Continued Development and Implementation of a Two-Course Sequence Designed to Transform the First-Year Experience for Engineering Undergraduates

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***Abstract* - Further pedagogical development continues at the University of Louisville (UofL) for *Engineering Methods, Tools, and Practice I* and *II*, a two-course sequence that will commence in Fall 2016 and be required by all first-year engineering students. This paper gives an overview of the sequence structure, highlights pertinent steps taken to further develop the sequence since FYEE 2015, discusses key components identified to ensure successful sequence implementation, and provides detail pertaining to planned course assessment. The sequence has been structured in a manner in which fundamental engineering skills will be introduced and practiced in a primarily classroom setting during the first course. The second course will be set in UofL's new student makerspace, and it will focus on integration and application of the fundamental engineering skills established in the first course including (but not limited to): 1) engineering professionalism (ethics, culture, and risk), 2) basic computational and programming skills, 3) graphical, oral and written communication, 4) problem solving, 5) design analysis, 6) teamwork (emphasizing diversity and inclusion), and 7) project management. The Paul-Elder Critical Thinking Framework will also be taught and used throughout both courses. The second-semester course will also provide the students with 3D printers for creating student-designed parts, and students will utilize Arduino components in conjunction with programming aspects of the curriculum. Primary means of instructional delivery (in both courses) will consist of in-class presentations and out-of-class videos, while students will practice and apply learned skills via written assignments, activities, construction, experimentation and design. Assessment for the two-course sequence will use both qualitative and quantitative analysis. The qualitative analysis will assess students' identification with engineering, critical thinking, and an understanding of the engineering design process. The quantitative assessment will include graded homework, team assignments, and designing and building products.**

Index Terms - first-year engineering education, design project, introduction to engineering

INTRODUCTION

In 2014, faculty at the J.B. Speed School of Engineering (SSoE) at the University of Louisville (UofL) initiated a process of reconsidering how students are introduced to the profession of engineering, and ensuring that the basic methods and tools that will be used in subsequent courses will be provided. The first step of this process involved the development of a college-wide committee tasked with evaluating existing instruction in introductory engineering, graphics, and programming courses. Committee action concluded with the recommendation to replace the current courses in these areas with a first-year, two-course sequence (ENGR 110 and ENGR 111, respectively) that provides an introduction to essential methods, tools, and practice for success in engineering.

Although curriculum for numerous fundamental engineering skills have since been developed for the sequence, the *primary* skill areas mandated by the committee include: 1) engineering professionalism (ethics, culture, and risk), 2) basic computational and programming skills, 3) graphical, oral and written communication, 4) problem solving, 5) design analysis, 6) teamwork (emphasizing diversity and inclusion), and 7) project management. ENGR 110 (*Engineering Methods, Tools & Practice I*) will focus on skills introduction and practice. This course will be set in a classroom environment. ENGR 111 (*Engineering Methods, Tools & Practice II*) will focus on hands-on skills integration and application. This course will be set in the Engineering Garage (EG), a 15,000 square feet makerspace (with two 48 seat classrooms) expected to uniquely impact the first-year experience. Early in ENGR 110, students will be taught the Paul-Elder (PE) Critical Thinking Framework [1] – [6] and teamwork, and both will be utilized throughout the rest of the two-course sequence. Initial details pertaining to this two-course sequence were disseminated through a conference paper and presentation at the FYEE 2015 Conference [**7**]. This paper will focus on new developments to the ENGR 110

and 111 sequence conducted this past year, including establishing plans for course assessment.

ENGINEERING METHODS, TOOLS & PRACTICE I (ENGR 110)

In addition to the primary skills described previously, this course provides an introduction to the National Academy of Engineers Grand Challenges for Engineering [8]. The Grand Challenges provide a framework and context for many of the course assignments. Details regarding assignments and instruction related to the major course elements are provide below.

