AC 2009-2334: DESIGNING A SEQUENCE OF DESIGN COURSES TO IMPROVE STUDENT PERFORMANCE AND RETENTION AT A MINORITY INSTITUTION

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Abstract

This paper describes the process of creating a sequence of design courses in the Department of Mechanical Engineering at California State University, Northridge. The overarching goals of the course sequence are to address and improve student performance and retention challenges unique to minority institutions by using the Conceive-Design-Implement-Operate (CDIO) framework as the context for engineering education. This framework facilitated a systems engineering design process by benchmarking and formulating the skills, knowledge, and attitudes desired by stakeholders (industry, faculty, students) as requirements for the design, engaging freshman students early and continuously in the program with continuity in the courses and relaxation of prerequisites, establishing mutually supporting contents and proficiency in skill levels among the courses, integrating the teaching of personal and interpersonal skills into the design projects, using active and experiential learning techniques, and planning for the laboratory infrastructure to support the design projects. The outcome of the curriculum design process is a sequence of design courses that meets the requirements and provides the basis for spearheading an NSF-funded project to generalize the framework to include other minority institutions in California.
I. Introduction

The Mechanical Engineering Department at California State University, Northridge (CSUN) enrolls approximately 300 undergraduate students and 50 graduate students; 39.6% of undergraduates are from groups underrepresented in engineering (Hispanic, African American, and American Indian) and 18.9% are Asians/Pacific Islanders. Like their peers in CSUN as a whole, the predominantly economically disadvantaged ME students are drawn largely from surrounding urban minority communities and are typically first-generation college students who must hold outside jobs while they pursue their studies.

The Department’s degree program has evolved from a general engineering degree program that required all students to attend the same core courses for their first three years and then take specialized courses during their senior year, to a specific formal BS degree program in Mechanical Engineering that was introduced in 1993. Since this introduction, the Department has offered its first lower-division courses. The most recent curriculum changes, made in response to input from faculty, the 2001 ABET review, the Minority Engineering Program, industry, alumni, graduating seniors, and other stakeholders, have sought to impart design concepts and related computational tools at the lower division to improve student preparation for the senior design capstone course and their future careers. These changes resulted in a mechanical design sequence of courses (shown in Figure 1) that comprise of the freshman orientation course ME101, the one-year sophomore design sequence ME286AB, the junior-level machine design course ME330, and a year of senior design. In this paper, this sequence will be referred to as the design-stem sequence.

![Figure 1: Existing Mechanical Design Courses (i.e., Design-Stem Sequence)](image)

While this development has improved the Department’s offerings, it also has resulted in a patchwork curriculum that is a product of an adaptive evolution rather than of good engineering design. For example, the ME 286A and 286B courses were independently created from previous courses rather than by developing a true two course sequence from scratch. ME 286B, in particular, suffered from being a mixture of topics, including content from a freshman programming course which was deleted from the program. The perception of faculty, complemented by senior exit interviews, indicated that there was a lack of continuity in the instruction related to Computer Aided Design and Finite Element Analysis (CAD/FEA) software, as well as its application to team projects of increasing complexity. Students also felt that their access and instruction related to machining and
shop equipment were limited. These weaknesses have led some students to feel somewhat lost in senior design, and unable to contribute successfully to their group projects.

To systematically reform the design-stem sequence in particular, and the entire curriculum in general, the Department has proposed to unify the curriculum under the cohesive Conceive–Design–Implement–Operate (CDIO) framework, which was pioneered by MIT and a growing consortium of 23 universities\(^3,4\). The CDIO framework is based on the principle that product and system lifecycle development and deployment – Conceiving, Designing, Implementing, and Operating – are the innate context for engineering education. The crux of the CDIO framework is its Syllabus (See Appendix in Section VI), a statement of undergraduate engineering education learning objectives expressed in terms of skills, knowledge, and attitudes; and a set of 12 Standards (See Table 1) designed to help achieve the learning objectives.

### Table 1. Twelve CDIO Standards

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CDIO as Context</td>
<td>Adoption of the principle that product and system lifecycle development and deployment are the context for engineering education</td>
</tr>
<tr>
<td>2. CDIO Syllabus Outcomes</td>
<td>Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders</td>
</tr>
<tr>
<td>3. Integrated Curriculum</td>
<td>A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills</td>
</tr>
<tr>
<td>4. Introduction to Engineering</td>
<td>An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills</td>
</tr>
<tr>
<td>5. Design-Build Experiences</td>
<td>A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level</td>
</tr>
<tr>
<td>6. CDIO Workspaces</td>
<td>Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning</td>
</tr>
<tr>
<td>7. Integrated Learning Experiences</td>
<td>Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills</td>
</tr>
<tr>
<td>8. Active Learning</td>
<td>Teaching and learning based on active experiential learning methods</td>
</tr>
<tr>
<td>9. Enhancement of Faculty CDIO Skills</td>
<td>Actions that enhance faculty competence in personal, interpersonal, and product and system building skills</td>
</tr>
<tr>
<td>10. Enhancement of Faculty Teaching Skills</td>
<td>Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning</td>
</tr>
<tr>
<td>11. CDIO Skills Assessment</td>
<td>Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge</td>
</tr>
<tr>
<td>12. CDIO Program Evaluation</td>
<td>A system that evaluates programs against these 12 standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement</td>
</tr>
</tbody>
</table>

With these Standards, the CDIO consortium envisions a curriculum that is

- organized around mutually supporting disciplines, with CDIO activities highly interwoven,
- rich with student design-build projects,
- set both in the classroom and in a modern learning laboratory,
- constantly improved through a robust assessment and evaluation process, and
characterized by active and experiential learning.

