EPISTEMIC PERSISTENCE: A SIMULATION-BASED APPROACH TO INCREASING PARTICIPATION OF WOMEN IN ENGINEERING

Golnaz Arastoopour,[1,] Naomi C. Chesler[2]*
& David Williamson Shaffer[1]

[1]*Department of Educational Psychology, University of Wisconsin-Madison, 1025 W. Johnson Street, Madison, Wisconsin 53706, USA*

[2]*Department of Biomedical Engineering, University of Wisconsin-Madison, 1550 Engineering Drive, Madison, Wisconsin 53706, USA*

*Address all correspondence to: E-mail: arastoopour@wisc.edu

Educational institutions have historically struggled with retaining women in engineering. A significant drop occurs in the first year of undergraduate studies. In response, some universities have modified first-year curricula to include more teamwork and collaboration. Using epistemic frame theory, we hypothesize that more women would remain in the field if they had authentic experiences of the engineering profession early in their undergraduate career. To test this hypothesis, we designed and implemented an epistemic game, Nephrotex¸ in which students engage in authentic engineering design in teams. We collected two sources of data from students in Nephrotex (experimental condition): (1) students' pre- and post-survey responses about attitudes toward engineering and (2) students' online discourse. We collected pre- and post-surveys from the comparison group (control condition), students who participated in a non-design-based introductory engineering course in which they researched global engineering problems and solutions in teams. We conducted a principal components analysis on the survey data and an epistemic network analysis on the discourse data. Our controlled study suggests that (1) women in the experimental condition had a greater increase in confidence in and commitment to engineering than women in the control condition, and (2) students in the experimental condition who focused mostly on engineering design instead of collaboration were more committed to engineering. While the sample sizes are not large for this experiment and the gender distribution is not equal between groups (experimental, 63 female 75 male; control, 35 female 95 male), our results suggest that an authentic engineering simulation can increase women's motivation to persist in engineering. Interestingly, this was not the finding for men. Of the male and female students who participated in Nephrotex, those who focused on engineering design talk in collaborative discussions reported that they were more committed and confident afterward, suggesting that design is a motivating element in authentic engineering simulations for both men and women.

KEY WORDS: *education, undergraduate, epistemology, learning sciences, games, simulations, first year*

1. INTRODUCTION

In a technological and growing global economy, countries can only remain competitive if they have a supply of highly trained workers in science, technology, engineering, and mathematics

(STEM) areas who can develop innovative solutions to problems in a variety of fields. Unfortunately, the United States is not producing enough experienced engineers to remain competitive in the global economy (Carnevale *et al.*, 2011).

The shortage of engineers in the United States can be partly attributed to the underrepresentation of women in engineering. Women have made substantial progress regarding equity in the workplace in the last three decades, but they remain underrepresented among engineers. As recently as 2009, women accounted for less than 11 percent of the nation's engineers (National Science Foundation, 2011) despite accounting for 46.7 percent of the educated workforce (Catalyst, 2011). According to recent reports, the engineering field may not represent women's viewpoints in the design of products and solutions (Hill *et al.*, 2010). And, if women's viewpoints are not incorporated into the design of products and solutions, the resulting product may not account for the needs of female clients and the broader community (Page, 2008).

Thus, increasing the number of women engineers would address three major issues: (1) the need for more engineers in the field, which is a matter of economics, (2) the persistent underrepresentation of women in engineering, which is a matter of equity, and (3) the lack of women's viewpoints in engineering design, which is a matter of community.

The underrepresentation of women in engineering is caused in part by the low number of women who enter the undergraduate level declaring an engineering major. In 2007, only 2.5 percent of female freshmen intended to major in engineering compared to 14 percent of male freshmen (National Science Foundation, 2010). This problem is worsened by high undergraduate attrition rates in engineering for both men and women. In 2007, only 1.4 percent of bachelor's degrees in engineering were awarded to women and only 8.5 percent were awarded to men (National Science Foundation, 2010). The largest decrease in engineering enrollment for both men and women occurs after the first year of college (Atkinson and Mayo, 2010).

In response to this high attrition rate in the first year, some universities have modified their first-year curricula to motivate women to persist in an engineering major and to increase interest of women to enroll in various engineering programs. Based, in part, on recent studies that suggest women are more interested in STEM classes when teamwork is involved (Berenson *et al.*, 2004; Thom *et al.*, 2002), many of these new first-year classes include team-based projects, such as working on homework in groups, conducting group research on a global engineering issue, and/or presenting work to peers and instructors in teams (Azarin and Ferrier, 2008; Pendergrass *et al.*, 2001).

Here we present a preliminary study examining an alternative hypothesis: that first-year undergraduate women leave engineering majors because basic mathematics and science courses that make up most of the traditional first-year engineering curriculum give students a distorted understanding of how engineers think and work. This hypothesis suggests more women would stay in the field if they had authentic engineering experiences, such as participating in a realistic engineering design project, during the first year of their undergraduate training.

To test this alternative hypothesis, we designed a simulation in which students role-play as interns for an engineering company and participate in a simulated but realistic engineering design project. We compare these two hypotheses about how curricular change might increase interest in engineering majors among first-year women. We report on a preliminary controlled study that examines whether participation in a simulated design project helps women develop a more positive view of engineering when compared to students conducting group research on a global engineering issue.

2. THEORY

For more than a decade, reports, studies, and policy recommendations have suggested that as in-

formation and communication technologies create a global economy, work that does not require specialized training flows across national borders to where it can be done most cost-effectively. Countries with high-wage economies, like the United States, can only remain competitive if they have a sufficient supply of workers skilled in science, technology, engineering, and mathematics who can develop innovative solutions problems in a variety of fields (Carnevale *et al.*, 2011).

However, many of these same studies show that the United States is not producing enough engineers to compete effectively in the global marketplace. The number of US citizens who earn undergraduate engineering degrees has been stagnant since 1993 at a level well below that of comparable countries. In 2006, the US had a lower percentage of graduates in engineering (4.5%) than countries in Asia (21%) and Europe (11.7%) (National Science Foundation, 2010). In 2009, the U.S. ranked twenty-seventh out of twenty-nine developed countries in the percentage of students who earned bachelor's degrees in science or engineering (Organisation for Economic Co-operation and Department, 2009).

