Collaborating in a Virtual Engineering Internship

Cynthia D'Angelo, Golnaz Arastoopour, Naomi Chesler, and David Williamson Shaffer, University of Wisconsin - Madison, 1025 West Johnson Street, Suite 499, Madison, WI 53706
Email: cmdangelo@wisc.edu, arastoopour@wisc.edu, chesler@engr.wisc.edu, dws@education.wisc.edu

Abstract: Teamwork and collaboration are vital 21st century skills that students need to master. Specially designed epistemic games modeled after professional practica can help students build and practice these skills. This paper presents preliminary results from a virtual engineering internship, an epistemic game for introductory engineering undergraduates. The game was designed to help build students' skills in teamwork and collaboration while providing experiences relevant to engineering and design. After the internship students reported a better understanding of what engineers do and about the practice of engineering. Students also made content learning gains. Students overwhelmingly enjoyed the experience and felt encouraged to stay on an engineering career path.

Introduction

STEM expertise in the 21st century requires complex problem solving that goes well beyond the basic facts and skills that traditional tests were designed to assess (National Academy of Sciences, 2005; Shaffer, 2004b). These 21st century skills include collaboration, innovation, and creativity. Real-world STEM problem solving involves generating links between STEM skills and knowledge on the one hand, and the values and ways of making decisions that characterize STEM professions on the other.

Epistemic games are computer simulations of STEM practices that develop the epistemic frames of STEM professionals (Beckett & Shaffer, 2005; Hatfield & Shaffer, 2006; Svarovsky & Shaffer, 2007). These games thus represent a promising approach to STEM learning because: (1) epistemic games are based explicitly on authentic STEM practices, and thus provide information about STEM problem solving, (2) epistemic games are computer simulations, and they record rich data about STEM problem-solving processes that take place during game play, and (3) epistemic games are designed based on the *epistemic frame hypothesis*, a theory of learning that analyzes thinking in terms of connections among *frame elements*: skills, knowledge, values, and justification or decision-making (otherwise known as *epistemology*) of a STEM profession.

We have developed *Nephrotex* as a virtual simulation of authentic engineering practice to give undergraduates an opportunity to work as engineers and see the relationship between basic engineering skills and knowledge and the values that underlie the profession. A key part of this professional experience is collaborating and working on teams to design a product. The biomedical engineering aspect of *Nephrotex*, in which the task is to design a next-generation hemodialysis ultrafiltration membrane, was selected to make real the ability of engineers to improve health care.

The research question explored by these preliminary analyses looks at whether or not the game is successful in fostering teamwork and collaboration in engineering students. This paper describes current progress on implementing *Nephrotex*, analysis of preliminary results from the first implementation, and discussion of future analyses that will be performed to better understand how the game builds the skills of teamwork and collaboration.

Nephrotex: A Virtual Internship

Nephrotex was created to increase the persistence of engineering undergraduates in pursuit of degree attainment. It is modeled on authentic engineering practices, has been pilot-tested, and has now been incorporated into a first-year engineering undergraduate course at the University of Wisconsin–Madison.

Nephrotex is not designed specifically for biomedical engineers but instead for any student who might someday work in a team, design a product, answer to multiple clients, and be forced to find the solution that "satisfices." This game is potentially transformative because it addresses a key aspect of engineering education (professional practice), as well as critical limiting factors in providing students with opportunities for experiencing professional practice (faculty time and institutional resources).

Learning Theory

Nephrotex is grounded in the epistemic frame hypothesis, which suggests that any professional community has a culture (Rohde & Shaffer, 2004; Shaffer, 2004a, 2005, 2006) and that culture has a grammar: a structure composed of *skills* (the things that members of the community do), *knowledge* (the understandings that members of the community share), *values* (the beliefs that members of the community hold), *identity* (the way that members of the community see themselves), and *epistemology* (the warrants that justify actions or claims as legitimate within the community). This collection of skills, knowledge, values, identity, and epistemology forms the epistemic frame of the community. The epistemic frame hypothesis suggests that (a) an epistemic frame binds together the skills, knowledge, values, identity, and epistemology that an individual takes on as a member of a community of practice; (b) such a frame is internalized through the training and induction processes by which an individual becomes a member of the community; and (c) once internalized, the epistemic frame of a community is used when an individual approaches a situation from the point of view (or in the role) of a member of the community (Shaffer, 2004a, 2005).

