Extended Abstract: Factors Affecting Student Ability to Internalize the Engineering Design Process

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***Abstract* – The primary goal of the research presented in this extended abstract is to identify factors affecting the degree to which first year engineering students internalize and "own" the engineering design process. The ability of two different student populations to do so is studied: traditional first year students in a four-year program and (mostly) non-traditional students in a two-year program. Insight comes also from second – fourth year students reflecting on their first year experiences and continued (non)use of the engineering design process. The data from which preliminary results are developed and conclusions drawn come from qualitative analysis of student responses to exam questions and scenarios.**

Index Terms – engineering design process, qualitative analysis, scenario evaluation.

INTRODUCTION

In first-year engineering undergraduate programs with a design component, students are typically introduced to the concept and practice of engineering design primarily through lecture, discussion, and project-based design-build-test activities. A key instructional decision is to select which pedagogy(ies) to emphasize; in turn, the selection drives the course syllabus. The decision(s) and resulting syllabus are shaped by, among other considerations, philosophy of engineering education, experience and research.

As an instructor of both cornerstone and capstone courses, I am interested in determining the extent to which design learning persists throughout the undergraduate career and the factors facilitating such persistence. Anecdotally, a number of fourth year students in the capstone course report that they have not had design experiences in courses during the intervening years and/or that their *Introduction to Engineering* course's focus was not on design. [1]

I had the opportunity to be the instructor of EGR 120, *Introduction to Engineering* at Piedmont Virginia Community College (PVCC) in Spring, 2013. Since it was a last-minute assignment, I agreed to work from the established syllabus and text instead of mine from ENGR 1620, *Introduction to Engineering*, at the University of Virginia. The syllabi are based on different philosophies as to what topics should be covered in an introductory course and have somewhat different content. Initially, the research question was whether the syllabus has an impact on the degree to which students internalize and "own" the process. I had been informed by students in the systems engineering courses I teach at PVCC that my courses were the only ones in which the process was mentioned more than once or twice, much less emphasized. A review of the syllabus for prior EGR 120 offerings provided confirmation. However, it became clear that student learning of the engineering design process was more dependent on other factors. Therefore, the research question has been refined to identifying factors affecting student ability to internalize the engineering design process.

In this paper, I will briefly describe the content of the courses and student demographics, the methodology used in this research, results of qualitative analysis of exam questions testing understanding of the design process, and preliminary conclusions. The engineering design process is addressed in a companion extended abstract, *Identifying Factors Connected with Persistence in Misconceptions Regarding the Engineering Process*, and in [2].

ENGR 1620

ENGR 1620, *Introduction to Engineering* at the University of Virginia (UVa) is described in [3]. It is a course with multiple sections, and instructors have broad latitude in determining the content of their section. The only instructional constraint is that we meet two common learning objectives and seven associated outcomes. I use project-based learning activities emphasizing design-build-test and, to a smaller extent, discussion, to maximize active learning opportunities. It is my belief, shared by many, that design is best taught through project-based learning. Students complete three small projects in the first half of the semester and one large project in the second. The small projects are based on the National Academy of Engineering's Grand Challenges [4] and the large project is based on the AbilityOne Project [5], a service-learning program in which students design products to increase the employability of people with physical challenges.

The discussions centered on topics I consider to be important to introduce to novice engineering designers: documentation, engineering design process activities and models, the National Academy of Engineering's Greatest Engineering Achievements of the Twentieth Century [6] and the Grand Challenges, the role of failure in design, human factors, design for X, ethics, reverse engineering, project management, safety, basic construction (shop) principles, technical drawing, life cycle analysis, and intellectual property.

Notebook checks, class participation, and project document drafts are used for formative assessment. Final project deliverables – design artifact and documentation – and a midterm and final are used for summative assessment of student learning.

This course is offered only in the fall semester, and has a companion lab in which students are introduced to computer applications they will be using throughout their undergraduate career.

Student demographics for the Fall, 2011 sections are in [3]. They are comparable to those figures for the Fall, 2012 sections which are provided in Table 1, below.

TABLE I
ENGR 1620 STUDENT DEMOGRAPHICS (FALL, 2012)

	Female	Male
African-American	1	2
Arab-American	--	2
Asian-American	4	5
Caucasian	20	40
Hispanic-American	1	1
International		
ESL	1	3
Not ESL	1	--
Totals	28	53

EGR 120

EGR 120 meets twice a week. One day is devoted to lectures on general engineering concepts and knowledge, focusing on fostering engineering "habits of mind." Topics covered are transferring to four-year programs, types of engineering majors and jobs, teamwork, engineering design process, ethics, technical writing and presentations, estimation techniques, problem solving using a method called SOLVEM (sketch, observe, list, variables, equations, and manipulation), notation, graphing, interpolation, basic descriptive statistics, and dimensional analysis.

The other day is a lab where students work through very detailed guides for four LEGO Mindstorms NXT robotics projects. Formative assessment of lecture material learning is performed by weekly homework assignments. Summative assessment is conducted using four tests and lab reports.

This course is offered in both the fall and spring semesters.