Moreover, women are historically underrepresented in engineering fields. In 2007, only 18.5% of engineering bachelor's degrees in the US were earned by women, and the number of bachelor's degrees in engineering earned by women has been declining since 2002 (National Science Foundation, 2010). Although there are some engineering fields such as environmental and biomedical engineering where about 40% of bachelor's degrees are awarded to women, these numbers have been declining as well since 2004 (American Society of Engineering Education, 2008; Chesler *et al.*, 2010c). This suggests that one way for the US to increase the number of engineering graduates *overall* is to increase the number of women in engineering (Snyder *et al.*, 2009).

Educational institutions at all levels have historically struggled with motivating and retaining women in engineering. Daniels (1995) and others (Alper, 1993; Blickenstaff, 2005; Davis *et al.*, 1996) have referred to this problem as a "leaky pipeline," in the sense that women opt out of STEM pathways at various points along their academic trajectories: from elementary school through university and on to STEM careers. One significant "leak" occurs when declaring an undergraduate major in the first year (Leveson, 1989; National Science Foundation, 2010) Research suggests that women with an interest in engineering enter undergraduate programs with high levels of self-confidence in academics, but these levels decline significantly during the first year (Marra *et al.*, 2009). The single biggest drop in engineering enrollment occurs between the freshman and sophomore year. However, women past this point who commit to a major in engineering are as likely as men to graduate as engineers (Huang *et al.*, 2000). Moreover, women who do choose to leave after the first year perform as well or better than their peers in their freshman engineering classes (Atkinson and Mayo, 2010). In other words, competent women are opting out of engineering careers in their first year.

First-year undergraduate courses thus play a pivotal role in a student's decision to major in engineering. But, current first-year programs do not motivate enough women to become engineers. In response, some universities have developed first-year undergraduate engineering programs in which, in addition to learning traditional engineering content, students work in teams to conduct research on global engineering problems and solutions (Coyle *et al.*, 2006; Dziedzic *et al.*, 2000; Knight *et al.*, 2003; Montgomery *et al.*, 2003). This change is in part based on recent studies that show that women are generally more interested in science and engineering when it involves teamwork, collaboration, and professionalism, and when the work being done emphasizes the pro-social aspects of engineering (Berenson *et al.*, 2004; Duncan and Zeng, 2005; Thom *et al.*, 2002; Zastavker *et al.*, 2006). For example, in the Integrated Math, Physics, Undergraduate

Laboratory Science and Engineering program, or IMPULSE, at the University of Massachusetts Dartmouth, engineering instructors integrate core first-year classes, such as calculus and physics, and have students work in teams during class, on homework assignments, and on projects (Pendergrass *et al.*, 2001). Thus, incorporating teamwork into first-year courses is one hypothesized method for motivating women to persist in engineering.

An alternative and less explored hypothesis is that some men and women opt out of engineering because they become disillusioned with the profession due to the basic math and science courses that are the focus of the first-year curriculum (Johnson *et al.*, 1991; Lumsdaine and Lumsdaine, 1995). In this view, more students would remain in the field if they had authentic experiences of the engineering profession early in their undergraduate career. Authentic professional experiences are situations that mimic essential aspects of real-world experiences. Strobel *et al.* (2013) identify five levels of authenticity: (1) context – resembles real-world context and content, (2) tasks – resembles real-world activities, (3) impact – products of students can be used outside of the classroom, (4) personal – projects are close to students' lives, and (5) value – projects satisfy personal or community needs. An effective authentic learning environment incorporates all of these levels of authenticity (Shaffer and Resnick, 1999). Thus, authentic *engineering* experiences involve real-world engineering activities such as working in teams, but also include such activities as analyzing data and participating in engineering design (Dutson *et al.*, 1997). Out of all these elements of the profession, engineering design is widely considered to be the most central aspect of engineering (Bucciarelli, 1994; Dym *et al.*, 2005). According to this hypothesis, if first-year female students had more exposure to engineering design, they would have *a better idea of what engineers actually do*. Thus, if women begin to think and work like professional engineers by participating in authentic engineering design, they might be more *motivated to persist* in an engineering major.

There have been several higher education institutions that have implemented authentic engineering design into undergraduate programs. Some higher level courses incorporate Problem-Based Learning—experiential, communal, and reflective learning around the investigation of real-world problems (Dahlgren and Dahlgren, 2002; Hmelo-Silver, 2004; Savery and Duffy, 2001). Many engineering programs require students to complete a senior design project or enroll in a "capstone" course during their final year. These design projects can be simulated—where faculty invent real-world scenarios and guide students through the design process or they can be genuine—where students interact with a client in the community (Dunlap, 2005; Dutson *et al.*, 1997). A few institutions have reported incorporating authentic design activities into the first-year curriculum (Atman *et al.*, 2000; Dym, 1994; Wang, 2001). For example, a freshman course at the US Air Force Academy provides students with a problem scenario where they work together to design a mission to Mars with the goals of building a research site and developing a renewable power source. Results showed that students in this course developed more effective problem solving skills when compared to a control group (Reeves and Laffey, 1999).

However, first-year students normally do not have opportunities to experience authentic engineering until they are further along in their undergraduate careers. One way students can develop their understanding of professional engineering is by participating in a practicum such as an engineering co-op or internship, but these are typically not available to first-year students. In an internship environment, learners can make decisions without facing the risk that an actual professional setting would involve (Schon, 1987). They take part in a *cognitive apprenticeship*, in which expert mentors offer scaffolded problem-solving opportunities, model professional practice, allow students to explore the professional domain, and perhaps most importantly, invite

them to participate in conversations to reflect on their work (Collins *et al.*, 1991, 1989). Through these reflective discussions, mentors model how to think and work like professionals in a domain.

Shaffer (2006, 2007) has characterized the learning that takes place in the practicum in terms of an *epistemic frame*. Epistemic frame theory suggests that every profession has unique collections of skills, knowledge, identities, values, and epistemology that construct an epistemic frame. Professionals in a field rely on domain-specific skills and knowledge to make and justify decisions. They have characteristics that define their identity as members of the group, as well as a set of values they use to identify important issues and problems in the field. Developing an epistemic frame means making connections between these skills, knowledge, identities, values, and epistemology elements. For example, in the engineering epistemic frame, an engineer might make a design decision to increase the safety factor of a product for the well-being of the client based on a completed stress analysis. In this case, the engineer is justifying a design decision by valuing the safety of the client and exhibiting the skill of completing a stress analysis. She knows which values to consider and which knowledge and skills to gather in order to make a design decision. Thus, the goal of a professional practicum is to build a professional epistemic frame—to develop the ability to think and work like a professional engineer.

