AC 2012-3103: NEPHROTEX: MEASURING FIRST-YEAR STUDENTS' WAYS OF PROFESSIONAL THINKING IN A VIRTUAL INTERNSHIP

Ms. Golnaz Arastoopour, University of Wisconsin, Madison

Before becoming interested in education, Golnaz Arastoopour studied mechanical engineering and Spanish at the University of Illinois, Urbana-Champaign. While earning her bachelor's degree, she worked as a computer science instructor at Campus Middle School for Girls. Along with a team of undergraduates, she headlined a project to develop a unique computer science curriculum for middle school students. She then earned her secondary mathematics teaching certification in New York City at Columbia University. Arastoopour then accepted a position teaching mathematics in the Chicago Public School system at Orr Academy High School, an AUSL school. Arastoopour is currently working on the Nephrotex project and is interested in how new technologies are effective and increase student engagement in STEM fields.

Dr. Naomi C. Chesler, University of Wisconsin, Madison

Naomi C. Chesler is an Associate Professor of biomedical engineering with an affiliate appointment in educational psychology. Her research interests include vascular biomechanics, hemodynamics, and cardiac function, as well as the factors that motivate students to pursue and persist in engineering careers, with a focus on women and under-represented minorities.

Dr. Cynthia M. D'Angelo, University of Wisconsin, Madison
Prof. David Williamson Shaffer, University of Wisconsin, Madison

David Williamson Shaffer is a professor at the University of Wisconsin, Madison, in the Department of Educational Psychology, and a Game Scientist at the Wisconsin Center for Education Research. His most recent book is How Computer Games Help Children Learn.

Jamon W. Opgenorth
Ms. Carrie Beth Reardan, Epistemic Games
Mr. Nathan Patrick Haggerty
Mr. Clayton Guy Lepak

Nephrotex: Measuring first-year students' ways of professional engineering thinking in a virtual internship

Introduction

Educational institutions at all levels have historically struggled with motivating and retaining women in science and engineering. Blickenstaff [1] and others have referred to this as the problem of a "leaky pipeline," in the sense that women opt out of the path from elementary school through university and on to STEM careers at various points along the way. One significant "leak" occurs when declaring an undergraduate major in the first year [2, 3]. Research suggests that women with an interest in engineering enter undergraduate programs with high levels of self-confidence, but these levels decline significantly during the first year [4]. The single biggest drop in engineering enrollment (23%) occurs between the freshmen and sophomore year [5].Once they pass this point, however, women who do commit to a major in engineering are as likely as men to graduate as engineers [6]. Moreover, those women who choose to leave after the first year perform as well or better than their peers in their freshmen classes [5]. In other words, competent women are disproportionately opting out of engineering careers during 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.

Recent studies 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 [7-10]. In response, some universities have developed first year undergraduate engineering programs where, in addition to learning traditional engineering content, students work in teams to conduct research on global engineering problems and solutions. For example, one large Midwestern university offers a first year course called Interdisciplinary Engineering (InterEgr 102) where students learn about the role of engineering in society's grand challenges. The course begins with several introductory lectures followed by two half-semester, theme-based modules. Students work in groups to discuss case studies of 21st century engineering challenges, complete writing assignments, and present their work through oral and poster presentations to their classmates and instructors.

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 [11, 12]. In this view, more students would remain in the field if they had authentic experiences of engineering design early in their undergraduate career to give them a better understanding of the work that professional engineers actually do. By this line of reasoning, if students begin to think and work like professional engineers, they might be more motivated to persist in an engineering major.

One way that advanced engineering students develop their understanding of professional engineering is by participating in a practicum. Professional practica simulate the world of professional practice and offer a training environment for professionals-in-training. In this environment, learners can make decisions without facing the risk that an actual professional setting would involve [13]. They take part in a *cognitive apprenticeship*, where 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 [14, 15]. Through these reflective discussions, mentors model how to think and work like professionals in a domain.

Shaffer [16] has characterized the learning that takes place in the practicum in terms of an *epistemic frame*. Epistemic frame theory suggests 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 elements. In the engineering epistemic frame, for example, 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.

