AC 2011-534: USE OF A PROFESSIONAL PRACTICE SIMULATION IN A FIRST YEAR INTRODUCTION TO ENGINEERING COURSE

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Use of a professional practice simulation in a first year Introduction to Engineering course

Abstract:

The design of first-year engineering courses represents a classic engineering design problem – there are multiple stakeholders with different criteria and constraints and, as a result, there is no single, optimal solution. Our goal was to develop a first-year engineering design course that meets the criteria and constraints of several traditional stakeholders and also provides a platform for studying the ways in which a first year engineering student progresses from thinking like a novice to thinking like a professional engineer. To do so, we developed a computer-based professional practice simulator that can be incorporated into pre-existing first-year Introduction to Engineering courses with minimal resources by course directors with no expertise in an engineering discipline. The simulation provides an introduction to professional communication styles, the engineering design process, library skills and citation requirements, and the engineering disciplines. Importantly, engineering knowledge and skills are not required to complete the two design-build-test cycles in the simulation; instead the emphasis is on managing conflicting client requirements, making trade-offs in selecting a final design and justifying design choices. This paper describes the design of the simulation and preliminary results from its inclusion in a first-year Introduction to Engineering course at our institution.

Introduction:

First year engineering curricula offer a critical window of opportunity to retain students in engineering disciplines and provide a strong foundation for future success. Incorporating design into these first year courses, often referred to as *cornerstone* design (in contrast to senior *capstone* design)[1], has been promoted as a way to give students some insight into the professional practice of engineering[2-4] as well as experience in the engineering design process[5,6]. The professional practice of engineering and the engineering design process are multifaceted and complex; it is difficult to conceive of a single first-year engineering course offering more than a cursory introduction to these two topics. Nevertheless, cornerstone design courses are typically charged to do so and also used as opportunities for training in basic skills such as how to log on to the College computer system, how to use the library, proper citation of references, introduction to the disciplines and best practices for oral and poster presentations.

First-year courses are further hindered by having to meet the needs of multiple stakeholders with various criteria and constraints. For example, school and college administrators would like all students to be retained in engineering disciplines and to increase their dedication to becoming an engineer. Departmental faculty members would like these courses to produce students who can make well-informed choices regarding their discipline/department of interest and who are prepared for subsequent upper level courses. Students would like these courses to be engaging, fun and not onerous. Few cornerstone courses can meet all of these demands with, often, rotating course directors, minimal resources and students with diverse backgrounds new to the demands of a college-level engineering curriculum.

In our view, the most important components of a cornerstone design course are giving students an introduction to the professional practice of engineering and experience with the engineering design process. The professional practice of engineering can be thought of as the application of engineering *thinking* to engineering *doing*, i.e., to solving a real-world problem. Thinking by a person in a profession such as engineering can be broadly defined as the way a professional makes decisions and justifies actions, which in turn are determined by his/her accumulated knowledge and skills, values, and identity[7, 8]. Together, these five elements make up the *epistemic frame* of a profession[9]. Prior work has shown that a key step in developing the epistemic frame of many professions, especially those that require innovation, is some form of *professional practicum*[7,8], which is an environment in which a learner takes professional action in a supervised setting and then reflects on the results with peers and mentors. Skills and knowledge become more and more closely tied as the student/learner learns to see the world using the epistemic frame of the profession. Cornerstone and capstone design courses in undergraduate curricula are examples of professional practica in engineering.

Prior work has also shown that *epistemic games*—learning environments where students game-play to develop the epistemic frame of a profession—increase students' understanding of and interest in the profession[10-12]. An effective realization of an epistemic game is in a computer-simulated virtual environment. Computer-based simulation games are an emerging and popular area of research and development in the learning sciences[10, 13-15]. One advantage of the virtual learning environment, especially when role-play is involved, may be the immersive element of the activities[13]. In our own prior work, the epistemic computer simulation games *Urban Science* and *Digital Zoo* have been shown to successfully lead to professional values and epistemology in urban planning and biomedical engineering, respectively, in K–12 students[11, 12]. An additional advantage of the on-line environment is that student communication and work output can be captured for later in-depth analysis of the learning process and progress.

The elements of engineering design that are critical to include in first-year engineering courses may well depend on one's definition of *engineering design*. According to Dym et al.[16],

> Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints. (p. 104).