Although participating in a practicum might encourage first-year students to persist through the basic math and science courses that dominate the first year of the engineering curriculum, the work in a practicum requires a basic competency in the engineering skills and knowledge that those math and science courses teach. In other words, students need to do real engineering to motivate them to take basic-level courses, but they cannot do real engineering until they have completed the basic-level work. The conundrum is that each experience provides lessons necessary for the other. A cycle emerges, causing otherwise competent students to drop out of engineering.

In this paper, we examine one approach to cutting this pedagogical Gordian knot: epistemic games. Epistemic games are computer simulations of professional workplaces (Shaffer, 2007). In these simulations novices role-play as interns for a company, interact with a virtual boss, access professional email, and can solve real-world problems without needing to first master basic domain content. The complex knowledge and skills that students do not yet have are embedded in the tools that novices use in the simulation. For example, in the epistemic game *Urban Science*, students play the role of interns at a fictitious urban and regional planning firm (Bagley, 2011). They consider the tradeoffs associated with social and environmental issues, try to meet virtual stakeholders' concerns, and use iPlan, a custom Geographic Information System. The iPlan tool is a custom simulation of professional software that allows students to model land use changes for a site. Students can make changes to the land model and see the effects of the changes through a dynamic visual representation without having to use complicated professional modeling software.

Given the opportunity to use this scaffolded tool while playing the game, students were able to engage in higher order problem solving and make connections between civic knowledge, planning skills, and the professional value of serving the public interest (Bagley and Shaffer, 2009; Beckett and Shaffer, 2005). In other words, after playing *Urban Science*, students were able to start solving problems and thinking like professional planners without having to learn the basic skills and knowledge of urban planning beforehand.

The development of students' epistemic frames through such experiences can be quantified using *epistemic network analysis* (ENA) (Rupp *et al.*, 2009; Shaffer *et al.*, 2009). Because the learning that takes place during a practicum can be characterized by the connections between elements of a professional frame, ENA measures when and how often students make such links during their work. ENA creates a network model (similar mathematically to a social network model) in which

the nodes of the network represent the skills, knowledge, identity, values, and epistemology from a domain. The links between these nodes quantify how often a person (or group of people, depending on the model) has made connections between these elements at some point in time. In this way, ENA models the development over time of a student's epistemic frame—and thus quantifies their ability to think and work like professionals.

In this study, we tested an epistemic game for engineering called *Nephrotex*. In *Nephrotex*, students play the role of interns at a fictitious medical device company (Chesler *et al.*, 2012). Students design a dialyzer filtration membrane for a hemodialysis machine while trying to meet the concerns of the company's internal consultants. They use a custom simulation of dialysis membrane design to develop and test their devices. Then, they analyze the results, iterate their designs, and justify their design decisions by writing reports in their digital engineering notebooks. Finally, students present and defend their final design to their colleagues and design advisors.

Our motivations in designing *Nephrotex* were (1) through the activities in the simulation, students would develop an engineering epistemic frame and that (2) development of an engineering epistemic frame could, in turn, lead to higher motivation for students to persist in engineering (Chesler *et al.*, 2010a, 2010b).

We implemented *Nephrotex* in two first-year engineering courses. In the first course, which was designed to increase participation in engineering among freshmen, students chose two half-semester modules in which they studied a single topic in engineering in depth. During the implementation, *Nephrotex* was offered as one possible module for students to select. In the other modules, which served as a control group, students worked in teams to read and discuss research addressing real-world problems in engineering, but did not engage in engineering design. In the second course, students in the experimental condition alternated participation in *Nephrotex* and attending lectures with guest speakers who discussed a variety of engineering careers and opportunities.

At the beginning and end of the course, students took pre- and post surveys with questions about their perceptions of engineering careers and their motivation to persist in engineering. We collected survey data from all students in the course. We also recorded all of the online conversations between students and between students and mentors in *Nephrotex*.

2.1 Research Questions

We used ENA to examine students' final epistemic frames after participating in *Nephrotex*. We coded students' work in the game for: engineering product design, professionalism, and collaboration, as well as other elements of the epistemic frame of engineering. These and other professional engineering elements are described further in the Methods section.

This study asks:

1. Did self-reported attitudes toward confidence in and commitment to engineering increase among women who participated in *Nephrotex* (experimental group)? Did they increase among women who did not participate in *Nephrotex* (control group)? [Research Question (RQ) 1]

2. Were students who made more connections with engineering design in their epistemic frames more confident and committed than those who made more connections with collaboration and professionalism? [RQ 2]

In doing so, we compare the existing hypothesis that teamwork will motivate first-year women to continue in engineering to the alternative hypothesis that engineering design will motivate women.

3. METHODS

3.1 Participants

We collected pre- and post-survey data from all students in the experimental and control groups and discourse data from students in the experimental group. We examined data from 130 control students and 138 experimental students. Participant information is summarized in Table 1. We used the Pittsburgh Engineering Attitudes Scale to measure freshman attitudes toward engineering. This scale has shown evidence of internal reliability, structural validity, and external validity (Besterfield-Sacre and Atman, 1994; Hilpert *et al.*, 2009).

TABLE 1: Participant information from four studies including experimental group and number of participants by gender

| Study	Group	Number of women	Number of men	Number of students
Large public university, Fall 2010	Control, traditional course	20	46	66
Large private university, Spring 2011	Experimental, *Nephrotex*	52	50	102
Large public university, Fall 2011	Experimental, *Nephrotex*	11	25	36
Large public university, Fall 2011	Control, traditional course	15	49	64

In Fall 2010, survey data about attitudes toward engineering were collected from students in an introductory engineering course (control group) at a large public university where they did not participate in engineering design. In Spring 2011, survey data were collected from a pilot *Nephrotex* study at a large private university with no control group. In Fall 2011, *Nephrotex* was implemented into the same introductory course as in 2010 at the same large public university. However, for this 2011 study survey data were collected from both *Nephrotex* students and control students. *Nephrotex* sessions in both the large private and large public university 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.

3.2 Nephrotex Game Description

Nephrotex is a professional practice simulation that uses a web-based PHP application and MYSQL database. All activities are web-based, which allows students to access the game from any browser with internet capabilities.