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. This suggests that if first year students could experience a professional practicum, they might be more likely to persist through the basic math and science courses that dominate the first year of the engineering curriculum. The problem, of course, is that because they have not yet completed those basic math and science courses, first year students have not developed the engineering skills and knowledge required to participate in a practicum. 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.

In this paper, we examine one approach to this problem: *epistemic games*.

Epistemic games are computer simulations of professional workplaces. These simulations are constructed so that novices can solve authentic problems without first mastering basic domain content. The complex knowledge and skills that students do not yet know are embedded in the tools that novices use in the simulation.

The development of students' epistemic frames through epistemic games can be quantified using *epistemic network analysis* [17, 18]. 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 and mentors 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.

Design and Implementation of Nephrotex

In this study, we designed and tested an epistemic game for engineering called Nephrotex. In Nephrotex, students play the role of interns at a fictitious medical device company. Students design a dialyzer filtration membrane for a hemodialysis machine by using a custom simulation of dialysis membrane design to develop and test their devices while trying to meet the concerns of the company's internal consultants.

We implemented Nephrotex in a first year engineering course, InterEgr 102. In this course, which was designed to increase participation in engineering among freshmen, students choose two half-semester modules in which they study a single topic in engineering in depth as described above. During the implementation, Nephrotex was offered as one possible module for students to select. In the other modules, students worked in teams to read and discuss research addressing real world problems in engineering, but did not engage in engineering design.

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 the Nephrotex condition.

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 attitudes towards engineering careers change more positively among women who played Nephrotex?
2. Were students who made more connections with engineering design more motivated to continue in engineering than those who made more connections with collaboration and professionalism?

That is, we compare the existing hypothesis that teamwork will motivate first year students to continue in engineering and the alternative hypothesis that engineering design is more motivating.

Methods

Game Description

Nephrotex is a professional practice simulation and 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.

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, interns examine fictionalized company research reports based on actual experimental data with a variety of polymeric materials, chemical surfactants, carbon nanotubes, and manufacturing processes.

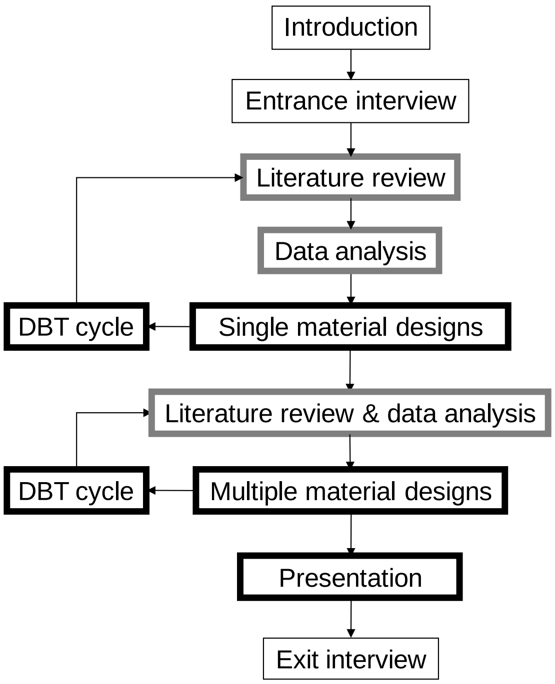

***Figure 1*. Nephrotex work flow diagram. Light borders around boxes indicate individual work; heavy borders indicate teamwork. DBT = design-build-test cycle.**

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. At the end of the internship, students present their work to their colleagues and supervisors.

Participants

In Fall 2010, 120 students enrolled in InterEng 102. The class had a modular design, which allowed us to implement Nephrotex with two groups of students over the course of the semester. In total, 45 students (13 female, 32 male) participated in Nephrotex. The remaining 75 students (24 female, 51 male; control group) participated in team-based research projects. The 45 students that participated in Nephrotex were divided into two modules. Module 1 was run first with 25 students, and module 2 was run second with 20 students. Class sessions were held in a computer lab where each student worked at his or her own computer. Conversations among students and between students and their design advisors were conducted in a chat program. Some students met virtually through the chat program or in person outside of class to finish assignments or plan for upcoming tasks. 29 out of 45 students self-identified as prospective biomedical engineering majors.

