Extended Abstract: Identifying Factors Connected With Development of and Persistence in Engineering Design Process Misconceptions

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Abstract – **The primary goal of the research presented in this extended abstract is to identify factors allowing misconceptions regarding the engineering design process to develop and persist. Knowledge of these factors can inform K-16 engineering pedagogy and K-12 outreach activities. Understanding engineering as a design-based profession in which curiosity, communication, and team management skills can be as important as math and science is important in recruiting and retaining students.**

Index Terms – Engineering design process, misconceptions, remediation.

INTRODUCTION

A companion task to the identification of misconceptions regarding a particular concept is identifying factors that lead to persistence of that misconception. It is well documented that students with hazy conceptual understanding can nonetheless develop strategies to perform well on tests using questions that rely on knowledge recall or elimination strategies for completion, such as true/false and multiple choice. The development of instruments and strategies for correcting misconceptions cannot proceed far without knowing the obstacles in the path, as it were.

The identification of factors connected to the persistence of misconceptions about the engineering design process is the main goal of the research presented in this extended abstract. The overall research goals are to develop a concept inventory to identify misconceptions about the engineering design process and remediation methods.

ENGINEERING DESIGN PROCESS

The engineering design process is at the heart of the discipline. ABET Student Outcome 3(c) directly addresses the need to know and apply the process. The cornerstone and capstone model, providing design education at the beginning and completion of the undergraduate engineering program, is widely used. Yet, we acknowledge that assessment of student learning in design classes is an admittedly difficult process and as a result, students may go through their undergraduate careers without having their misconceptions corrected, much less identified.

There are many models in use, but for the most part they have several features in common: engineering design is problem-based and starts with the identification of and research on an issue; a design space is defined; solutions are developed and evaluated; the best solution is selected for prototyping; an internally iterative cycle of build-test-evaluate occurs; and, when a stopping rule is encountered, the artifact is reviewed to determine if it meets, within tolerances, expectations or whether the design team needs to re-enter the process at a phase appropriate to the amount of redesign that needs to occur. Throughout, there is communication among team members and with client(s).

A representative process model is displayed in Figure 1 at the end of the paper. It was developed based on my assessment of other models [see, for example, 1 – 4] and my experiences as an instructor of ENGR 1620, *Introduction to Engineering* at the University of Virginia and of EGR 120, *Introduction to Engineering* and EGR 295, *Introduction to Systems Engineering* at Piedmont Virginia Community College, and as a facilitator of P-16 outreach / enrichment experiences.

MISCONCEPTIONS AND METHODS FOR IDENTIFYING THEM

It is important to understand the process of cognition when developing definitions of concepts and misconceptions. The most basic definition of cognition is the "process of knowing…and the content of those processes." It is a **fundamental** concept in the science of learning, since learning is dependent on prior knowledge and the nature of changes students can make in both processes and content. (see, for example, [5]; emphasis added) The primary components affecting a person's level of cognition are declarative knowledge and procedural knowledge. Declarative knowledge can also be defined as "semantic information…(knowledge about ideas)" and procedural knowledge as the "complement" of declarative knowledge; together, they "represent categories for describing knowledge in general" [6, p. 28]. The interplay between the acquisition and application of sets of related declarative and procedural knowledge helps students identify and internalize underlying concepts. However, students may internalize concepts incorrectly for a variety of reasons, and the resulting misconceptions can be a factor in student disengagement and other negative (re)actions.

A concept, therefore, is a mental construct or model that helps a person organize knowledge. It is inductively built from interactions and experiences [7]. Misconceptions, also known as an alternative framework or invented theory, develop from a flawed development process and can be resistant to change [7 – 9].

There are several validated methods for evaluating conceptual knowledge; the most commonly used are concept inventories [10], direct interview [11], and strategy writing [12]. Course assessments, a rich source of data, can be used to harvest these data as well, serving as a proxy for interviews, and this method is used in this research.

METHODOLOGY

Essay answers and reflections are reviewed and coded. The code list is emergent, and is originally based on a review of the literature [see, for example, 13 – 16], classroom observations, and discussions with colleagues.