Student demographics for the Spring, 2013 section are provided in Table 2. Because of the different mission of PVCC, student ages range from high school (dual enrollment) through the 30s. "Traditional" students are in their late teens, the same ages as the UVa students; "non traditional" students are both younger and older than "traditional" students. ESL students are those for whom English is a second (or third or fourth) language.

METHODOLOGY

Course assessments can be a rich source of data. For this research, answers to essay questions and reflections are reviewed. The essay question answers are recorded according to accuracy and to the underlying factor aggregating individual responses into categories of meaning. The code list is emergent, and is originally based on a review of the literature [see, for example, 3 and 7 – 10], classroom observations, and discussions with colleagues. The reflections are similarly coded.

Insight and partial validation of results come from the responses to reflections provided by second through fourth-year students in another course I teach, SYS 2004, *Data and Information Management*, at the University of Virginia. Students come from both the School of Engineering and Applied Science and the College of Liberal Arts and Sciences. Because I have found that I cannot expect students – yes, even engineering students – to have knowledge of the engineering design process, the process is introduced early in the course and stressed through talk and example throughout the semester. I repeated the practice and reflection question in establishing a version of this course at PVCC. The number of student reflections analyzed is 63 (24 F and 39 M).

The reflections, questions, and scenarios analyzed are in the appendix.

TABLE I1
EGR 120 STUDENT DEMOGRAPHICS (SPRING, 2013)

	Female	Male
African American		
Non-Traditional	--	2
Traditional	--	2
International (ESL)		
Non-Traditional	--	1
Traditional	1	1
Caucasian		
Non-Traditional	--	8
Traditional	2	4
Totals	3	18

PRELIMINARY RESULTS AND CONCLUSIONS

Analysis of responses to exam questions indicates that, as would be hoped, student understanding and use of the engineering design process in the *Introduction to Engineering* classes increased over the semester, but the responses indicate that the majority are still in the novice state, which is to be expected. For example, there is a consistent pattern in students wanting to relate all process steps to a given scenario, for example, but the number is fewer (moreso at UVa than at PVCC, and at PVCC, moreso among the non-traditional students than the traditional students) at the end of the semester. These preliminary results, coupled with analysis of reflection comments from students in the *Data and Information Management* classes (denoted as *SYS 2004*, below), lead to three main conclusions, none of which should be surprising:

1. While the syllabus does have some impact on student internalization of the engineering design process, it is the instructor that has the greater impact. It is the instructor who
   - sets the syllabus and thus establishes course content
   - decides the number and type of projects on which students will work
   - provides the framework within which the project(s) are conducted
   - chooses to emphasize the process through numerous mentions and connections with course topics in lectures and discussions (*SYS 2004*: 26 responses with positive experiences; 12 responses with negative experiences; 8 responses reporting no [memory of] experience with the process in an introductory course)
   - provides opportunities for iteration
   - gives clues for the importance of the process in project work; students with instructors who are dismissive of the process or otherwise indicates that its use is not important tended to have more difficulty adopting the process in other courses where it is used (*SYS 2004*: 4 responses)
2. Therefore, the type of project is less important than the opportunities to apply the process. Repetition is important. The more a student uses the process, the more its use becomes second nature. (*SYS 2004*: 19 responses regarding the importance of iteration and all but 2 with responses indicating that it's the process, not the project)
3. It is critical to choose a process model that is both intuitively understood and logically constructed. (*SYS 2004*: 10 responses for intuitive and all but 3 mentioning need for a logical, consistent framework)

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APPENDIX – EXAM REFLECTIONS, QUESTIONS AND SCENARIOS

UVa 2011 Midterm Scenario: You are a general consulting engineer. A prospective client asks for help in building a prototype of the device he's sketched out. You make a copy of the signed and dated sketch so that you can evaluate the situation and possibly draw up a project schedule and cost estimate if you think the project is a good fit with your skill set. Evaluate *wrt* the engineering design process.

UVa 2012 Midterm and PVCC Final Q: Revisit the IDEO Deep Dive video, and critique what you see in the video *wrt* the engineering design process.

UVa 2012 and PVCC 2013 Final Reflection: What are two ideas or conceptions about the engineering design process (or engineering in general) you had at the beginning of the semester? Have they changed? If not, state that. What process or project do you think helped most in either reinforcing or changing these ideas or conceptions?

PVCC 2013 Test 1 Scenario: You are a general consulting engineer. A prospective client comes into your office asking for help in building a prototype of the device he's sketched out. You build the prototype and deliver it to him. Refer to the engineering design process model given below (see companion extended abstract for figure). What steps are involved in the above scenario? Which steps are not?

SYS 2004 2012-3 Final Reflection Q: Refer to the Engineering Design Process Notes. To what degree (percentage) did your project processes follow those models, in general? Did your team make a conscious decision to use the engineering design process as a guide as to how to proceed? If your team didn't follow the general design model, what model did you use? If you didn't consciously use a design model, if the project management process was a more useful guide, or you used an ad-hoc approach, please state that. Has the emphasis on the design process in this course been helpful?

Engineering majors: How much, expressed as a percentage, was the engineering design process stressed throughout the semester in your ENGR 1620 course?

College majors: Have you had exposure to any design process models, regardless of the discipline? If yes, what are they?