Data Collection and Coding

Two sources of data were collected for this analysis of Nephrotex: (1) students' pre and post survey responses and (2) students' discourse through participation in the chat program. All data was recorded and collected digitally.

All chat discourse from the virtual internship was segmented by utterance. An utterance, in this case, is when a student sends a single instant message in the chat program. We coded the discourse using a set of 21 codes shown in table 1. The codes were developed from ABET criteria for undergraduate engineering program outcomes [19] 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.

Table 1
Engineering epistemic frame elements coding scheme

Code	**Description**
Epistemology of Data	Justifying decisions using data such as graphs, results tables, numerical values, or research papers.
Epistemology of Design	Justifying decisions using design references such as device development, device specifications, ranking/priority of attributes, or tradeoffs in design.
Epistemology of Client	Justifying decisions by referring to the client's or patient's safety, health, or comfort.
Epistemology of Internal Consultants	Justifying decisions by stating internal consultants' preferences and concerns.
Value of Client	Valuing the client/patient or stating that their needs are important
Value of Internal Consultants	Valuing the internal consultants' needs and thresholds or stating that their needs are important.
Skill of Data	The action of using numerical values, results tables, graphs, or research papers.
Skill of Design	The action of design development, prioritizing, tradeoffs, and making design decisions.
Skill of Professionalism	The action of using the company website, email, staff pages, or other internship related objects.
Skill of Collaboration	The action of collaborating or participating in a team meeting.
Identity of Engineer	Identifying as an engineer or member of a team. Possession/ownership of an engineering notebook, lab result, team, or company.
Identity of Intern	Identifying as an intern or staff member.
Knowledge of Nanotechnology	Referring to carbon nanotubes.

Knowledge of Surfactants	Referring to chemical surfactants (biological, hydrophilic, negative charge, and steric hindrance)
Knowledge of Attributes	Referring to attributes: reliability, flux, biocompatibility, marketability, and cost.
Knowledge of Product	Referring to the device, prototype, experiment, or filtration membrane.
Knowledge of Data	Referring to numerical values, results tables, graphs, or research papers.
Knowledge of Client	Referring to the health, comfort, and safety of the client/patient.
Knowledge of Materials	Referring to materials (PMMA, polyrenalate, polysulfone, PESPVP, Polyamide)
Knowledge of Manufacturing Process	Referring to manufacturing processes (dry-jet, phase inversion, vapor deposition polymerization)

Principal Component Analysis (PCA)

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). We conducted a principal components analyses (PCA) on 41 Nephrotex (11 female and 30 male) and 66 control group (20 female and 46 male) students. Component 1 loaded >0.2 for questions that assessed a positive view of engineering careers (24% of the variance accounted for). Four students were eliminated from the data analysis due to incomplete responses. The mean scores on the component for women and men students were calculated, and t-tests were used to compare the responses from pre-survey to post-survey.

Epistemic Network Analysis (ENA)

ENA measures relationships between epistemic frame elements by quantifying the co-occurance of those elements in discourse [17, 18, 20]. We used ENA in the epistemic game Nephrotex to measure the development of connections made between skills, knowledge, identity, values, and epistemology, and not simply quantify the isolated occurrences of these elements. For this analysis, the data was segmented into stanzas defined by class sessions.

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, s, each segment of engineering discourse, $D^{p,s}$, provides evidence of whether participant p was using one or more epistemic frame elements.

As mentioned above, discourse was coded using ones and zeros. Thus, each coded utterance can be represented as binary vector. Links between epistemic frame elements were defined as co-occurances of the codes within each utterance. Each coded utterance vector was then converted into an adjacency matrix, $A^{p,s}$, for participant p in a given segment, s (1).

$$A_{i,j}^{p,s} = 1, if\ both\ f_i and\ f_j are\ in\ D^{p,s} \qquad (1)$$

Each coded adjacency matrix, $A_{i,j}^{p,s}$, was then 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.

$$U^{p,s} = \sum A^{p,s} \qquad (2)$$

The cumulative adjacency vectors were then 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).