Students are welcomed to the internship program at Nephrotex, a fictitious medical device company. They begin by logging into the company website, which includes an email and chat interface. Interns send and receive emails to and from their non-player character supervisor and use

the chat window for instant messaging with other team members and their assigned design advisor. At the start of the internship, students take an entrance interview with survey questions, create a staff biography page, review internal documents about hemodialysis, filtration membranes, and diffusion, and summarize this information in their online engineering notebooks. After conducting background research within the *Nephrotex* website, interns examine fictionalized company research reports based on actual experimental data with a variety of polymeric materials, chemical surfactants, carbon nanotubes, and manufacturing processes. After collecting and summarizing research data, interns begin the actual design process. First individually, then in teams, students develop hypotheses based on their research, test these hypotheses in the provided design space, and analyze the results provided. The design space contains four inputs and five outputs (Fig. 1). Interns also become knowledgeable about internal consultants within the company who have a stake in the outcome of their designed prototype. These consultants value different outputs. For example, the clinical engineer is concerned about biocompatibility and flux, and the manufacturing engineer values reliability and cost. During the final days of the internship, students present their final device design and justifications to the class and instructor and complete an exit interview with survey questions.
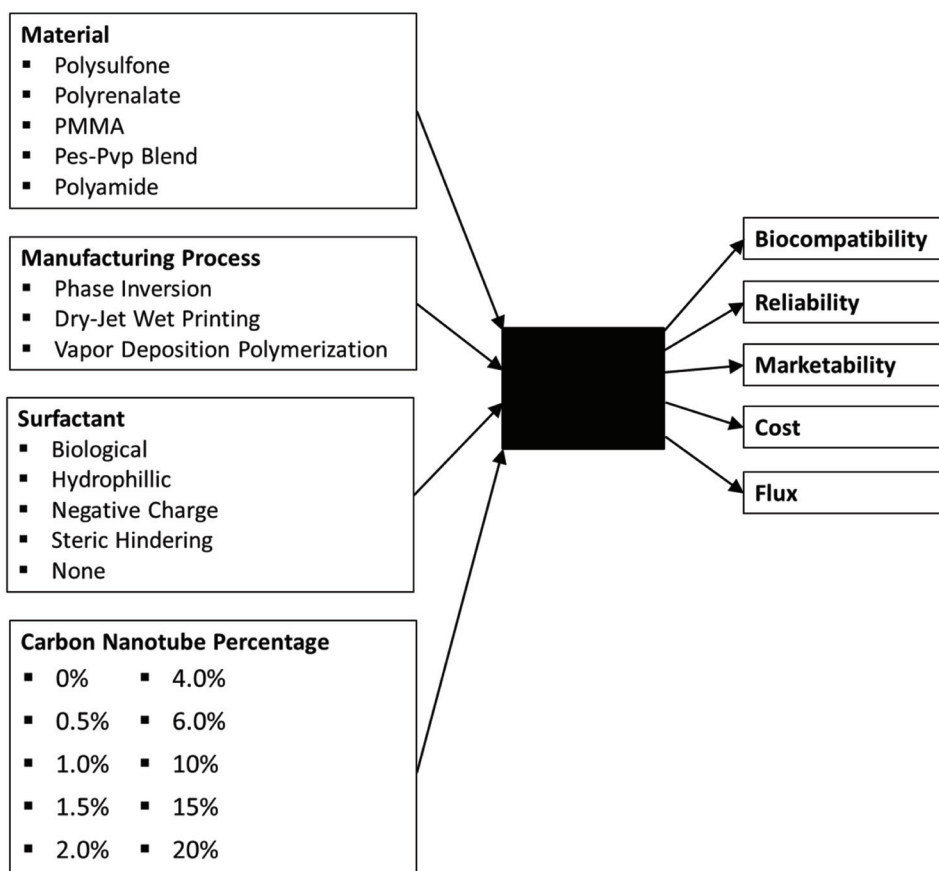
FIG. 1: *Nephrotex* design space (black box) with four categories of inputs (left) and five categories of outputs (right)

3.3 Course Descriptions

One of the goals of the introductory course (control group) at the large public university is for undergraduate students to be introduced to interdisciplinary learning by using a case-studies approach. Students listen to a few introductory lectures, and then after choosing a case study, participate in classroom discussions, read the technical and lay literature related to engineering challenges, write summaries and research papers, and present their work to their peers and instructors. These students do not participate in authentic engineering design. Table 2 summarizes and compares activities between *Nephrotex* and the control group in the introductory course.

TABLE 2: Summary of *Nephrotex* and introductory course activities. Checkmarks indicate that activity was present in *Nephrotex* or introductory course.

Activity	*Nephrotex*	Introductory course (control group)
Attend lectures		✔
Conduct research	✔	✔
Write reports	✔	✔
Participate in discussions	✔	✔
Present work	✔	✔
Analyze data	✔	✔
Design a product	✔	
Keep a design notebook	✔	

3.4 Principal Component Analysis (PCA)

Two sources of data were collected for this analysis: (1) students' pre- and post-survey responses and (2) students' discourse through participation in the chat program. Survey data were collected from both the experimental Nephrotex condition and the control group. Discourse data were only collected from the experimental Nephrotex condition because the virtual internship allowed for discourse data collection. The control group did not participate in the virtual internship program, and as a result, no discourse data were collected from the control group. All data were recorded and collected digitally.

Students in the *Nephrotex* condition and in the control group answered 20 Likert-scale questions on their perceptions of engineering careers and their commitment to the field in a pre- and post survey. Answers were on a four-point scale from 1 (strongly disagree) to 4 (strongly agree). Four students were eliminated from the data analysis due to incomplete responses. We conducted a principal components analysis (PCA) on 138 *Nephrotex* (63 female and 75 male) and 130 control group (35 female and 95 male) students using a covariance matrix. We conducted one PCA on the pre- and post responses together. We identified questions that were positively or negatively correlated with the survey question, *How committed are you to a career in engineering?* or with *I feel confident in my ability to succeed in engineering*, at

greater than 0.25 (Pearson's correlation coefficient). This resulted in a subset of eight highly correlated items seen in Table 3.

TABLE 3: Correlation table where correlations are greater than 0.25 for either commitment or confidence survey questions

	How committed are you to a career in engineering?	I feel confident in my ability to succeed in engineering
How committed are you to a career in engineering?	1	0.45
I feel confident in my ability to succeed in engineering	0.45	1
The future benefits of studying engineering are worth the effort	0.43	0.44
Someone like me can succeed in an engineering career	0.28	0.65
I like the professionalism that goes with being an engineer	0.25	0.20
Engineers are innovative	0.20	0.26
From what I know, engineering is boring.	-0.27	-0.34
I enjoy taking liberal arts courses more than math and science course	-0.26	-0.32

The first component was the only component that had an eigenvalue greater than 1 and assessed commitment and confidence to the field (48% of the variance accounted for). The mean scores on the component for women and men students were calculated. Student's t-tests were used to assess the significance of difference between the control group and experimental group's change from pre to post.