Put in more concrete terms, engineers act like engineers, identify themselves as engineers, are interested in engineering, and know about physics, electricity, mechanics, chemistry, and other technical fields. These skills, affiliations, habits, and understandings are made possible by looking at the world in a particular way: by thinking like an engineer. The same is true for biologists but for different ways of thinking—and for mathematicians, computer scientists, science journalists, and so on, each with a different epistemic frame.

The key step in developing the epistemic frame of most professional communities is some form of professional practicum (Schon, 1983, 1987). Professional practica are environments 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 learns to see the world using the epistemic frame of the community. Examples include capstone design courses in undergraduate engineering programs, medical internships and residencies, and almost any STEM graduate program.

Thus, one way to give students a realistic understanding of a profession early in their undergraduate careers is to create a virtual simulation of a professional practicum, which is what *Nephrotex* is designed to do.

Internship Activities

In *Nephrotex*, students become interns in the fictitious company Nephrotex, whose core technology is the ultrafiltration unit, or dialyzer, of a hemodialysis machine. The students' assigned task is to design a next-generation dialyzer membrane. This task is assigned to them by the head of research and development, a virtual nonplayer character, and explained to them in depth by their engineering manager, a nonvirtual nonplayer character (i.e., a real person playing a role in the game). To redesign the dialyzer unit, four aspects of the hollow fiber material can be altered: the base polymer, percent carbon nanotubes, material processing method, and surfactant. If students choose to test a combination of these parameters, their choices serve as the input to a "black box" that yields the following outputs or performance characteristics: biocompatibility, marketability, reliability, ultrafiltration rate, and cost (Figure 1).

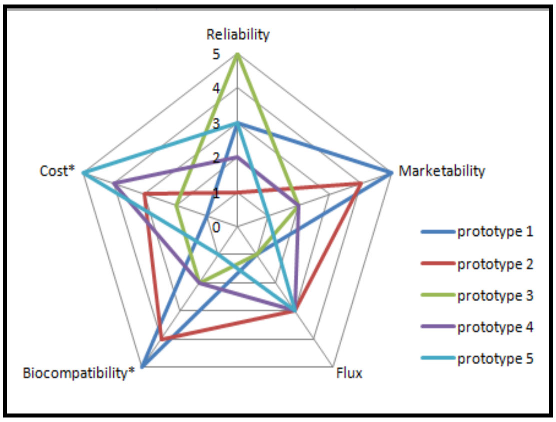

Figure 1. A graph based on the outputs the students have to consider when designing their prototype.

Students first familiarize themselves with the virtual environment by completing an intake interview, writing a staff page biography, and reading others' staff pages. They then explore a portion of the design space by performing a preliminary data analysis of variations in output parameters for one material based on changes in percent carbon nanotubes, processing method and surfactant, i.e., the other input parameters. Students work in small groups and are guided by a design advisor, a nonvirtual nonplayer character with whom they interact through an email 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, including all possible values of all input parameters (see Figure 2). They receive feedback on designs from virtual nonplayer characters with an interest in the project—a clinical engineer, a manufacturing engineer, a focus group liaison, and representatives from marketing and product support—all of whom are programmed to evaluate students' design choices. 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 game 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 and justify the solution that "satisfices."

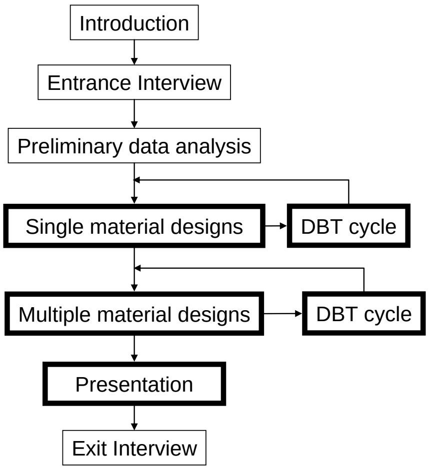

Figure 2. Nephrotex work flow diagram. Light borders around boxes indicate individual work; heavy borders indicate teamwork. DBT = design-build-test cycle.

Furthermore, to make it simple to implement in a first-year introduction to engineering course, the game includes elements common to many first year engineering courses, such as literature searching and citation, different engineering disciplines, poster and podium presentations, engineering ethics, and teamwork. But it does so in the context of a simulation of real engineering processes and practices. As such, 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.