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

A singular value decomposition (SVD) was then performed to explore the structure of the code co-occurrances in the set of stanzas. We used SVD to project the normalized cumulative adjacency vectors into a high dimensional space of 441 dimensions (all possible co-occurrances of 21 codes). In order to interpret each component, the pattern and contribution of each element within the component was examined. To simplify the interpretation of the components, we averaged every epistemic frame element loading and its relative co-occurrances to interpret 21 elements instead of 441 possible elements. For example, if we are interested in looking at the epistemology of design element, we could take the mean of all the possible combinations of epistemology of design with other epistemic frame elements. This allows us to identify a single mean location for epistemology of design (instead of 20 locations) while still accounting for the connections made in discourse between elements.

Results

The data support two claims about the experience of students in Nephrotex. First, women in Nephrotex had a statistically significant increase in positively viewing engineering careers compared to the control group. Second, women and men in Nephrotex who made more connections between the skills, knowledge, and epistemology of engineering *design* and other elements of engineering practice showed positive change in *positive view of engineering careers.*

Survey Results: Nephrotex Women View Engineering More Positively

Figure 2 shows a plot of questions that loaded greater than 0.2 on the component 1 (C1), which assessed *positive view of engineering careers* and accounted for 28% of the variance. Questions that loaded negatively on C1 (negative on the x axis) are related to a negative view of engineering careers and questions that loaded positively on C1 (positive on the x axis) are positive aspects of engineering careers. The plot below is of mean loadings from component 1 and component 2. Component 2, however, was not interpreted since the second component only accounted for 12% of the variance.