This vision is consistent with the Department’s mission\(^1\), and provides a systematic method for mapping the attributes desired by stakeholders (i.e., industry, faculty, alumni, students) into a curriculum that produces engineering graduates with these desirable attributes\(^5\). In the past four years since joining CDIO as a collaborator, the Department has been making significant progress in achieving the 12 Standards. Because the CDIO framework was developed as a model, in adopting and adapting the framework to reform our curriculum, there existed a need to develop a design process that systematically takes into account the uniqueness of the Department’s diverse student population and its available resources while achieving the overarching goals of improving student learning and retention. Thus, the objectives of this paper are to describe the CDIO-based systems engineering design process which was utilized for reforming the design-stem sequence, and to discuss the insights to be used as the basis for spearheading a new NSF-funded project to establish a model framework for adapting and implementing CDIO to improve student learning and retention at institutions similar to CSUN which serve minority and underrepresented undergraduate engineering students\(^6\).

II. Systems Engineering Design Process

In the same spirit that systems engineering concepts are used for designing, implementing, and operating complex systems, the same approach is used here for the design and reform of the Department’s curriculum. This approach leverages the fact that faculty members are engineers who are best at systematically solving design problems in a team-based environment. The team members comprised of five faculty members who teach design courses and the Department Chair. Two of the five faculty members are part-time lecturers with significant industry experience. Involving all relevant faculty members with the leadership of the Chair ensured that there was buy-in from the faculty members and allowed them to take ownership of the classes. The team met for two semesters with team meetings every two weeks, worked on assignments outside meetings, and updated progress to the Department twice per semester.

Figure 2 shows the iterative design steps that the team developed. First, the input from relevant key stakeholders and CDIO Standards were synthesized to identify sets of skills, knowledge, and attitudes (SKA) that students are expected to have upon graduation, while taking into account the uniqueness of our student population, the entire existing curriculum, and the resources (e.g., staff, lab space, equipment, operational funds) available to the Department. With the SKA sets formulated as design requirements, the team identified strategies and constraints of the design and explored different ways to map the requirements to new curricular structures, and to organize the courses around important threads (the most important threads include projects, skills, and disciplines) by weaving one thread into another in stages that are cognitively conducive to students’ natural learning progression. In the creation of the new courses, best teaching and learning methods were utilized to help ensure that students achieve the level of
II.A. Stakeholders’ Inputs and Benchmarking

The first step in implementing the design process shown above was to review and take into account the SKA’s desired by stakeholders through the data obtained from surveys (e.g., senior design exit surveys, interviews, Educational Benchmarking, Inc. surveys) and evaluations (e.g., senior design project evaluation by industry, faculty course evaluations, and ABET report). One of the main data sources that the team used was the result of a benchmarking study that the Department conducted with industry, faculty, and alumni to determine the complete sets of SKA’s for the entire curriculum, and the level of proficiency expected for each SKA. The tool used for the benchmarking was a survey designed by customizing the CDIO Syllabus (See Appendix in Section VI) with inputs from the Department’s faculty and Industrial Advisory Board members. The survey results for selected SKA’s, shown in Figure 3, indicated that there was significant agreement among the stakeholder groups regarding the desirable level of proficiency for these SKA’s\(^6\). More importantly, the results indicated that essential personal, professional, and interpersonal skills such as teamwork and communications are highly valued by industry partners. Currently, these SKA’s are inadequately taught and applied in existing courses, and must be taken into account in the design-stem sequence.

Because the SKA’s shown in Figure 3 were identified for the entire program at a high level, the team used these SKAs to further decompose them into lower levels and adapt them specifically for the design-stem sequence.

\(^6\) Technical knowledge in specific disciplines was not a part of this survey and was left to faculty members in those disciplines to identify. For instance, the technical knowledge in mechanical design was determined by the design-stem sequence faculty team.
II.B. Design Requirements and Constraints for New Curricular Structures

In order to synthesize the design requirements, the team used a four-step approach:

Step 1: Identify strategies for achieving the design goals and constraints

Given that the goals of reforming the design-stem sequence were to improve student learning and retention, in the first step the team identified a set of strategies to achieve this goal and satisfy a set of constraints that the design must meet.

a) Engaging students early and continuously in the program: at present, it takes incoming ME freshmen an average of three semesters to finish the preparatory math, physics, and chemistry requirements before they are qualified to take the first sophomore mechanical engineering course (i.e., ME286A, which requires knowledge of materials science). During this three semester period, the only available mechanical engineering course is ME 101. Thus, to address this disengagement, the team resolved to move more classes to the first two years and relax some of the pre-requisites in order to engage freshmen sooner and continuously with the program.

b) Establishing mutually supporting contents and proficiency in skill levels among the courses: as noted in Section I, the existing design-stem sequence has a number of broken links in passing SKA’s from one class to another, especially in the lack of preparation for students who are entering senior design courses with the expected CAD, FEA, and teamwork and communication skills. Thus, the team resolved to make the courses mutually supportive in contents and proficiency, so that students must be introduced to an
SKA before it is taught and then utilized and that there is enhanced continuity among the courses.

c) *Integrating the teaching of personal and interpersonal skills into the design projects:* Taking into account the benchmarking results presented in Section II.A, the team resolved to enhance collaborative learning by integrating personal and interpersonal skills (communication and teamwork) and CDIO skills into the design projects.

d) *Using active and experiential learning techniques, and planning for the laboratory infrastructure to support the design projects:* Consistent with the Department’s vision outlined in Section I, the team resolved to build three to four experiential design experiences (with a minimum of two hands-on projects) into the curriculum, and to re-task the learning work spaces to enable the implementation of these experiential design projects.

e) *Minimizing impact on total credits and resources:* Given that students must complete 126 credits to meet graduation requirements, and that there is strong push by the university to decrease the total credits to accelerate student graduation and cut operating costs, a constraint that the design must satisfy is that it must have no impact on the credit requirements as well as the financial resources available to the Department.