Elements of the design process critical to producing a quality product are gathering information, considering multiple alternatives and iterating through all the steps in the design process[17]. Learning design also requires learning to tolerate ambiguity, handle uncertainty, make and justify decisions, think as part of a team and communicate with both technical and non-technical audiences[16]. For first-year students, engineering skills and knowledge cannot be assumed. Ideally, then, first year engineering design courses should guide students through the design process and allow them to practice design in the absence of skills and knowledge. Our own work suggest that interactions with both clients and mentors[18, 19] are key to learning design.

Based on this prior work, we designed a novel computer-based engineering epistemic game that can be included in pre-existing first year engineering design courses with minimal resources by course directors with no expertise in an engineering discipline. Importantly, specific engineering knowledge and skills are not required to complete the two design-build-test cycles in the simulation; instead the emphasis is on managing conflicting client requirements, making trade-offs in selecting a final design and justifying design choices. Below we describe the simulation and preliminary results from its inclusion in a first-year Introduction to Engineering course at our institution.

Methods:

In the simulation, students are welcomed as early career hires into the fictitious company *Nephrotex*. The students' assigned task is to design a next-generation dialyzer that incorporates carbon nanotubes and chemical surfactants into the hollow fibers of the dialyzer unit. This task is assigned to them by a virtual non-player character and explained to them in depth by their engineering manager, an actual (non-virtual) non-player character, who also supplies some introductory background material. To redesign the dialyzer unit, four aspects of the hollow fiber material can be altered: the base material, the percent carbon nanotubes, the processing method and the surfactant used during material processing. Device performance is characterized in five dimensions: biocompatibility, marketability, reliability, ultrafiltration rate and cost.

To accomplish this goal, students work with a collection of actual and virtual *nonplayer characters*: that is, with real people playing the role of mentors and supervisors in the virtual internship, as well as computer-generated characters who play the roles of company president, head of research and development, and internal consultants. The virtual internship requires a total of three actual non-player characters, two *design advisors* who serve as mentors and interact with players using instant messaging and email, and an *internship coordinator*, who interacts with players in person and is responsible for monitoring professionalism of the players during class time and troubleshooting the performance of the game software.

The design advisors have to be on-line during every class period and check in frequently between classes. These mentors need to be able to answer students' content and game-related questions, understand how the virtual internship system works and help troubleshoot it, guide students in reflection discussions, and at all times maintain a professional persona in the virtual internship. In the implementations this past fall, the design advisors were undergraduate teaching assistants; the internship coordinator was the professor for the course, who has minimal expertise relevant to hemodialysis membrane design.

Students work in small groups throughout the internship and are guided by their design advisor, with whom they interact using an e-mail and Internet chat system built into the simulation. Teams proceed through design-build-test cycles, first with just one material and subsequently with all materials. They receive feedback on designs from virtual nonplayer characters acting as clients: a clinical engineer, a manufacturing engineer, a focus group liaison, and representatives from marketing and product support, all of whom are programmed to evaluate device performance. At the end of each design phase, students make a recommendation and justify their choice based on how it satisfies the competing demands of these stakeholders. One key element of the virtual internship is that there is no optimal solution—that is, no solution that both minimizes cost and maximizes the other performance criteria. The students must find a solution that they believe is optimal given the constraints of the problem, and then defend that choice in a formal presentation.

The current format requires 11 hours of class time, which is roughly equivalent to a 1-credit course at our institution. For 5 groups of 5 students, two trained undergraduate student assistants are required. As noted above, the game includes elements common to many first year engineering courses, such as literature searching and citation, introduction to different engineering disciplines, poster and podium presentations, engineering ethics, and teamwork. In addition, it covers important supplementary topics that often are not covered in introductory courses such as keeping a design notebook, time management, and interacting professionally with clients and employers.

Results:

In Fall 2010, 45 students participated in *Nephrotex* at our institution. Class sessions were held in a computer lab where each student worked at his or her own computer. Some students met virtually through the chat program or in person outside of class to finish assignments or plan for upcoming tasks. Most of the students self-identified as prospective biomedical engineering majors. Frequent email and chat communication between student-players and design advisors were required; expectations regarding professional communication styles were made clear at the outset and reinforced frequently. One assignment required students to conduct a literature search and summarize findings in their design notebooks; many other assignments required students to read pre-selected material and summarize the content in their notebooks. Citation requirements were again made clear at the outset and reinforced. The engineering disciplines were introduced via staff pages that students were required to read. Also, at one point students were asked to add current staff members to their team based on their expertise in another discipline and describe how that person's skills and training would contribute to a particular aspect of future product development.