Preliminary Results and Discussion

In fall 2010, 45 students became virtual interns at *Nephrotex* as part of their first-year introductory engineering course. Nephrotex was offered as one of the project-based modules that students signed up for in the course. Other parts of the course introduced students to the different engineering disciplines, how to do research, use the library, etc. Students participated in the internship during a one hour class period either once or twice a week for a total of 10 hours. The class met in a computer lab where each student worked on their own computer. Some students met virtually 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.

Preliminary results include the pre and post interviews that students completed on the first and last days of their virtual internship. The interviews were done through the internship on the computer. We also collected pre and post survey data from all of the students that were enrolled in the introductory course that *Nephrotex* was embedded in (N = 122). The surveys were completed online during the first and last weeks of the course. The following aspects of the results will be discussed: the value of teamwork and collaboration as an integral part of the internship experience, the learning gains that students had from pre to post interview, and how the internship helped students understand engineering as a discipline better.

Teamwork and Collaboration

Nephrotex assigns students to one of five teams at the beginning of the game. Each team has five members and is responsible for learning about one of the five materials that the fictitious company is interested in using as a hemodialysis ultrafiltration membrane. Each team has an online design advisor that helps coordinate some group discussions and provides feedback and assistance when they have questions. Some activities in Nephrotex are done as individuals and then discussed with a team, while others need to be completed as a team. After going through the first DBT cycle as a team, students are reassigned to new teams using a jigsaw scheme so that each of the five final teams includes one person knowledgeable in each of the five materials. This structure allows each student to be responsible for some amount of content knowledge and forces students to work with different people. This new team completes a second DBT cycle.

On the post interview, when asked about what part of the internship they found most enjoyable, about half of the students (21 out of 45) responded that they enjoyed working in teams and valued the teamwork and group collaboration activities the most.

> I enjoyed working with a team; it is fun talk with others who are working on the same thing, and also to bounce ideas off of each other.

> I enjoyed the group work most because it allowed all of us to share our ideas and work with each other. It was interesting to hear all the different perspectives and I learned so

> much from my teammates. Group work allowed us to make the best decisions and come up with the best device possible to complete our presentation on.

Another set of questions on the pre and post interviews asked about how much they think a career in engineering is associated with different things (such as prestige, healthy work-life balance, innovation/creativity, and working on teams). Working on teams was one of the highest rated items on the list. On a scale of 1 to 4, with 1 being not at all and 4 being a great deal, the average student rating for working on teams was 3.5. Other highly rated items include: opportunities to help other people, opportunities to make the world a better place, and intellectual stimulation (all above 3.5).

Engineering Learning Gains

Although content learning gains were not a major focus of *Nephrotex*, we included pre and post interview questions about some content areas related to the activities of the internship. It was clear in the pre interview that many students did not know very much about the content in the game.

Topics on the pre and post-interview included experimental setup, general design decisions, strategies to prevent membrane fouling, kidney functions, reliability of membranes, diffusion, and hemo-compatibility issues. Students answered two multiple choice and seven short answer content questions on the pre- and post-interviews. These matched-pair questions were analytically coded for each question. Overall, students showed significant gains from pre (M = 38) to post (M = 68) on these questions ($p < .01$). Two of the questions represent central concepts in the game, (a) setting up an experiment and (b) strategies to prevent membrane fouling, and had the largest significant gains from pre- to post-interview for students. About 30% of students got each question correct on the pre-interview and 70% (question a) and 85% (question b) got the questions correct on the post-interview. Both of these gains were significant ($p < .05$).

While it is encouraging to see students choose the correct answer in a multiple choice scenario, we also asked students to explain their answer in order to see how well they really understood the content (see Table 2). Student 2 in particular learned a lot about this content area, as before the internship he/she was unsure how to answer the question and after he/she gives a detailed and thoughtful response.

Table 2: Explanation of answers to the question about strategies to prevent membrane fouling.

	Pre Interview	Post Interview
Student 1	By giving a patient blood thinners, the blood will be able to filter more easily through smaller openings when clogging becomes a problem.	By adding a charge, such as a negative charge surfactant, this can aid in the reliability and flux rate of the membrane which will reduce fouling and increase flow.
Student 2	I am not sure, but it [carbon nanotube] may allow blood to flow through easier.	Adding a charge to the surfactant will allow particles to flow through the membrane easier. The charge on the membrane will attract or repel the unwanted materials, and this prevents clogging of the pores.

Understanding Engineering

One of the most positive outcomes of the internship is related to how much and in what ways students improved their understanding of the practice of engineering. Not only did most students also report that they would persist in engineering as a career choice, many identified the reason for their persistence as the clearer image of the practice of engineering that was presented in the internship.