3.5 Discourse Coding Scheme

All chat discourse from the virtual internship was segmented by utterance. An utterance, in this case, was when a student sent a single instant message in the chat program. We coded the discourse using a set of twenty codes shown in Table 4. The codes were developed from ABET criteria for undergraduate engineering program outcomes (ABET, 2011) and using epistemic frame theory as a guide for professional practices. Each utterance segment was coded separately (1 = present, 0 = absent) for evidence of the codes.

We used an automated keyword coding system to code for the presence of all twenty codes. This system was developed by identifying simple keywords and identifying complex character string matching that represented the coding scheme. This automated coding process was validated for use in this study by comparing three sets of one hundred utterances that were hand-coded

TABLE 4: Engineering epistemic frame coding scheme and descriptions based on the epistemic frame theory composed of epistemology, value, skills, identity, and knowledge categories

Element category	Code	Description	Examples from data
Epistemology	Epistemology of data	Justifying decisions using data such as graphs, results tables, numerical values, or research papers.	All my devices have a biocompatibility of 87.78, I think that's the best you can get from Psf.
	Epistemology of design	Justifying decisions using design references such as device development, device specifications, ranking/priority of attributes, or tradeoffs in design.	Well, we have to create five devices in the end. So maybe we can have 2% in a few, and a higher content in one or two as well as a compromise?
	Epistemology of client	Justifying decisions by referring to the client's or patient's safety, health, or comfort.	I agree with Rolando that biocompatibility is the most important because it takes into account safety of the patient as well.
	Epistemology of internal consultants	Justifying decisions by stating internal consultants' preferences and concerns.	I changed the percentage of CNT between the devices because it seemed as though the flux at 4% CNT was still somewhat in the consultant's range.
Values	Value of client	Valuing the client/patient or stating that their needs are important	I think it depends on which attributes are the most important to us and patients.
	Value of internal consultants	Valuing the internal consultants' needs and thresholds or stating that their needs are important.	My consultant, Rudy, set her price goal as under $100. The highest version of the CNT-PMMA is $7, so for me, any of these processes works well. I think we should focus on other attributes that have more of a drastic effect.

TABLE 4: continued

Element category	Code	Description	Examples from data
Skills	Skill of data	The action of using numerical values, results tables, graphs, or research papers.	Oh, and I agree with using 2% for all of the devices, since it had great flux and reliability, if I remember right.
	Skill of design	The action of design development, prioritizing, tradeoffs, and making design decisions.	When deciding which ones to test, we took into account our attribute rankings as well as considering what good properties of certain processes canceled out others' shortcomings.
	Skill of professionalism	The action of using the company website, email, staff pages, or other internship related objects.	Well we need to e-mail Alex our reasons for each device we submit.
	Skill of collaboration	The action of collaborating or participating in a team meeting.	From last week's discussion it seemed like we were pretty decided on the devices though.
Identity	Identity of engineer	Identifying as an engineer or member of a team. Possession/ownership of an engineering notebook, lab result, team, or company.	Should we also share our notebook entries too? That basically says what we're going to discuss today too!
	Identity of intern	Identifying as an intern or staff member. Possession/ownership of professional items.	What do we do if we finished our staff page?

TABLE 4: continued

Element category	Code	Description	Examples from data
Knowledge	Knowledge of nanotechnology	Referring to carbon nanotubes.	I found that carbon nanotube content had no significant effects on biocompatibility
	Knowledge of surfactants	Referring to chemical surfactants (biological, hydrophilic, negative charge, and steric hindrance)	The Hydrophilic Surfactant has some of the highest numbers according to desirability.
	Knowledge of attributes	Referring to attributes: reliability, flux, biocompatibility, marketability, and cost	Cost was more of a secondary factor to consider.
	Knowledge of product	Referring to the device, prototype, experiment, or filtration membrane	So first and foremost, they must use the device.
	Knowledge of data	Referring to numerical values, results tables, graphs, or research papers	My best device had cost of 110, biocompatibility of 76.67, flux of 19…
	Knowledge of client	Referring to the health, comfort, and safety of the client/patient	From the company's point of view, cost and marketability are large concerns, but for the patient [client], it needs to be biocompatible and reliable.
	Knowledge of materials	Referring to materials (PMMA, polyrenalate, polysulfone, PESPVP, Polyamide)	We decided to use all the materials for our devices. That way, we can see how each perform after we test them.
	Knowledge of manufacturing process	Referring to manufacturing processes (dry-jet, phase inversion, vapor deposition polymerization)	Dry-jet processing is cheaper.

by multiple, independent human coders, and by comparing these hand-coded utterances to the automated coding system. For all code categories, Cohen's kappa scores were between 0.80 and 0.98 between the automated system and human coders. These results compare favorably to previous human-to-human coder outcomes, and, in some cases, outperform them. Thus, all utterances were coded using the automated coding system.

3.6 Epistemic Network Analysis (ENA)

ENA measures relationships between epistemic frame elements by quantifying the co-occurrences of those elements in discourse (Orrill *et al.*, 2013; Rupp *et al.*, 2009, 2010; Shaffer *et al.*, 2009). We used ENA in the epistemic game, *Nephrotex*, to measure students' development of connections made between skills, knowledge, identity, values, and epistemology, and not simply quantify the isolated occurrences of these elements. For this epistemic network analysis, chats utterances were segmented by class sessions. For each class session, for each student, we calculated the co-occurrences for each pair of codes. For example, if one student's discourse during one class session was coded for epistemology of data and skill of collaboration, then this would be recorded as a co-occurrence of these two codes.

After all co-occurrences were recorded, a network representation in the form of an adjacency matrix representing all possible co-occurrences of codes was created for each student for every class session. These adjacency matrices were converted (unwrapped) to adjacency vectors and were summed for each student. Finally, a singular value decomposition was conducted on the adjacency matrices which rotated the vectors in space to show the greatest variance. This approach is mathematically similar to a principal components analysis. In this rotated space, each student's adjacency vector that contains the co-occurrences of codes could then be represented as a point in high-dimensional space. Each dimension in this space can be interpreted by examining the loadings (rotation) matrix, again, similar to the interpretation in a principal components analysis. As a result, each student's final network representation at the end of the virtual internship can be represented as an ENA network score.[1]

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[1]Formally, the engineering epistemic frame can be depicted by individual frame elements f_i, where i = a coded engineering frame element. For any participant p, in any utterance segment u, each segment of engineering discourse $D^{p,u}$ provides evidence of whether participant p was using one or more epistemic frame elements.