**Step 2: Define the level of proficiency for each SKA**

In the second step, the team first used the revised CDIO Syllabus adapted for the Department to identify SKA’s for the design-stem sequence, which were divided into the four topics of: technical knowledge related to mechanical design; software skills; personal, professional, and interpersonal (teamwork and communication); and CDIO skills and attitudes. The results are presented in the first column of Tables 2a-2d. To determine the level of proficiency of each SKA, each team member assigned a rating based on a scale of 1 to 3, where a rating of 1 means “having been exposed to”, 2 means “to be able to participate in and contribute”, and 3 means “to be skilled in practice and implementation.” The average ratings given by the team are shown in the “Average Rating” column in the table.

**Step 3: Map SKA sets to years and define the teaching depth (e.g., Introduce, Teach, and Utilize) for each SKA**

Having defined the level of proficiency for each set, the next task was to determine the depth for the teaching of the SKA in each year, from freshman to senior. An I-T-U rating was used to accomplished this, where I means “introduction, without providing homework and feedback,” T means “teach, where assignments are provided and graded”, and U means “utilize the SKA that student had already mastered in a previous course.” The lower case i,t,u denote the existing depth, while the upper case I,T,U denote the new teaching depth that the team proposed. These definitions allowed the team to consider how the SKA should be mapped into and taught in different years from freshman to senior and in a way that is cognitively conducive to students’ natural learning.
progression. For instance, teamwork skill was designed to be first introduced and taught in the freshman year, and then be taught again and utilized in each of the following years. Similarly, CDIO skills were repeatedly taught and utilized after the first time they were introduced in the freshman year.

Using a combination of this assignment of ITU and the level of proficiency identified in Step 2, the instructors can prepare teaching materials and create projects/assignments that are consistent with the required teaching depth (i.e., ITU) by changing the grading, complexity and time duration of the projects and assignments.

**Step 4: Compare design requirements with existing curriculum**

To ensure that the design requirements capture and address all the existing shortcomings in the curriculum, the team compared the teaching depth in the existing design-stem sequence (denoted by lower cases i,t,u) with the proposed teaching depth (denoted by upper case I,T,U), and identified broken links and weaknesses. As indicated in Table 2a-2d, many SKA’s, shown with lower case i,t,u are not currently addressed, and in many cases, students are expected to have a certain SKA for utilization but this SKA either was only introduced, or was not introduced or taught in previous year(s). Some of the key areas with broken links and weaknesses included: a) computer-aided design (CAD) and finite element analysis (FEA) software skills, where students are being expected to be proficient with a CAD tool and numerical stress analysis by the time they enter senior design, but CAD and FEA are being introduced sparingly or taught in piecemeal fashion prior to senior design; b) machine shop skills are not taught in the curriculum but students are expected to have some proficiency to complete their senior design project; and c) personal, interpersonal, and CDIO skills are either inadequately or not mutually supportively introduced or taught in the design-stem sequence on a consistent basis.

<table>
<thead>
<tr>
<th>Technical Knowledge</th>
<th>Average Rating</th>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
</tr>
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<tbody>
<tr>
<td>Free body diagram</td>
<td>2.8</td>
<td>i → I</td>
<td>t → T</td>
<td>t/u → T/U</td>
<td>u → U</td>
</tr>
<tr>
<td>Stress analysis</td>
<td>2.7</td>
<td>i → I</td>
<td>i → I</td>
<td>t → T</td>
<td>u → U</td>
</tr>
<tr>
<td>Failure theories</td>
<td>2.5</td>
<td>i → I</td>
<td>i → I</td>
<td>t → T</td>
<td>u → U</td>
</tr>
<tr>
<td>Dynamics and statics</td>
<td>2.7</td>
<td>i → I</td>
<td>t → T</td>
<td>t → U</td>
<td>u → T</td>
</tr>
<tr>
<td>Vibrations</td>
<td>2.0</td>
<td></td>
<td>i → I</td>
<td>t → T</td>
<td>u → U</td>
</tr>
<tr>
<td>Machine elements</td>
<td>2.5</td>
<td>i → I</td>
<td>i → I</td>
<td>t → T</td>
<td>u → U</td>
</tr>
<tr>
<td>Materials selection</td>
<td>2.3</td>
<td>i → I</td>
<td>t → T</td>
<td>t → T</td>
<td>t/u → T/U</td>
</tr>
<tr>
<td>Manufacturing processes</td>
<td>2.3</td>
<td>→ I</td>
<td>t → T</td>
<td>→ U</td>
<td>u → U</td>
</tr>
<tr>
<td>Design for manufacturing</td>
<td>2.0</td>
<td>→ I</td>
<td>t → T</td>
<td>u → U</td>
<td>u → U</td>
</tr>
<tr>
<td>Numerical analysis</td>
<td>2.3</td>
<td>→ I</td>
<td>i → I</td>
<td>t → T</td>
<td>u → U</td>
</tr>
<tr>
<td>Thermal-Fluid</td>
<td>2.5</td>
<td>→ I</td>
<td>t → T</td>
<td>u → U</td>
<td>t/u → T/U</td>
</tr>
<tr>
<td>Electrical</td>
<td>2.3</td>
<td>→ I</td>
<td>t → T</td>
<td>u → U</td>
<td>t/u → T/U</td>
</tr>
</tbody>
</table>