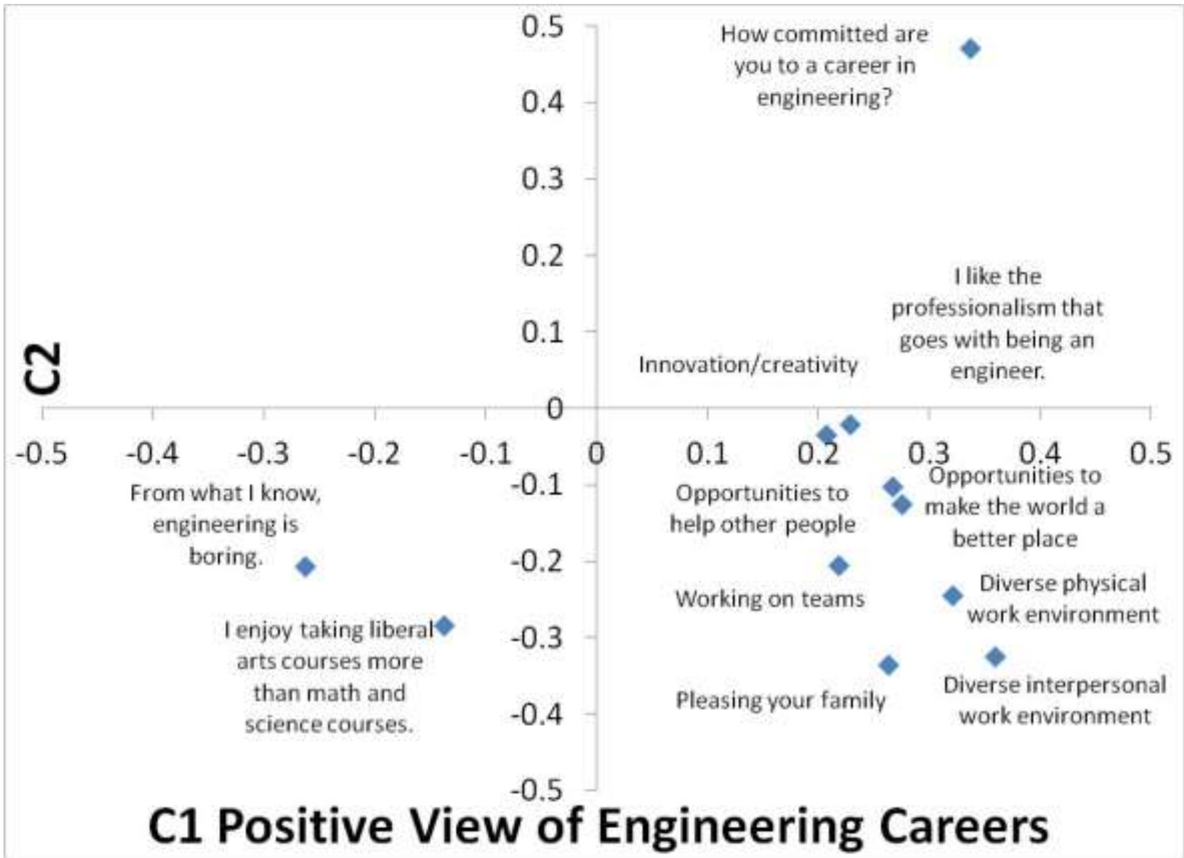

Figure 2. **Plot of loadings from C1 and C2**

Each of the women and men's change in score from pre-survey to post-survey were multiplied by the loadings for C1 and C2 and the women's scores are plotted in figure 3.

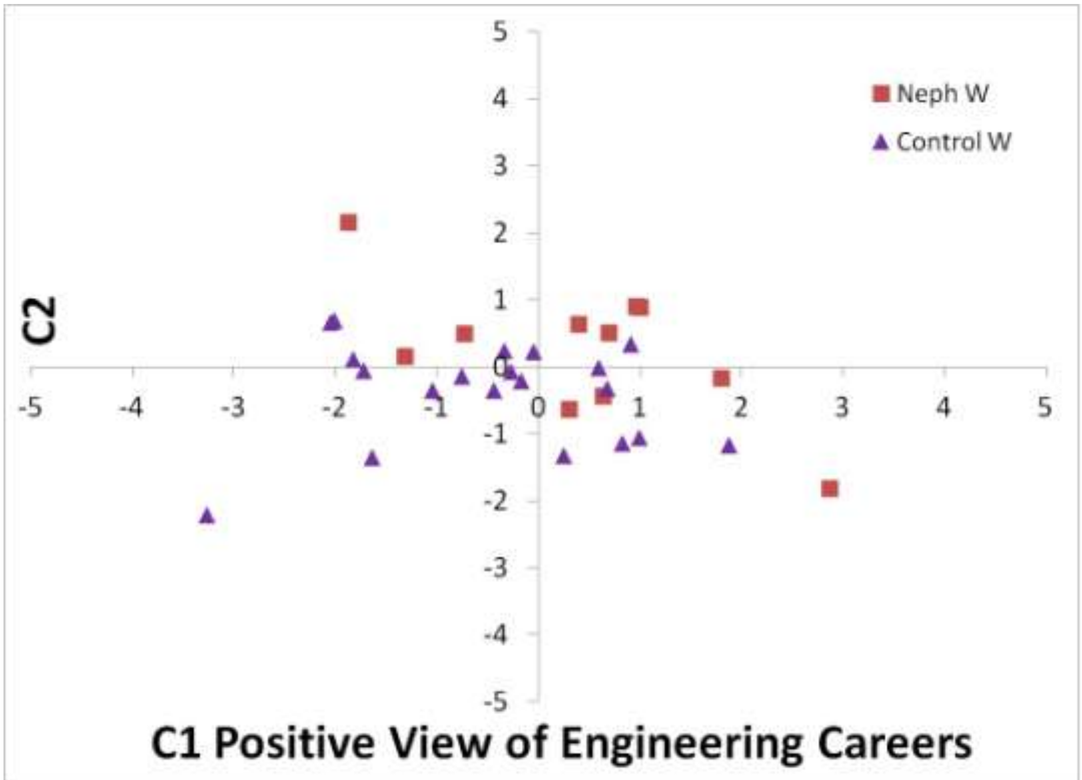

Figure 3. **Nephrotex and control group women survey scores on first two components**

The percentage of women in Nephrotex that had a positive change in mean scores (M = 72%, SD= .19) was significantly larger than the percentage of women in the control group that had a positive change in mean scores (M = 35%, SD = .22, $p < .05$) on C1 (positive view of engineering careers) as seen in Figure 4.