Each coded utterance can be represented as binary vector V. Each coded utterance vector is converted into an adjacency matrix $A^{p,u}$ for participant p in a given utterance segment, u (1).

$$A^{p,u} = V \times t(V), \quad \text{where } A(i,i) = 0 \tag{1}$$

Each coded adjacency matrix $A^{p,u}$ is converted into an adjacency vector and summed into a single cumulative adjacency vector $U^{p,s}$, for each participant p in a given segment, s for each stanza (2). Each stanza is composed of several utterances from a student during a particular class. session.

$$U^{p,s} = \sum A^{p,u} \tag{2}$$

The cumulative adjacency vectors are normalized to a unit hypersphere to control for the variation in vector length, by dividing each value by the square root of the sum of squares of the vector (3).

$$nU^{p,s} = \frac{U^{p,s}}{\sqrt{\sum(U^{p,s})^2}} \tag{3}$$

A singular value decomposition (SVD) is performed to explore the structure of the code co-occurrences in the set of stanzas. We used SVD to project the normalized cumulative adjacency vectors into a high-dimensional space of 400 dimensions (all possible co-occurrences of twenty codes).

3.7 Research Questions

Using these analytic tools, we addressed the following research questions:

[RQ1] Did self-reported attitudes toward confidence in and commitment to engineering increase among women who participated in *Nephrotex*? Did they increase among women in students who did not participate in *Nephrotex* (control group)?

We used PCA on pre- and post-survey questions to create a composite score for each student's attitude toward engineering. We then used a Student's t-test to determine whether differences between *Nephrotex* students and students in the control group as measured by the computed composite score for attitude toward engineering were statistically significant.

[RQ2] Were students who made more connections with engineering design in their epistemic frames more confident and committed than those who made more connections with collaboration and professionalism?

We coded 2985 student chat utterances with the epistemic discourse coding method, and then segmented the data by each student's chat contribution in each class session. We used ENA on the segmented data to determine which connections students were making in their epistemic frames. We calculated two final ENA network scores for students' connections with collaboration/professionalism and connections with engineering design in their epistemic frames. We then used linear regression to determine whether there were positive correlations between ENA network scores on engineering design and confidence and commitment survey scores.

4. RESULTS

The data support two claims about the experiences of students in *Nephrotex*. First, women in *Nephrotex* (or "*Nephrotex* women") had a statistically significant increase in confidence and commitment to the field compared to women in the control group ("control women"). Second, *Nephrotex* women and men who had high positive change in commitment and confidence scores made more connections between the *epistemology of engineering design* and other elements of engineering practice.

Nephrotex women had an increase in commitment and confidence and control women had a decrease in commitment and confidence from pre to post. There was a significant difference between *Nephrotex* women (M = 0.23, SD = 1.34) and control women (M=-0.92, SD=1.88) change scores from pre to post; $t(53.64) = 3.2$, $p = 0.002$ with an effect size of 0.942 as seen in Fig. 2. There was no difference between *Nephrotex* men (M = -0.07, SD = 1.68) and control men (M = -0.38, SD = 1.90).

For example, one *Nephrotex* woman on the post survey responded:

I think working with this company and working with the product kept me very busy and interested in the engineering field. This internship has opened my eyes to Biomedical Engineering and it has created interest for me in that particular field. I am considering Biomedical Engineering as my career choice and this internship helped me understand what a Biomedical Engineer does on a regular basis.

Our preliminary epistemic network analysis showed that students in *Nephrotex* who made more connections between *epistemology of engineering design* and other elements of engineering practice showed positive change in *confidence and commitment* from pre to post survey (Fig. 3). In other words, ENA network scores on epistemology of design significantly predicted changes in confidence and commitment scores ($\beta = 1.25$, $p < 0.05$, $R^2 = 0.03$).
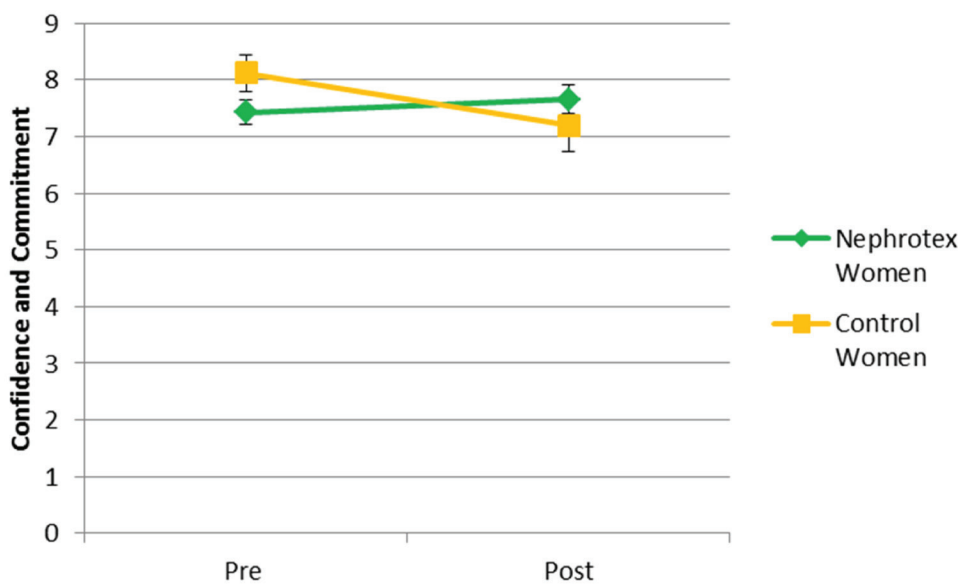
FIG. 2: *Nephrotex* and control women pre- and post-survey scores on confidence and commitment (Mean ± Standard Error)
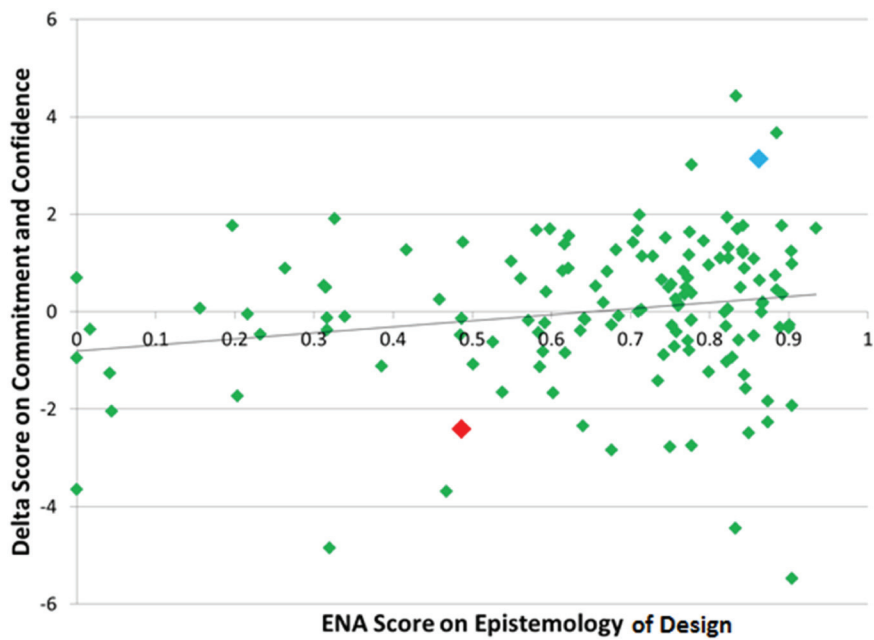
FIG. 3: Scatterplot of *Nephrotex* student delta scores on Confidence and Commitment vs. ENA scores on Epistemology of Design. Red point is a student with a low delta score and low design epistemology score. Blue point is a student with a high delta score and high design epistemology score.

