduced to the overarching theme of the SUCCEEd program, which consisted of a hypothetical remodeling project of a small single family residence. Features of the project included the installation of an air conditioning (AC) unit on the roof, and the subsequent removal of an exterior wall to open up access to the yard. As much as possible, competencies learned in the Statics course were integrated to the other courses. For example, as students worked on free-body diagrams (FBDs), to determine the forces in the roof truss, in the Matrix Algebra course they learned how to solve the system of equations generated from the truss problem using matrix-based techniques. In the Numerical Methods class, on the other hand, students developed their programming skills by performing parametric analyses of the truss under varying location of AC unit. In the 3D CAD class, students worked on sketching the truss and its components. Additional details on the project are available in Rodriguez-Nikl et al.[25]. It is important to note that not each every-day class was contextualized, since basic concepts needed to be introduced at times, but the overall goal was continuously brought up.

Throughout the quarter students worked together during various mini projects in-class and during the "Independent Study" lab sessions. The mentor/tutor worked with faculty members and students to identify topics that were considered to be difficult and reviewed them during these labs as well. Students were also given the opportunity to study for courses that were not part of the SUCCEEd program.

Measures of Impact, Preliminary Results and Discussion

As a part of the SUCCEEd program, we wished to assess both student achievement and other factors that may contribute to student success in the program. Achievement was measured via students' grades, tests and quizzes results, and project results. The college self-efficacy (CSE), which refers to the students' belief that they can succeed in college, was also measured. In the literature in higher education and engineering education, CSE has been found to impact persistence and achievement of students in college[26]. College social capital (CSC) was also measured as an affective construct. CSC refers to students "college knowledge," which is students' understanding of how to navigate college/university systems and practices, college requisite skills, and college community culture. This construct has been also linked to students' success and persistence towards college degree.[27]

We have also chosen to measure students' engineering creativity and propensity for innovation using a well-established engineering education measure using constructs that have been identified by the National Academy of Engineering (NAE) [28]. Relationships amongst these factors were also explored. Results of these metrics are preliminary given that the project has been in full operation with students for one quarter only. These data will be tracked over time and will inform the program's design both formatively and summatively. Preliminary results of the assessment of the program are as follows. In terms of achievement and student knowledge, the participants in the SUCCEEd program increased in their understanding of statics principles, (M_{pre} = 4.40; SD = 3.10; M_{post} = 6.40, SD = 4.16; max score = 27) after taking their first quarter of SUCCEEd. This difference approached statistical significant t (9) = 1.962, p = 0.09, indicative of promising practice for the future quarters using the SUCCEEd approaches. The participating students' college self-efficacy increased in one quarter and this was positively correlated with their college social capital (r = 0.306, $p < 0.05$). The participating students' post assessment score on the statics concept inventory highly correlated with their level of college social capital (r = 0.270, $p < 0.05$). These results indicate that those students who had increased their CSC after participating in the program for one quarter also had higher increases in their understanding of statics principles at the close of the quarter. The engineering creativity and propensity for innovation of the students in the program increased during the quarter (M_{pre} = 3.70; SD = 0.79; M_{post} = 3.86, SD = 0.96). This was also positively correlated with their course grades (r = 0.347, $p < 0.01$), which serves as further evidence of the formative impact from the program. Importantly, the students with higher grades had higher levels of propensity for innovation. Given the modest sample size for the first period of this program (N=10), we interpret these results cautiously; however, it is clear that the impact of the SUCCEED program formatively represents the positive potential of the program for future groups of students across time.

To build a community among students, collaboration and camaraderie was promoted from the very first meeting when groups of students were given Lego-type structural elements to build a bridge. Camaraderie among students was strengthened as they were given opportunities to work together on their homework problems as well as on various projects. Towards the end of the first quarter, the students seemed to have built a sense of community and belonging in the SUCCEEd group. As evidence of this, we queried them about their impressions of the SUCCEEd program. Some of their qualitative comments about the program as it relates to their connectedness as a group include: *"Getting to meet new people and create a bond to study the same classes in order to pass and succeed in our classes;"* and *"In such a small group of people, the professors are very willing to help with any struggle within the course."* These data were collected via an open-ended questionnaire at the end of the first quarter of the program and the ten pilot participants completed this questionnaire. These comments are illustrative of the bond created between students and its relative impact on them. We are hopeful that this impact will increase across quarters in the program. Accordingly, in future quarters, the role that the program plays in developing a sense of community for the students will be assessed using periodic focus groups based upon the participating students.

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