*Table 2a – Technical Knowledge for Design-Stem Sequence (Existing → New)*
### Table 2b – Software Skill for Design-Stem Sequence (Existing → New)

<table>
<thead>
<tr>
<th>Software Skill</th>
<th>Average Rating</th>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
</tr>
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<tbody>
<tr>
<td>Basic computer skills (Word, Spreadsheet, PowerPoint)</td>
<td>3.0</td>
<td>i/t→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
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<tr>
<td>Simulation (Matlab tool)</td>
<td>2.5</td>
<td>→I</td>
<td></td>
<td>t→T</td>
<td>u→U</td>
</tr>
<tr>
<td>Simulation (FEA tool)</td>
<td>2.5</td>
<td>i→I</td>
<td>i→T</td>
<td>u→U</td>
<td></td>
</tr>
<tr>
<td>Labview tool</td>
<td>2.0</td>
<td>i→I</td>
<td>t→T</td>
<td>u→U</td>
<td></td>
</tr>
<tr>
<td>CAD (SolidWorks tool)</td>
<td>2.8</td>
<td>i→T</td>
<td>t→U</td>
<td>u→U</td>
<td>t/u→T/U</td>
</tr>
<tr>
<td>CAM (ESPRIT)</td>
<td>2.0</td>
<td>→I</td>
<td></td>
<td></td>
<td>u→U</td>
</tr>
<tr>
<td>Plotting/graphing</td>
<td>2.7</td>
<td>→T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Programming (VBA)</td>
<td>2.1</td>
<td>t→T</td>
<td>t/u→T/U</td>
<td>u→U</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2c – Personal, Professional, and Interpersonal SKA for Design-Stem Sequence (Existing → New)

<table>
<thead>
<tr>
<th>Personal, Professional, Interpersonal SKA</th>
<th>Average Rating</th>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimentation</td>
<td>2.3</td>
<td>i→I</td>
<td>i→I</td>
<td>t→T</td>
<td>u→U</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>2.0</td>
<td>i→I</td>
<td>t→T</td>
<td>u→U</td>
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</tr>
<tr>
<td>Machine shop</td>
<td>1.5</td>
<td>i→T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Tolerance</td>
<td>1.7</td>
<td>i→I</td>
<td>t→T</td>
<td>t/u→T/U</td>
<td>u→U</td>
</tr>
<tr>
<td>Statistics (uncertainty)</td>
<td>2.0</td>
<td>i→I</td>
<td>t→T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethics</td>
<td>2.0</td>
<td>i→T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Writing emails</td>
<td>2.0</td>
<td>i→T/U</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Technical writing</td>
<td>2.5</td>
<td>i→T/U</td>
<td>t/u→T/U</td>
<td>t/u→T/U</td>
<td>u→U</td>
</tr>
<tr>
<td>Presentation skills</td>
<td>2.7</td>
<td>t→T</td>
<td>t/u→T/U</td>
<td>t/u→T/U</td>
<td>u→U</td>
</tr>
<tr>
<td>Sketching</td>
<td>1.3</td>
<td>i→I</td>
<td>u→T/U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Networking</td>
<td>2.0</td>
<td>i→T/I</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>“Info research”</td>
<td>1.8</td>
<td>i→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Life-long learning</td>
<td>1.8</td>
<td>i→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Interviewing/resume writing</td>
<td>1.8</td>
<td>i→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Career planning</td>
<td>2.0</td>
<td>i→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Critical thinking/Systems problem solving</td>
<td>2.2</td>
<td>i→I</td>
<td>t→T</td>
<td>t/u→T/U</td>
<td>t/u→T/U</td>
</tr>
<tr>
<td>Time and resource management</td>
<td>2.2</td>
<td>i/t→I/T</td>
<td>u→U</td>
<td>u→U</td>
<td>u→U</td>
</tr>
<tr>
<td>Team work</td>
<td>1.3</td>
<td>i→I/T</td>
<td>u→T/U</td>
<td>u→T/U</td>
<td>u→T/U</td>
</tr>
</tbody>
</table>

Table 2c – Personal, Professional, and Interpersonal SKA for Design-Stem Sequence (Existing → New)
Table 2d – CDIO Skills for Design-Stem Sequence (Existing → New)