> 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.

> This internship with Nephrotex has strengthened my enjoyment of biomedical engineering and I feel that I will continue to follow this career path.

On the post survey that the *Nephrotex* students as well as the control students took, there were clear differences in how their views about engineering were changed during the course. The typical response from a *Nephrotex* student was more detailed and discussed more of the different aspects of engineering practice than a typical response from a non-*Nephrotex* (control) student (see Table 3).

Table 3. Course Post-Survey Short Answer Responses: How has your perception of engineering changed this semester?

Typical Control students	Typical *Nephrotex* students
Engineering is a lot of math and science but a good engineers can do the math and science but they can also can write and speak cohertly too. There are a lot more engineering disciplines than I was aware of. A lot of engineers work together on projects.	The first module really helped me to see how an engineer will maximize and minimize things in a design a prototype and how engineers work together as a team. I see know how many different solutions there are to a problem and I see how each solution has its benefits and weaknesses. I realize they must decide what is most important when solving a problem.

Although many students came into the course thinking they knew what engineering was, the *Nephrotex* virtual internship gave them a more accurate and grounded view of what engineering is in practice. It is our hypothesis that this more accurate view of engineering, including valuing teamwork, innovation, and creativity, encourages a larger and more diverse pool of candidates to persist in engineering as a career.

Future Work

While analysis is ongoing, our preliminary results point to progress in understanding how students can use a virtual internship such as *Nephrotex* to build and practice the important skills of teamwork and collaboration, gain engineering content knowledge, and envision themselves in the role of an engineer in a realistic practice.

Future work in this area includes coding the discourse generated during Nephrotex and analyzing it for the important skills, knowledge, identities, values, and epistemologies that define the field of engineering. Since the game is able to facilitate teamwork and collaboration, we can continue to explore how this process happens. This further analysis will help give us a better picture of how the simulation added to students' views of engineering, how it facilitated teamwork and collaboration within teams, and how the online design advisors were able to help in this process.

References

Beckett, K. & Shaffer, D. W. (2005). Augmented by reality: The pedagogical praxis of urban planning as a pathway to ecological thinking. *Journal of Educational Computing Research, 33*(1), 31-52.

Hatfield, D. & Shaffer, D. W. (2006). Press play: Designing an epistemic game engine for journalism. In S. A., Barab, K. E Hay & D. T. Hickey (Eds.), *Learning sciences making a difference: Proceedings of the seventh International Conference of the Learning Sciences*. Mahwah, NJ: Lawrence Erlbaum Associates.

National Academy of Sciences (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future. In Committee on Prospering in the Global Economy of the 21st Century*. Washington, D.C.: National Academies Press.

Rohde, M. & Shaffer, D. W. (2004). Us, ourselves and we: Thoughts about social (self-) categorization. *Association for Computing Machinery (ACM) SigGROUP Bulletin, 24*(3), 19–24.

Schon, D.A. (1983). *The reflexive practitioner: How professionals think in action*. New York: Basic Books.

Schon, D.A. (1987). *Educating the reflexive practitioner: Toward a new design for teaching and learning in the professions*. San Francisco: Jossey-Bass.

Shaffer, D.W. (2004a). Epistemic frames and islands of expertise: Learning from infusion experiences. In Y. Kafai, W. Sandoval, N. Enyedy, A. S. Nixon, & F. Herrera, (Eds.), *Embracing diversity in the learning sciences: Proceedings of the sixth International Conference of the Learning Sciences*. Mahwah, NJ: Lawrence Erlbaum Associates.

Shaffer, D.W. (2004b). Pedagogical praxis: The professions as models for post-industrial education. *Teachers College Record, 106*(7), 1401-1421.

Shaffer, D.W. (2005). *Multisubculuralism: Computers and the end of progressive education*. University of Wisconsin–Madison, Wisconsin Center for Education Research.

Shaffer, D.W. (2006). Epistemic frames for epistemic games. *Computers and Education, 46*(3), 223–234.

Svarovsky, G. & Shaffer, D. W. (2007). SodaConstructing knowledge through exploratoids. *Journal of Research in Science Teaching, 44*(1), 133-153.

Acknowledgments

This work was funded in part by the MacArthur Foundation and the National Science Foundation through grants REC-0347000, DUE-091934, DRL-0918409, and DRL-0946372. The opinions, findings, and conclusions do not reflect the views of the funding agencies, cooperating institutions, or other individuals.