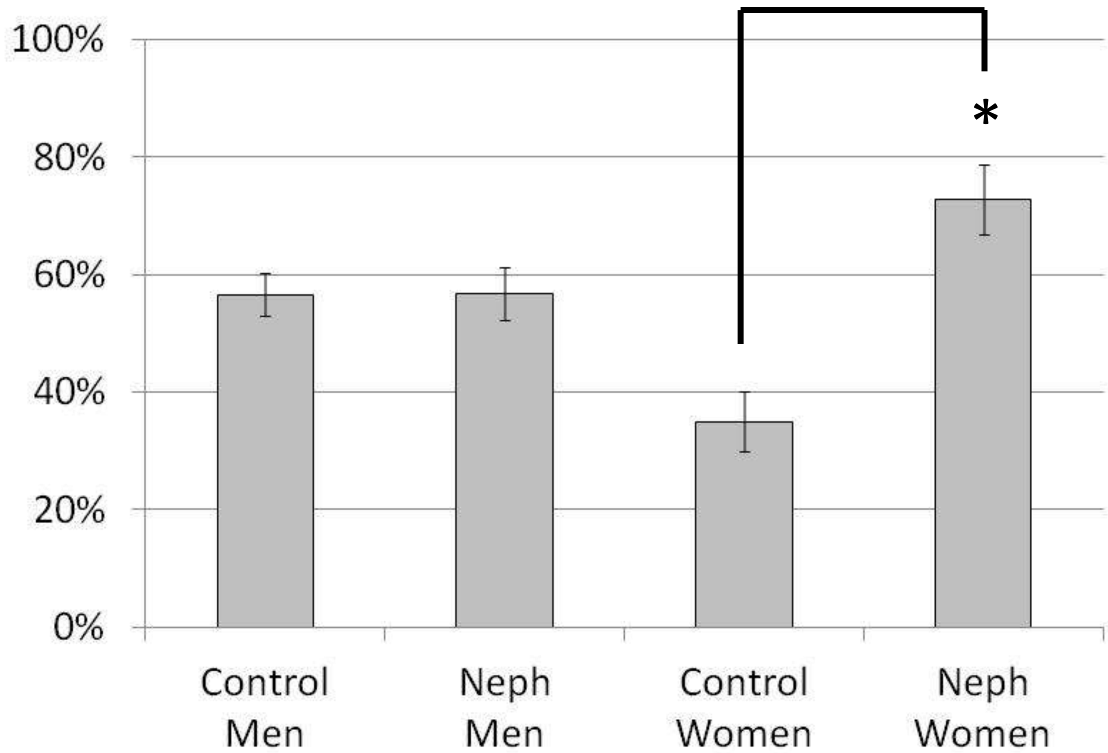

Figure 4. **Percentage of students that had a positive change in mean scores on *positive view of engineering careers.* (Mean ± Standard Error, * p<.05)**

ENA Results: Student Who Talk About Engineering Design View Engineering More Positively

ENA component 1 (ENA1) and ENA component 2 (ENA2) loaded > .02 for mean loadings for epistemology, skills and knowledge of design; epistemology, skills, and knowledge of data; and skills of professionalism and collaboration (Figure 5). Based on the plot of the loadings, items that loaded negatively on ENA 1 (negative on the x axis) are related to professionalism and collaboration, and items that loaded positively on ENA 1 (positive on the x axis) are related to the data analysis. Items that loaded negatively on ENA 2 (negative on the y axis) are related to data analysis and professionalism, and items that loaded positively on ENA 2 (positive on the y axis) are related to engineering design. The plot below is of loadings from ENA 1 and ENA 2.