The data come primarily from students in ENGR 1620, *Introduction to Engineering*, at the University of Virginia (UVa). In 2011, I reviewed and coded answers, using an emergent code list, from seventy-five first year students (25 females, 50 males) to a midterm question that asked for a response to a scenario based on an incomplete description of the engineering design process, after [15]. The result – that 26 students (35%) perceive the engineering design process as solution, not problem, driven – is reported in [16]. By the end of the semester, the number of students holding that misconception dropped to six.

Additional data come from responses to exams questions and scenarios and end-of-semester reflections of eighty-one first year students in ENGR 1620 in Fall, 2012 and twenty-one students in EGR 120, *Introduction to Engineering*, at Piedmont Virginia Community College (PVCC) in Spring, 2013. Student demographics are given in Tables I and II, respectively. Because PVCC serves a different student population from UVa, additional entries are needed for the table. For example, 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.

The reflections, questions, and scenarios are provided in the Appendix.

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

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

Misconceptions and factors connected to their development and/or persistence developed from a qualitative analysis of the described data, listed in order of prevalence among the reviewed artifacts with the most prevalent first, include:

1. Engineering is a solution-based process, with the engineer essentially being a fabricator. Being given the solution instead of the problem in "engineering class" or enrichment activities contributes to this misconception. Also, a student may shadow or be mentored by an engineer who works outside the design process – for example, in maintenance – and may not receive a "big picture" view. (18 M, 7 F)
2. Misconceptions about how engineers work are numerous, and include "engineers work alone," "engineers don't need verbal and written communication skills," "engineers aren't creative," and "you don't need a process for engineering design." (Total: 14 M, 10 F)
3. Engineering is a linear, non-repeating task. This misconception comes from students being given one pass to build or complete a particular solution assigned by the instructor. It may also come from lack of introduction or reinforcement of the engineering design process. The process needs to be presented and used consistently not just with the design challenge but also with related tasks, such as documentation. Using document template with sections directly mappable to a process model has been helpful in ENGR 1620. (12 M, 4 F)
4. Engineering is only math and science. This misconception comes from a lack of knowledge about engineering as a design-based profession for which traits such as curiosity and creativity can be as important as a solid grounding in math and science. As pointed out by Henry Petroski [17], engineering can occur and has occurred ahead of scientific knowledge. (7 M, 3 F)
5. There are no limits or boundaries to consider and factor in. If there are any, they are flexible or otherwise

changeable. This misconception can be attacked, for example, by sticking with limits on materials and times, and adhering to milestones/due dates. (6 M, 1 F)

Given the source of these data, it is fairly safe to assume that they are developed and reinforced during K-12 and certain 13-16 environments. Recommendations include the need to provide pre-service and in-service exposure to engineering to *all* teachers and guidance counselors; promote family engineering activities [18]; and bring engineering to *all* classrooms.

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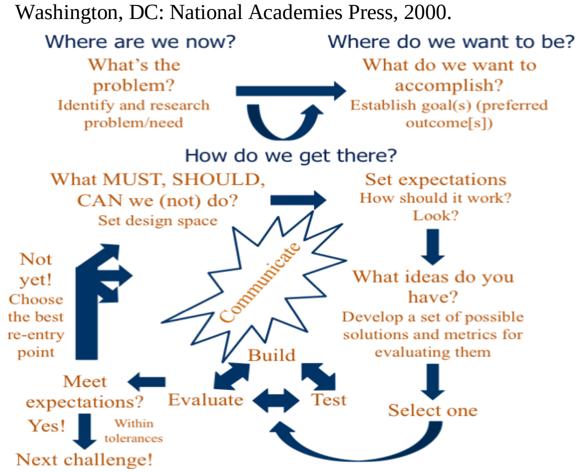

FIGURE 1
A REPRESENTATIONAL ENGINEERING DESIGN PROCESS MODEL

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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 Q 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 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 (an earlier version of Figure 1, above). What steps are involved in the above scenario? Which steps are not?