During the second design iteration activity, interns discussed and designed final devices with their teams to send to the lab for testing. Representative data (actual names are replaced with pseudonyms) are shown in Fig. 4; here we chose one student with low commitment and confidence and low epistemology of design scores (Allison is represented by the red point) and one student that had high commitment and confidence and high epistemology of design scores (Janice is represented by the blue point). Janice makes descriptive statements as well as justifies her decisions with design parameters and data. She also draws on her knowledge of carbon nanotubes and attributes. Allison makes descriptive statements about materials, data, and manufacturing processes without justifying her statements or describing her design process.

Results from this study show that:

1. Women who participated in *Nephrotex* were more confident and committed to engineering than women in the control group. There was no difference between *Nephrotex* and control men.

2. For both men and women in *Nephrotex,* positive changes in commitment and confidence were associated with engineering design activities in the internship. Specifically, students who made more connections between engineering design and other engineering epistemic elements were more likely to feel more confident and committed to engineering.

Janice	*Yes, there are always going to be **trade-offs**, which is why we had to **rank the attributes**.*
High commitment and confidence High design epistemology ◆	*but **based on the conclusions from the other devices**, I would recommend using 2% CNT because it lowers the cost and has the same results in terms of quality*
Allison	*The most reliable device had mediocre marketability, flux, and biocompatible values, and a high cost of $100/unit*
Low commitment and confidence Low design epistemology ◆	*The most marketable PSf product had a value of 500,000. It is also the most biocompatible of the models, with a value of 65.56. It was treated with a steric hindering surfactant and manufactured through phase inversion.*

FIG. 4: Chat discourse samples from a design activity in *Nephrotex* from two students

5. DISCUSSION

In this study, 138 first-year undergraduate students participated in the *Nephrotex* virtual internship program. This virtual internship let students experience authentic but simulated engineering design. The reported results show that women who participated in the virtual internship felt more confident in and committed to engineering than women who participated in a first-year introduc-

tory course with group work but no design component. Furthermore, those students in *Nephrotex* whose chat discussion focused mostly on engineering design felt more confident in and committed to engineering after the internship than those whose chat discussion did not focus as much on engineering design issues.

The development of this study was based on two key ideas: first, that design is the most central aspect of engineering (Dym *et al.*, 2005); therefore, activities that focus on design can provide an authentic experience of the profession (Strobel *et al.*, 2013). In doing so, this study builds on previous work on problem-based learning (Dahlgren and Dahlgren, 2002; Hmelo-Silver, 2004) and authentic engineering design learning (Atman *et al.*, 2000; Wang, 2001), but is unique in incorporating authentic engineering design within an epistemic game that allows students to role-play as interns for an engineering company and simulates professional engineering practice. Second, thinking as an engineer can be characterized in terms of an epistemic frame: a set of skills, knowledge, identities, values, and epistemologies (Shaffer, 2006). Crucial to the idea of an epistemic frame is that this set is connected: skills are linked to each other, and to values and knowledge; knowledge is linked to epistemology, and so on. Learning to think like a professional means building the appropriate network of connections between these different frame elements. Thus, learning to think like an *engineer* means building an epistemic frame that includes significant connections between engineering design and other skills, knowledge, and values of the profession.

It is in this sense, then, that *Nephrotex* is an *epistemic* game. Players participate in a simulation of authentic professional practice and as a result have an opportunity to develop the epistemic frame of the profession (Chesler *et al.*, 2012).

We measured the development of the epistemic frame using ENA (Orrill *et al.*, 2013; Shaffer *et al.*, 2009). This method can take what players say and do in epistemic games and create network models of complex thinking. Network models, in this case, were created by measuring the connections students made between engineering epistemic elements. In other words, ENA can quantify complex engineering design thinking and problem solving.

The purpose of this study was to examine first-year undergraduate women in *Nephrotex* who (1) participated in authentic engineering design and (2) as a result, developed an engineering epistemic frame. The question we address is whether these women showed an increase in self-reported confidence in and commitment to engineering after engaging in the following pathway in Fig. 5.
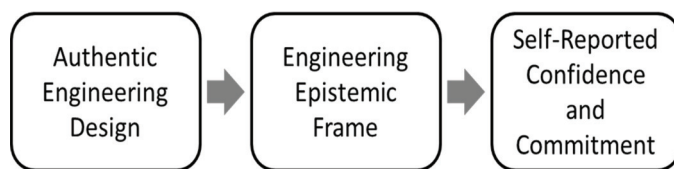
FIG. 5: Schematic representation of our hypothesis: authentic engineering design leads to development of an epistemic frame which leads to confidence and commitment to engineering for women

This is in contrast with a more traditional hypothesis, enacted in this study's control condition and in many current first-year undergraduate courses. These courses are designed to increase women's confidence and positive associations with engineering and in turn increase retention by (1) using collaborative processes to (2) introduce students to the social utility of engineering as shown in Fig. 6.