The entire virtual internship was an introduction to how professional engineers work and do engineering. Students received no explicit training in the engineering design process but were guided through two design-build-test cycles in which they had to justify the designs they sought to test. We investigated the impact of the virtual internship on students' intentions to major in engineering, understanding of engineering of a profession and engagement with the simulation with pre- and post-interviews. These pre- and post-interviews, which took the form of short-answer survey questions completed online, were completed on the first and last days of the virtual internship. Analysis of these interviews suggests that:

- Most students felt that it reinforced their intentions to major in engineering.
- *Nephrotex* gave students a more realistic understanding of what engineers actually do.
- Students were engaged in the simulation and were invested in the outcomes of their virtual projects.

Furthermore, the interviews queried engineering knowledge and skill to assess development of skills and knowledge during *Nephrotex*; these results are reported in Ref. 20.

Intentions to Major in Engineering

After playing *Nephrotex*, 71% of students reported that they were committed to pursuing engineering as a career choice. Students explicitly stated that the internship influenced their decision to continue with a career in engineering now that they have a better understanding of the field, and some claimed that the experience would be a valuable reference for future internships and professional experiences. For example, students reported:

> I believe it has encouraged my decision to push forward with a career in biomedical engineering. Starting the class I wasn't sure if engineering was right for me anymore, but finishing this internship I believe I could do well in a career in engineering and enjoy it.
>
> Being a member of Nephrotex gave me a great opportunity to experience what an internship in engineering will be. This will help me be more efficient and professional in my future experiences. Additionally, it helped me understand how to work in a team and analyze engineering designs.

Understanding Engineering

During the post-interview, 56% of students explicitly mentioned they had a better understanding of engineering after completing the internship. For example, students reported:

> Nephrotex helped make some parts of my future clearer. I have a little better understanding about engineering works in the real world.

> Nephrotex was a good lead into what engineering is about. It showed me what engineers do in their lives creating new designs and testing them.

Engagement

A series of *engagement questions* were asked of students during the post-interview to determine their level of immersion and engagement in the virtual internship. These questions were adapted from Green and Brock's *transportation index* that measures a readers' immersion in the fictional world of a novel[21]. The four point scale ranges from 1 (strongly disengaged) to 4 (strongly engaged). Overall, students playing *Nephrotex* had a mean *engagement score* of 2.66 on the scale, which is a statistically significant positive response at $\alpha = 0.05$ (where 2.50 is a neutral response). Table 1 reports the average score for each question.

Table 1. Immersion in the internship experience as measured by Green and Brock's transportation index [21]. Scores with * signify that the average was significantly higher than 2.5 (at $\alpha = 0.05$ level).

Post Interview Question	Average Score
The Nephrotex experience changed my life.	2.25
While I was an intern at Nephrotex, I could easily picture the events in it taking place.	2.88 *
I could picture myself as an intern at Nephrotex.	2.88 *
I was mentally involved in the Nephrotex internship while it was going on.	3.17 *
After finishing the Nephrotex internship, I found it easy to put it out of my mind. (opposite)	2.63
I wanted to learn how the new Nephrotex device would turn out.	3.08 *
The Nephrotex experience affected me emotionally.	2.09
I found myself thinking of ways the Nephrotex internship could have turned out differently.	2.63
I found my mind wandering while doing the Nephrotex internship. (opposite)	1.92 *
The events in the Nephrotex internship were relevant to my everyday life.	2.71 *

Students responded particularly positively to "I was mentally involved in the *Nephrotex* internship while it was going on" (mean 3.17) and "I wanted to learn how the new *Nephrotex* device would turn out" (mean 3.08). The less positive responses to questions such as "The Nephrotex experience changed my life" and "The Nephrotex experience affected me emotionally" serve as a useful check on student responses.

Discussion:

Here we report on the design and development of an engineering epistemic game for first-year engineering curricula that provides an authentic engineering experience, introduction to a real-world design problem, as well as introduction to professional communication styles, library skills and citation requirements, and the engineering disciplines. It meets many of the standard requirements of Introduction to Engineering courses and exceeds some others. Our preliminary results suggest that this epistemic game has a positive impact on intention to obtain an engineering degree, understanding of engineering as a profession and is highly engaging to first-year undergraduate engineering students. Furthermore, use of this epistemic game in the classroom can provide a wealth of data for assessment of the development of engineering skills, knowledge, values, identity and epistemology.

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