II.C. New Curricular Structure(s) for Design-Stem Sequence

With the SKA’s defined for the design-stem, the team went through an iterative process to explore different ways to map the SKA’s into new curricular structures while taking into account the constraints defined in Section II.B. Essentially the 14 units associated with the courses shown in Figure 1 were available, as well as the current 15 elective units in the program. The team iterated through a few curricular structure alternatives and chose the one shown in the last column in Table 3 below. This curricular structure meets the design requirements and constraints while balancing the resources available to the Department. The new structure adds three units to the number of units in the existing structure by reducing the program elective units from fifteen to twelve. The engagement of freshman students is maintained continuously in the program with a new CAD course (ME186), a new non-credit machine shop seminar, and the existing ME101. The engagement is maintained into the sophomore year with a Mechanical Design Course in ME286, and a Programming for Mechanical Engineers course in ME209. With this structure, most of our students will be able to take at least one mechanical engineering course per semester in the first two years with the program, while completing the math, physics, and chemistry requirements. Following the two sophomore courses, the continuity in the design sequence is extended into the junior year with a new Computer-Aided Analysis and Design course (ME386) that teaches finite element analysis in place of a required senior elective. This course specifically addresses the present weakness in student ability to perform numerical stress analysis and will help prepare students for senior design and modern industrial practice.
<table>
<thead>
<tr>
<th>Freshman</th>
<th>Existing Design-Stem Sequence Curricular Structure</th>
<th>New Design-Stem Sequence Curricular Structure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME101 Intro to Mechanical Engineering (Freshman, 1 unit lecture and 1 unit lab) Prerequisite: None</td>
<td>ME101 Intro to Mechanical Engineering (Freshman, 1 unit lecture and 1 unit lab) Prerequisite: None</td>
<td>Content changed to include additional SKA’s</td>
</tr>
<tr>
<td></td>
<td>ME 186 Computer-Aided Design (Freshman, 1 unit lecture and 1 unit lab) Prerequisite: ME101</td>
<td>Machine Shop Seminar (Freshman/Sophomore, Non-Credit) Prerequisite: None</td>
<td>CAD content previously in 286AL moved to freshman level</td>
</tr>
<tr>
<td>Sophomore</td>
<td>ME286A Mechanical Design I (Sophomore, 2 units lecture and 1 unit lab) Prerequisite: Physics I and Calculus I</td>
<td>ME286 Mechanical Design (Sophomore, 2 units lecture) Prerequisite: ME186</td>
<td>Includes lecture material from 286A (design for manufacturing)</td>
</tr>
<tr>
<td></td>
<td>ME286B Mechanical Design II (Sophomore, 1 unit lecture and 1 unit lab) Prerequisite: ME286A and Calculus II</td>
<td>ME209 Programming for Mechanical Engineers (Sophomore, 1 unit lab) Prerequisite: Calculus I</td>
<td>Introduction to programming is presented in separate course</td>
</tr>
<tr>
<td>Junior</td>
<td>ME330 Machine Design (Junior, 3 units lecture) Prerequisite: ME286B and CE340</td>
<td>ME330 Machine Design (Junior, 3 units lecture) Prerequisite: ME286 and CE340</td>
<td>Essentially unchanged</td>
</tr>
<tr>
<td>Senior</td>
<td>ME486 Senior Design (Senior, 4 units lab) Prerequisite: Senior Standing</td>
<td>ME486 Senior Design (Senior, 4 units lab) Prerequisite: Senior Standing</td>
<td>Essentially unchanged</td>
</tr>
</tbody>
</table>

Table 3: New and Existing Design-Stem Structure

The team also addressed the inadequacy in the personal, interpersonal, and CDIO skills by weaving these SKA’s into the courses’ design projects. To facilitate this, the team built five design projects into the sequence: first by maintaining two hands-on projects in ME101 and ME486 that involve students in all phases of conceiving-designing-implementing-operating a product/system; and three paper design projects of increasing complexity in ME 186, ME286 and ME386 that involve students in the conceiving and designing phases with a heavy emphasis on related software skills. All three paper design projects involve student teams working together to produce design concepts, CAD models, and written and oral presentations of their results. The project scope in each of these courses can be described as follows:
- ME 186 – project focus is on learning and applying appropriate design methodology, development of CAD skills using SolidWorks, and effectively communicating project results in written and oral formats

- ME 286 – utilizes SKA’s learned in ME 186, with an emphasis on materials used in the design and manufacturing processes required for fabrication

- ME 386 – utilizes SKA’s learned in ME 186 and ME 286, with an emphasis on stress analysis using CosmosWorks to ensure that the design will perform under expected service loads. This course will be closely integrated with ME 330 (Machine Design), which teaches the analysis of machine elements using traditional methods.

It is believed that this repeated exposure to design projects and the gradual development of related SKA’s will significantly enhance the effectiveness of the senior design project experience for our students, as well as their preparation for jobs with local industry.

Finally, the Department has been working in the past two years to design and construct a new Design Center, which was mainly funded by a grant from the Department of Defense. The Design Center, completed as of the writing of this paper, provides the necessary industry-like workspaces for the implementation of the new design projects. It houses a team project space and a general computer workstation space for students to Conceive and Design systems/products, a high-performance workstation space dedicated to senior design projects, and a professional conference room for students to practice and make technical presentations.

### III. Conclusion and Call for Collaboration

In order to reform its design-stem sequence of courses to improve student learning and retention, the team leveraged on a systems engineering approach to develop a CDIO-based design process that involves taking into account stakeholders’ inputs, formulating the inputs as design requirements, identifying design constraints, mapping the design requirements into viable curricular structures, and re-tasking workspaces to support the design project activities. The result of the implementation of the curriculum design process was a new design-stem sequence that met all the design requirements and constraints, and will be implemented and evaluated continuously starting in the Fall of 2009. To further refine and improve this CDIO-based design process, we are currently using it to examine and modify the thermal-fluid sequence.

The successful utilization of the developed design process suggests that the process itself and the strategies can form the basis for developing a more generalizable framework that can be exported and replicated outside CSUN. To build on this success, the Department has recently been awarded with an NSF CCLI grant that proposes to establish a CDIO framework that can be generalized for and has programmatic impact at minority institutions with student populations similar to CSUN. The proposed framework consists
of two components: adaptation and implementation. The first component is the Department adaptation of the 12 CDIO Standards in such a way that will promote and integrate activities that lead to increasing the amount of time students devote to studying on campus; interacting with other students and faculty members; and participating in professional engineering organizations. The second component is the implementation that seeks to benchmark the curriculum, design a curriculum that reflects the stakeholders’ inputs and ensure that the curriculum continues to meet CDIO Standards over the long run. The implementation also seeks to identify key factors that enable the change process such as having the faculty members understand—and commit to—the need for change; generating visibility for early successes; gaining support from influential administrators and faculty members; allocating adequate resources; enhancing faculty learning of the process; and recognizing the contribution of faculty members who are involved.