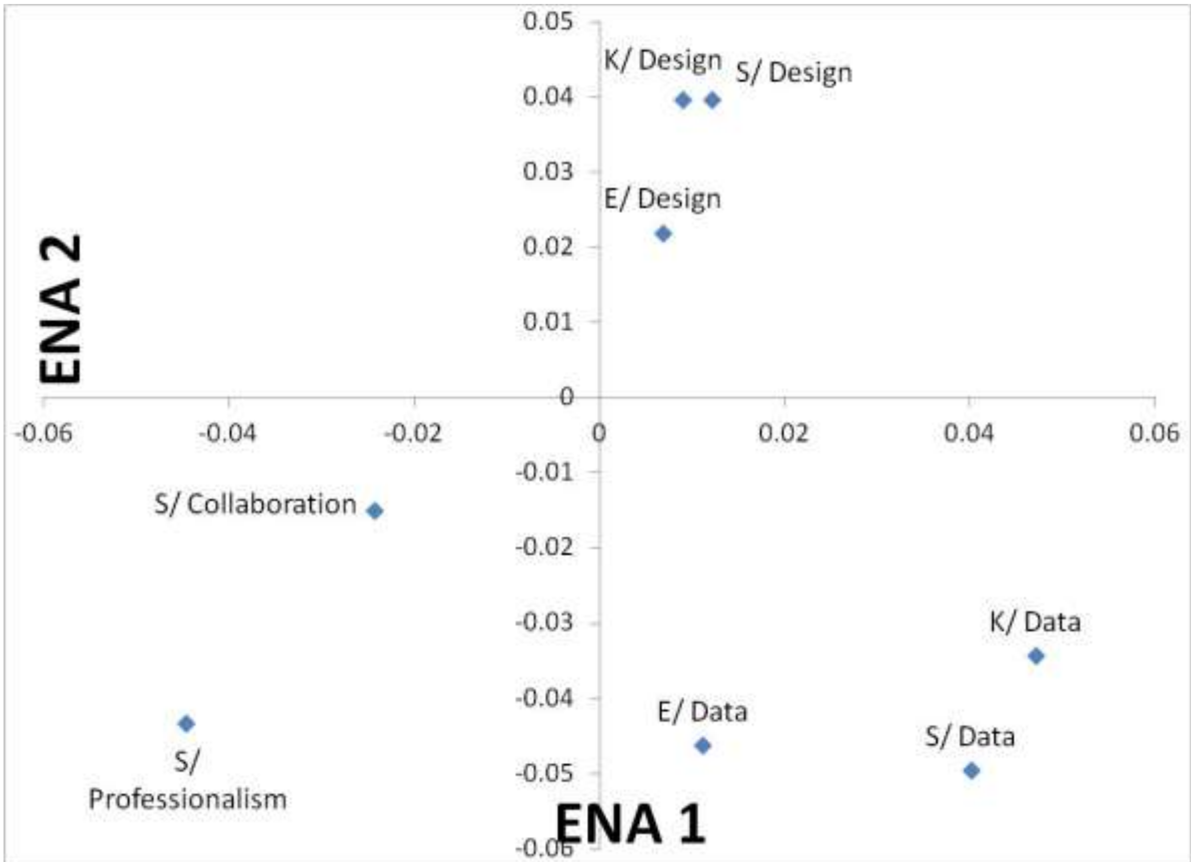

Figure 5. **Plot of loadings for first two principal components ENA 1 and ENA 2**

Each of the women and men's discourse scores from the end of the game were multiplied by the loadings for ENA1 and ENA2.

Students in Nephrotex who made more connections between the skills, knowledge, and epistemology of engineering *design* and other elements of engineering practice (i.e. other frame elements) showed positive change in *positive view of engineering careers* from pre-survey to post-survey (Figure 6). In other words, changes in ENA2 significantly predicted changes in C1 post scores when controlling for pre scores ($\beta = 1.789$, $p < .05$, $R^2 = .411$).