I. Critical Thinking

Upon early exposure to and instruction on critical thinking, students are required to utilize the PE critical thinking framework while writing two personal reflections; the first centers on the Grand Challenges, writing about which one they would address if given a large sum of money. The other critical thinking reflection is on their choice of major. The students apply the PE critical thinking framework, reflecting on how they chose a major or discipline. Another critical thinking activity, the end-of-semester final project is a team-based hands-on vector report and presentation [9]. In the vector project, students are given a tape measure and compass to measure two different vector paths between specified start and stop locations on campus. They are then instructed to compare measured results to theoretical results and reflect critically on these outcomes.

II. Teamwork

Instruction on teamwork emphasizes diversity and inclusion, and teams are made within the first couple weeks of class. Course administrators utilize a system of wed-based tools that enable instructors to implement the best practices in managing student teams, called the Comprehensive Assessment of Team Member Effectiveness (CATME) [10-15]. CATME Team-Maker will help the instructors create teams [12-15], and students will utilize CATME Peer Evaluation for self- and peer-evaluations of fellow teammates using a behaviorally-anchored rating scale [10-11,16].

III. Communication

Graphical communication is integrated into ENGR 110 with a focus on hand drafting and visualization over a 3-4 week period. It is pertinent to note that an additional graphics course focused on 2D modeling software will be offered separately for majors that require more depth in graphics instruction. Oral communication will be practiced through a team-based student-created video that summarizes one of the Grand Challenges and through the vector project presentation. Written communication will be practiced via a team-written report for the vector project and the reflections. Prior to delivery of the vector project report for grading, students are provided the opportunity to receive feedback by means of peer assessment from other teams.

IV. Excel and Programming

Introductory pedagogy in programming and problem solving will be conducted via online modules from the Pearson international media company [17]. Utilizing MyProgrammingLab [18], Python is the programming language for the course. Programming skills are taught through 6 modules over a 6-week period. Students will also develop and refine their skills in Microsoft Excel by utilizing MyITLab [19]. The Excel component will consist of 4 modules over a 4-week period.

V. Other Elements of ENGR 110

Additional key features of ENGR 110 include introduction to engineering professionalism, ethics, culture and risk, and the process for becoming a licensed Professional Engineer in Kentucky. All freshmen have open time in their Friday afternoon schedules, thus students will be provided further opportunities to strengthen their academic and professional foundations by attending extra weekly (Friday) sessions to include: 1) departmental presentations to provide first-year engineers a deeper understanding of the engineering majors taught at SSoE, 2) employer panels consisting of personnel from various companies that hire SSoE engineering graduates that provide tips and share experience(s) pertaining to the transition from academia to the professional world, and 3) student-success seminars developed by SSoE's Academic Affairs department, and designed specifically for engineering majors to further enhance the likelihood of success at SSoE.

ENGINEERING METHODS, TOOLS & PRACTICE II (ENGR 111)

ENGR 111 will promote integration and application of skills through the following modes: written assignments, activities, construction, experimentation and design. The first few weeks in the course will take place in the classroom space in the EG. All required written assignments for this course occur during this period (with the exception of a final written report due at the end of the semester), and topics covered during this time include safety proficiency, project management, technical writing, 3D modeling & printing, circuitry, and introduction to design. Upon completion of this early stage of the course, students will be moved to the maker-space within the EG facility, teams will be formed in the same manner as ENGR 110, and pedagogical modes will be team-based for the rest of the semester. Course activities will be accompanied with lab sheets for students to record established team roles, measurements, etc., and most of these lab sheets will be concluded with follow-up questions that are rooted in the critical thinking elements. Most of the daily curriculum for this course has been developed so that

fundamental engineering skills are integrated with the construction of, experimentation with, and design for a bench-scale power plant. The semester will finish with team-written report(s) and oral presentation(s) on this project.