Given that U.S. engineering workforce needs call for 48% representation by underrepresented minorities by 2050\textsuperscript{7,8}, and meeting this need will be challenging (data show that STEM students who are African American, Latino, and American Indian remain vastly underrepresented in university populations compared to their presence in the U.S. population\textsuperscript{9,10}), we believe that the solutions must take a multi-disciplinary, multi-institution, and multi-stakeholder approach in which we can learn from the important resources and approaches that various organizations are developing. Thus, we would like to invite you to collaborate with us on this NSF project in our pursuit of developing a framework to retain more minority engineers in particular, and working towards a common, shared goal of improving engineering education in general.

IV. References

1. www.csun.edu/me
2. R. Ryan, N. Ho, "A Sophomore Design Course Sequence for Mechanical Engineering Students," ASEE Pacific Southwest Conference, California State Polytechnic University, Pomona, April 20-21, 2006
3. www.cdio.org
5. N. Ho, R. Ryan, M. Filbeck, S. Plunkett, "Design, Build, and Learn -- Adapting the CDIO Framework to Improve Learning in a Diverse Student Population," Department of Mechanical Engineering, California State University, Northridge, Report 2005-2, May 17, 2005


V. Acknowledgements

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VI. Appendix - The CDIO Syllabus in Topical Form (v 4.2.3)

1. TECHNICAL KNOWLEDGE AND REASONING

1.1 KNOWLEDGE OF UNDERLYING SCIENCES [a]

1.1.1 Mathematics (including statistics)
1.1.2 Physics
1.1.3 Chemistry
1.1.4 Biology

1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [a]

1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE [k]

2. PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ENGINEERING REASONING AND PROBLEM SOLVING [e]

2.1.1 Problem Identification and Formulation
Data and symptoms
Assumptions and sources of bias
Issue prioritization in context of overall goals
A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)

2.1.2 Modeling
Assumptions to simplify complex systems and environment
Conceptual and qualitative models
Quantitative models and simulations

2.1.3 Estimation and Qualitative Analysis
Orders of magnitude, bounds and trends
Tests for consistency and errors (limits, units, etc.)
The generalization of analytical solutions

2.1.4 Analysis With Uncertainty
Incomplete and ambiguous information
Probabilistic and statistical models of events and sequences
Engineering cost-benefit and risk analysis
Decision analysis
2.1.5 **Solution and Recommendation**
- Problem solutions
- Essential results of solutions and test data
- Discrepancies in results
- Summary recommendations
- Possible improvements in the problem solving process

2.2 **EXPERIMENTATION AND KNOWLEDGE DISCOVERY**

2.2.1 **Hypothesis Formulation**
- Critical questions to be examined
- Hypotheses to be tested
- Controls and control groups

2.2.2 **Survey of Print and Electronic Literature**
- The literature research strategy
- Information search and identification using library tools (on-line catalogs, databases, search engines)
- Sorting and classifying the primary information
- The quality and reliability of information
- The essentials and innovations contained in the information
- Research questions that are unanswered
- Citations to references

2.2.3 **Experimental Inquiry**
- The experimental concept and strategy
- The precautions when humans are used in experiments
- Experiment construction
- Test protocols and experimental procedures
- Experimental measurements
- Experimental data
- Experimental data vs. available models

2.2.4 **Hypothesis Test, and Defense**
- The statistical validity of data
- The limitations of data employed
- Conclusions, supported by data, needs and values
- Possible improvements in knowledge discovery process

2.3 **SYSTEM THINKING**

2.3.1 **Thinking Holistically**
- A system, its behavior, and its elements
- Trans-disciplinary approaches that ensure the system is understood from all relevant perspectives
- The societal, enterprise and technical context of the system
- The interactions external to the system, and the behavioral impact of the system

2.3.2 **Emergence and Interactions in Systems**
- The abstractions necessary to define and model system
- The behavioral and functional properties (intended and unintended) which emerge from the system
- The important interfaces among elements
- Evolutionary adaptation over time

2.3.3 **Prioritization and Focus**
- All factors relevant to the system in the whole
- The driving factors from among the whole
- Energy and resource allocations to resolve the driving issues

2.3.4 **Trade-offs, Judgment and Balance in Resolution**
- Tensions and factors to resolve through trade-offs
- Solutions that balance various factors, resolve tensions and optimize the system as a whole
Flexible vs. optimal solutions over the system lifetime
Possible improvements in the system thinking used

2.4 PERSONAL SKILLS AND ATTITUDES

2.4.1 Initiative and Willingness to Take Risks
The needs and opportunities for initiative
The potential benefits and risks of an action
The methods and timing of project initiation
Leadership in new endeavors, with a bias for appropriate action
Definitive action, delivery of results and reporting on actions

2.4.2 Perseverance and Flexibility
Self-confidence, enthusiasm, and passion
The importance of hard work, intensity and attention to detail
Adaptation to change
A willingness and ability to work independently
A willingness to work with others, and to consider and embrace various viewpoints
An acceptance of criticism and positive response
The balance between personal and professional life

2.4.3 Creative Thinking
Conceptualization and abstraction
Synthesis and generalization
The process of invention
The role of creativity in art, science, the humanities and technology

2.4.4 Critical Thinking
The statement of the problem
Logical arguments and solutions
Supporting evidence
Contradictory perspectives, theories and facts
Logical fallacies
Hypotheses and conclusions