The results above show that women in the *Nephrotex* condition were more confident and committed than women in the control group. *Nephrotex* men were not significantly more confident and committed than control men. One possible explanation is that men enter the first year of undergraduate studies already committed to an engineering major—they enter with the same levels of confidence and leave with the same level of confidence. Women, however, enter engi-
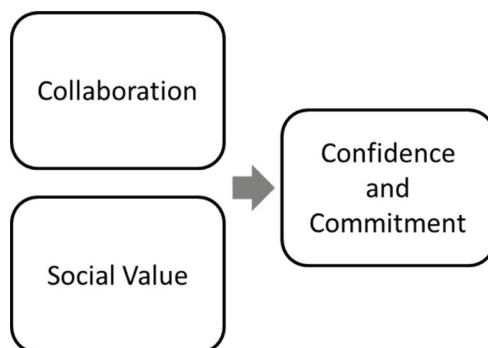
FIG. 6: Schematic representation of the traditional hypothesis: collaboration and social value lead to confidence and commitment

neering programs with lower levels of confidence compared to men, which may lead to attrition (Atkinson and Mayo, 2010; Brainard and Carlin, 1998).

To examine the details of this positive experience for *Nephrotex* women, we used ENA to quantify students' epistemic frames. *Nephrotex* students who developed epistemic frames that contained more connections with engineering design were more committed than those students whose frames had fewer connections with design. In other words, students who focused on engineering design were more committed to the field.

Based on this preliminary study, we therefore propose the *epistemic persistence hypothesis* (Fig. 7) for women participating in epistemic games that are simulations of engineering internships. In this pathway, students participate in authentic engineering design in an epistemic game to build an epistemic frame, feel more confident and committed to engineering, and as a result are motivated to persist in engineering. If correct, incorporating simulated authentic engineering design programs, such as *Nephrotex*, into first-year undergraduate courses will help women feel more confident as engineers, which will in turn motivate them to persist in an engineering career.
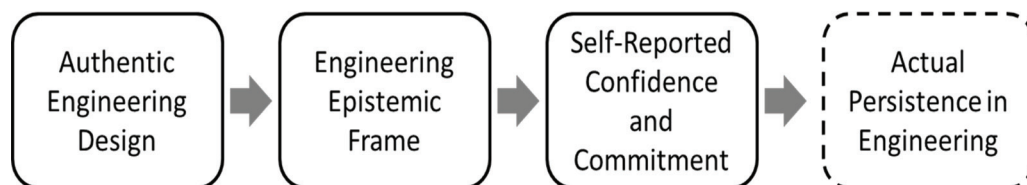
FIG. 7: Epistemic persistence hypothesis

If this process were to be successful, the resulting increase in women engineers, who are currently the largest unrepresented group, could help the United States produce the number of engineers needed to compete more effectively in a high-wage global marketplace. In addition, this persistence of women in engineering careers will provide a diverse viewpoint for the development of innovative engineering solutions and products.

Further study is needed to test the epistemic persistence hypothesis for first-year undergraduate women, possibly in a longitudinal study. In addition, these studies can be expanded to include other underrepresented groups in engineering and students in K-12 institutions. Specifically, instructors at higher education institutions can develop digital or in-person simulations of authentic professional engineering practice to retain women in engineering. Educators in K-12 programs may be able to adapt ideas of simulating authentic engineering design environments in classrooms for a younger population.

5.1 Limitations

This study has several limitations. First, the methods in this study involved a discourse coding scheme based on epistemic frame theory and ABET criteria. This coding scheme was developed before the discourse data were collected. As a result, the research questions are limited by the coding scheme and there was no exploratory discourse analysis in this study.

Second, these preliminary analyses examine a group of first-year students participating in a design project that is *embedded* in an engineering professional practice simulation. In this case, students experience engineering design and the professional practice simulation at the same time. These two experiences have not been tested in separate conditions, and it is possible that students could develop positive associations with engineering by participating in a simulation that does not involve design, or in a design problem that is *not embedded* within a simulation. In the latter case the opportunity to collect robust discourse data on the development of engineering thinking does not exist, which makes any hypotheses difficult to test. For the former case, future studies could involve having students participate in a professional practice simulation that does not include a design problem.

Third, due to the complexities of experimental design within classrooms, the sample sizes for gender vary across experimental and control conditions. Enrollment differs among institutions and classrooms, and as a result there are unequal sample sizes in the experimental and control groups and unequal numbers of women in each group.

Fourth, students in Nephrotex participated in a design project that focused on only two areas of engineering: materials science and engineering and biomedical engineering. The percentages of women obtaining Bachelor's degrees in biomedical engineering are higher than most other engineering disciplines (American Society of Engineering Education, 2008). In this study, the intervention was implemented in (1) an introductory general engineering course at a large public university and (2) an introductory biomedical engineering course at a large private university. In the general engineering course at the public university, the enrollment of women in course was 7% higher than the enrollment of women in the college of engineering. In the biomedical engineering course at the private university, the enrollment of women in course was 20% higher than the enrollment of women in the college of engineering. The relative over-enrollment of women in the private university introductory course is common to biomedical engineering courses. For our study, a consequence was an increased number of women in the experimental condition. To understand whether the relatively high proportion of women in the experimental sample affected the results, additional studies with larger sample sizes and more equal gender distribution are required.

The choice of a medically relevant problem was based on women's greater interest in biomedical engineering and was an intentional aspect of the engineering epistemic game design (Chesler *et al.*, 2012). We speculate that an engineering simulation about jet engine or silicone chip design would not have had the same positive results. However, our intent is not to increase the percentage of women who enroll in biomedical engineering degree programs compared to other degree programs through medically relevant engineering epistemic games, but rather to allow students to learn through experience how engineering training in other disciplines (for example, with Nephrotex, materials science and engineering) contribute to medical technologies and advances. Future studies will include building virtual internships in which medically relevant problems are solved with expertise derived from additional engineering disciplines.

Finally, the engineering profession itself comprises several disciplines, and each discipline requires varying sets of knowledge and skills. For example, biomedical engineers know about and design medical devices such as pacemakers, insulin pumps, and dialyzers, and mechanical engineers know about and design mechanical systems such as aircraft engines, gas turbines, and automated robots. Although skills and knowledge are varied among engineering fields, the element of design is considered to be the central activity in engineering (Dym *et al.*, 2005). However, it is not clear across engineering fields, *how* central design is within each field. In other words, if there is a field of engineering for which design is not as central, then a focus on engineering design might not be correlated as highly with positive views of engineering in this discipline. Future studies should include building virtual internships with design projects in other areas of engineering.

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