Sample activities include those associated with hand tool training (the first activity conducted once the class moves to the makerspace), and hands-on problem solving exercises of the 'brain teaser' variety. Student teams will also construct their own bench-scale windmill and AC motor. Integrated within these constructs will be various mechanical and electrical experiments. For example, one experiment requires teams to calculate power generation via lifting weights, pumping water, and directly measuring with a multimeter. Teams will then compare respective results and reflect critically on them.

Distribution of the electrical power generated will be accomplished via student-constructed circuitry using the Arduino electronics platform. Arduino will also be used for two different programming assignments that students will be tasked with during the course. The first programming objective will be to write & de-bug a tachometer program. Students will construct a sensor assembly on the windmill shaft & write a program that measures the revolutions per minute (rpm) of the windmill. The second programming objective will involve, using the Arduino display and switches/buttons, writing a program that will display three different system parameters: power output, rpm (from the tachometer) & system efficiency.

Student instruction in design procedure begins with introduction to the early stages of the design process, including problem definition, gathering information, and creating objective trees and decision matrices. Students will also experience their first exposure to design methodology and analysis, including generative design and optimization. In addition to basic blade design for the windmill earlier in the course, the major design objective for ENGR 111 tasks teams with designing and creating (by means of 3D printing) a motor mount for fastening the windmill-driven AC motor to the top of the windmill.

Finally, course administrators have identified three key areas of collaborative and logistical requirements for ensuring efficient and successful course administration, as follows:

- **Safety**: Student safety is paramount, and steps have been taken to ensure all requisite safety supplies and equipment are provided and/or installed in the EG. Safety training, developed to encompass all safety guidelines in accordance with university and state mandates, will take place during the first week of the course; and all students will be required to satisfactorily complete a safety proficiency exam prior to moving from the classroom to the makerspace within the EG.
- **Manpower**: Steps have been taken to ensure that resources, assistance, and support are successfully provided for the large quantity of students (approximately 600) that will be participating in a multitude of tasks during course implementation. This includes maintaining course equipment such as tools, parts and 3D printers, assisting in the development of course curriculum, and providing student guidance and supervision during class hours. In the spring of 2016, course administrators sought to strengthen these manpower requirements by interviewing numerous graduate students from SSoE, resulting in the hiring of seven teaching assistants.
- **Space Readiness**: In addition to the aforementioned requirement of ensuring the makerspace satisfies safety standards, other space readiness requirements that needed to be resolved prior to course implementation were the establishment of student work stations, tools and toolboxes, and the formation of a storage area for student projects and 3D printers. Also, since the EG is a shared space amongst various entities within UofL, strategies have been developed and agreed upon with respect to rules and procedures that are to be followed by said entities (during ENGR 111 class hours) to ensure no external distractions or interference with student learning experience.

ASSESSMENT

Assessment for the two-course sequence will use both qualitative and quantitative analysis. The qualitative analysis includes students' identification with different aspects of engineering, critical thinking (choice of major reflection, Grand Challenges reflection, and vector project), and an understanding of the engineering design process. The assessment of students' comprehension of different aspects of engineering will utilize an epistemology of engineering. The students will write a short essay on what they think engineering is after taking both ENGR 110 and 111 and it will be analyzed using the epistemology. Critical thinking reflections will be assessed using a rubric created for assessing critical thinking [1-2, 5-6]. The engineering design process is being taught in ENGR 111 with a hands-on project. The assessment of the design process will be through the completion of the project, and the end-of-semester presentation and the paper.

The quantitative assessment will include many of the quantifiable pieces of the course, such as homework, team assignments, designing and building products, and CATME self- and peer-evaluations. Homework and team assignments have rubrics that will assess how well the students learned the objectives for the course. The CATME self- and peer-evaluations are run online through the CATME website to assess how well the teams do at being team members. The CATME system analyses the data and flags unusual rating patterns for faculty to follow up with students.

The assessment of the two course sequence is essential in building and maintaining a continuous improvement system for the courses to be able to identify and change certain aspects of the course to meet the needs of the students, faculty, and university.

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