2.4.5 Awareness of One’s Personal Knowledge, Skills and Attitudes
One’s skills, interests, strengths, weaknesses
The extent of one’s abilities, and one’s responsibility for self-improvement to overcome important weaknesses
The importance of both depth and breadth of knowledge

2.4.6 Curiosity and Lifelong Learning
The motivation for continued self-education
The skills of self-education
One’s own learning style
Developing relationships with mentors

2.4.7 Time and Resource Management
Task prioritization
The importance and/or urgency of tasks
Efficient execution of tasks

2.5 PROFESSIONAL SKILLS AND ATTITUDES

2.5.1 Professional Ethics, Integrity, Responsibility and Accountability
One’s ethical standards and principles
The courage to act on principle despite adversity
The possibility of conflict between professionally ethical imperatives
An understanding that it is acceptable to make mistakes, but that one must be accountable for them
Proper allocation of credit to collaborators
A commitment to service

2.5.2 Professional Behavior
A professional bearing
Professional courtesy
International customs and norms of interpersonal contact

2.5.3 **Proactively Planning for One's Career**
- A personal vision for one’s future
- Networks with professionals
- One’s portfolio of professional skills

2.5.4 **Staying Current on World of Engineer**
- The potential impact of new scientific discoveries
- The social and technical impact of new technologies and innovations
- A familiarity with current practices/technology in engineering
- The links between engineering theory and practice

3. **INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**

3.1 **TEAMWORK**

3.1.1 **Forming Effective Teams**
- The stages of team formation and life cycle
- Task and team processes
- Team roles and responsibilities
- The goals, needs and characteristics (works styles, cultural differences) of individual team members
- The strengths and weakness of the team
- Ground rules on norms of team confidentiality, accountability and initiative

3.1.2 **Team Operation**
- Goals and agenda
- The planning and facilitation of effective meetings
- Team ground rules
- Effective communication (active listening, collaboration, providing and obtaining information)
- Positive and effective feedback
- The planning, scheduling and execution of a project
- Solutions to problems (team creativity and decision making)
- Conflict negotiation and resolution

3.1.3 **Team Growth and Evolution**
- Strategies for reflection, assessment, and self-assessment
- Skills for team maintenance and growth
- Skills for individual growth within the team
- Strategies for team communication and writing

3.1.4 **Leadership**
- Team goals and objectives
- Team process management
- Leadership and facilitation styles (directing, coaching, supporting, delegating)
- Approaches to motivation (incentives, example, recognition, etc)
- Representing the team to others
- Mentoring and counseling

3.1.5 **Technical Teaming**
- Working in different types of teams:
  - Cross-disciplinary teams (including non-engineer)
  - Small team vs. large team
  - Distance, distributed and electronic environments
- Technical collaboration with team members

3.2 **COMMUNICATIONS**

3.2.1 **Communications Strategy**
- The communication situation
- Communications objectives
- The needs and character of the audience
3.2.2 Communications Structure
Logical, persuasive arguments
- The appropriate structure and relationship amongst ideas
- Relevant, credible, accurate supporting evidence
- Conciseness, crispness, precision and clarity of language
- Rhetorical factors (e.g. audience bias)
Cross-disciplinary cross-cultural communications

3.2.3 Written Communication
Writing with coherence and flow
Writing with correct spelling, punctuation and grammar
Formatting the document
Technical writing
Various written styles (informal, formal memos, reports, etc)

3.2.4 Electronic/Multimedia Communication
Preparing electronic presentations
- The norms associated with the use of e-mail, voice mail, and videoconferencing
- Various electronic styles (charts, web, etc)

3.2.5 Graphical Communication
Sketching and drawing
Construction of tables, graphs and charts
Formal technical drawings and renderings

3.2.6 Oral Presentation and Inter-Personal Communications
Preparing presentations and supporting media with appropriate language, style, timing and flow
- Appropriate nonverbal communications (gestures, eye contact, poise)
- Answering questions effectively

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
3.3.1 English
3.3.2 Languages of Regional Industrialized Nations
3.3.3 Other Languages

4. CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT
4.1 EXTERNAL AND SOCIETAL CONTEXT [h]
4.1.1 Roles and Responsibility of Engineers
The goals and roles of the engineering profession
The responsibilities of engineers to society

4.1.2 The Impact of Engineering on Society
The impact of engineering on the environment, social, knowledge and economic systems in modern culture

4.1.3 Society’s Regulation of Engineering
The role of society and its agents to regulate engineering
The way in which legal and political systems regulate and influence engineering
How professional societies license and set standards
How intellectual property is created, utilized and defended

4.1.4 The Historical and Cultural Context
The diverse nature and history of human societies as well as their literary, philosophical, and artistic traditions
The discourse and analysis appropriate to the discussion of language, thought
and values

4.1.5 Contemporary Issues and Values \[j\]
The important contemporary political, social, legal and environmental issues and values
The process by which contemporary values are set, and one’s role in these processes
The mechanisms for expansion and diffusion of knowledge

4.1.6 Developing a Global Perspective
The internationalization of human activity
The similarities and differences in the political, social, economic, business and technical norms of various cultures
International inter-enterprise and inter-governmental agreements and alliances

4.2 ENTERPRISE AND BUSINESS CONTEXT

4.2.1 Appreciating Different Enterprise Cultures
The differences in process, culture, and metrics of success in various enterprise cultures:
Corporate vs. academic vs. governmental vs. non-profit/NGO
Market vs. policy driven
Large vs. small
Centralized vs. distributed
Research and development vs. operations
Mature vs. growth phase vs. entrepreneurial
Longer vs. faster development cycles
With vs. without the participation of organized labor

4.2.2 Enterprise Strategy, Goals, and Planning
The mission and scope of the enterprise
An enterprise’s core competence and markets
The research and technology process
Key alliances and supplier relations
Financial and managerial goals and metrics
Financial planning and control
The stake-holders (owners, employees, customers, etc.)