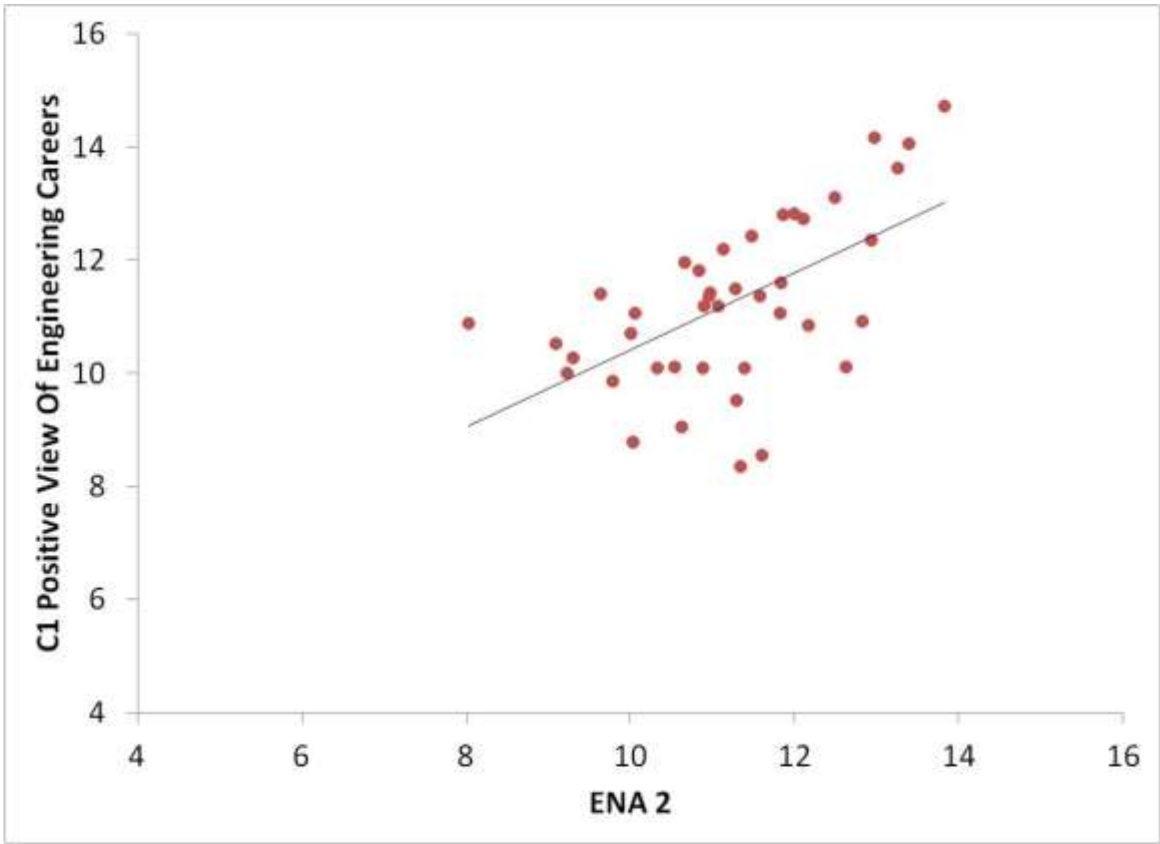

Figure 6. **Correlation between C1 *positive view of engineering careers* and ENA 2**

Discussion

This study examined the problem of women persisting in an undergraduate engineering major. Results from this study showed that women who participated in Nephrotex viewed a career in engineering more positively than women in the control group.

Furthermore, these positive changes were associated with engineering design activities in the internship, rather than collaboration. Specifically, students (women and men) who made more *connections* between engineering design and other engineering epistemic elements (such as collaboration, professionalism, and data analysis) were more likely to view engineering positively. Students who made more *connections* between collaboration and other engineering epistemic elements were more likely to view engineering negatively.

This result is significant because it violates the existing hypothesis that classes that focus on teamwork motivate women to persist in engineering. However, this study shows that when students are focusing on engineering design and making connections between design and collaboration, they are more likely to favor a career in engineering.

Future studies include retesting to obtain a larger sample size, collecting and using ENA on data from students in actual practica and internships and building virtual internships with design projects in other fields of engineering to compare students' experiences.

Conclusion

These results show that students in Nephrotex who made more connections with engineering design and other epistemic engineering elements viewed a career in engineering more positively than those who made more connections with collaboration. Reforming first year classes so that the central concept is engineering design may motivate first year students, especially women, to continue in the field of engineering.

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