4.2.3 Technical Entrepreneurship
Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products and systems
Entrepreneurial finance and organization

4.2.4 Working Successfully in Organizations
The function of management
Various roles and responsibilities in an organization
The roles of functional and program organizations
Working effectively within hierarchy and organizations
Change, dynamics and evolution in organizations

4.3 CONCEIVING AND ENGINEERING SYSTEMS \[c\]

4.3.1 Setting System Goals and Requirements
Market needs and opportunities
Customer needs
Opportunities which derive from new technology or latent needs
Factors that set the context of the requirements
Enterprise goals, strategies, capabilities and alliances
Competitors and benchmarking information
Ethical, social, environmental, legal and regulatory influences
The probability of change in the factors that influence the system, its goals and resources available
System goals and requirements
4.3.2 Defining Function, Concept and Architecture

- Necessary system functions (and behavioral specifications)
- System concepts
- The appropriate level of technology
- Trade-offs among and recombination of concepts
- High level architectural form and structure
- The decomposition of form into elements, assignment of function to elements, and definition of interfaces

4.3.3 Modeling of System and Ensuring Goals Can Be Met

- Appropriate models of technical performance
- The concept of implementation and operations
- Life cycle value and costs (design, implementation, operations, opportunity, etc.)
- Trade-offs among various goals, function, concept and structure and iteration until convergence

4.3.4 Development Project Management

- Project control for cost, performance, and schedule
- Appropriate transition points and reviews
- Configuration management and documentation
- Performance compared to baseline
- Earned value recognition
- The estimation and allocation of resources
- Risks and alternatives
- Possible development process improvements

4.4 Designing

4.4.1 The Design Process

- Requirements for each element or component derived from system level goals and requirements
- Alternatives in design
- The initial design
- Experiment prototypes and test articles in design development
- Appropriate optimization in the presence of constraints
- Iteration until convergence
- The final design
- Accommodation of changing requirements

4.4.2 The Design Process Phasing and Approaches

- The activities in the phases of system design (e.g. conceptual, preliminary, and detailed design)
- Process models appropriate for particular development projects (waterfall, spiral, concurrent, etc.)
- The process for single, platform and derivative products

4.4.3 Utilization of Knowledge in Design

- Technical and scientific knowledge
- Creative and critical thinking, and problem solving
- Prior work in the field, standardization and reuse of designs (including reverse engineer and redesign)
- Design knowledge capture

4.4.4 Disciplinary Design

- Appropriate techniques, tools, and processes
- Design tool calibration and validation
- Quantitative analysis of alternatives
Modeling, simulation and test
Analytical refinement of the design

4.4.5 Multidisciplinary Design
Interactions between disciplines
Dissimilar conventions and assumptions
Differences in the maturity of disciplinary models
Multidisciplinary design environments
Multidisciplinary design

4.4.6 Multi-Objective Design (DFX)
Design for:
- Performance, life cycle cost and value
- Aesthetics and human factors
- Implementation, verification, test and environmental sustainability
- Operations
- Maintainability, reliability, and safety
- Robustness, evolution, product improvement and retirement

4.5 IMPLEMENTING [c]

4.5.1 Designing the Implementation Process
The goals and metrics for implementation performance, cost and quality
The implementation system design:
- Task allocation and cell/unit layout
- Work flow
- Considerations for human user/operators

4.5.2 Hardware Manufacturing Process
The manufacturing of parts
The assembly of parts into larger constructs
- Tolerances, variability, key characteristics and statistical process control

4.5.3 Software Implementing Process
The break down of high level components into module designs (including algorithms and data structures)
- Algorithms (data structures, control flow, data flow)
- The programming language
- The low-level design (coding)
- The system build

4.5.4 Hardware Software Integration
The integration of software in electronic hardware (size of processor, communications, etc)
The integration of software with sensor, actuators and mechanical hardware
- Hardware/software function and safety

4.5.5 Test, Verification, Validation, and Certification
Test and analysis procedures (hardware vs. software, acceptance vs. qualification)
The verification of performance to system requirements
The validation of performance to customer needs
The certification to standards

4.5.6 Implementation Management
The organization and structure for implementation
- Sourcing, partnering, and supply chains
- Control of implementation cost, performance and schedule
- Quality and safety assurance
- Possible implementation process improvements

4.6 OPERATING [c]

4.6.1 Designing and Optimizing Operations
The goals and metrics for operational performance, cost, and value
Operations process architecture and development
Operations (and mission) analysis and modeling
4.6.2 Training and Operations
   Training for professional operations:
   Simulation
   Instruction and programs
   Procedures
   Education for consumer operation
   Operations processes
   Operations process interactions

4.6.3 Supporting the System Lifecycle
   Maintenance and logistics
   Lifecycle performance and reliability
   Lifecycle value and costs
   Feedback to facilitate system improvement

4.6.4 System Improvement and Evolution
   Pre-planned product improvement
   Improvements based on needs observed in operation
   Evolutionary system upgrades
   Contingency improvements/solutions resulting from operational necessity

4.6.5 Disposal and Life-End Issues
   The end of useful life
   Disposal options
   Residual value at life-end
   Environmental considerations for disposal

4.6.6 Operations Management
   The organization and structure for operations
   Partnerships and alliances
   Control of operations cost, performance and scheduling
   Quality and safety assurance
   Possible operations process improvements
   Life cycle management