Design of a Professional Practice Simulator for Educating and Motivating First-Year Engineering Students

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Abstract

Increasingly, first-year engineering curricula incorporate design projects. However, the faculty and staff effort and physical resources required for the number of students enrolled can be daunting and affect the quality of instruction. To reduce these costs, ensure a high quality educational experience, and reduce variability in student outcomes that occur with individual design projects, we developed a simulation of engineering professional practice, *NephroTex*, in which teams of students are guided through multiple design-build-test cycles by a mentor in a virtual internship. Here we report on the design process for the virtual internship and results of testing with first-year engineering students at a large, public university. Our results demonstrate that the novel virtual internship successfully educated and motivated first-year-engineering students. Importantly, the virtual environment captures rich discourse that can be used to assess the process of student learning with tools from existing learning theory.

Keywords: Epistemic frame, engineering education, learning sciences, virtual internship

I. Introduction

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

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

The design of first-year curricula is also critical to retaining women and other underrepresented groups in engineering degree programs. Women and underrepresented minorities are disproportionately lost at the gatekeeper math and science courses required in the first year [7], which are the prerequisites for advanced engineering courses. Cornerstone courses can help offset the negative impact of these courses by emphasizing teamwork, communication skills and other professional skills in which women engineering students often are more confident [8]. Courses in which positive women engineering role models are present can also offset the negative impact of the more traditional, masculine image of engineers, which is a key factor in the relative absence of women pursuing undergraduate degrees in engineering [9]. Lastly, the "Women's Experiences in College Engineering" project [10] found that an attraction to the *altruistic* kind of work that engineers do, particularly helping people and society, was one of the main reasons why women select engineering as an undergraduate major. The report emphasizes the potential value of exposing women early on in their undergraduate careers to the ways in which engineering has led to improvements in society and the quality of people's lives [10].

Thus, first-year courses should expose students to what it means to "be an engineer," including professional practices and the engineering design process. In addition, these courses should be engaging and utilize minimal financial resources. To improve gender diversity in undergraduate engineering programs, first-year courses should involve team work and emphasize communication skills, promote an image of a successful, practicing engineer that women can relate to, and seek to solve a design problem that is clearly relevant to improving society and/or the quality of people's lives. Lastly, the impact of first-year courses on student learning and motivation to pursue an engineering degree should be able to be robustly assessed.

Based on these course design criteria, we developed a 1-credit (11 contact-hour) module for use in pre-existing first-year engineering design courses. Importantly, the course director or instructor does not need specific engineering knowledge or skills. The emphasis of the module is on designing a product through multiple design-build-test cycles, working in a team, managing conflicting client requirements, making trade-offs in selecting a final design, justifying design choices and communication. In these ways, our module is designed to provide first-year students with the experience of being a practicing engineer.

II. Background

Epistemic frame theory suggests that learning to solve complex science, technology, engineering and math (STEM) problems comes from being part of a *community of practice* [11-13]: a group of people who share similar ways of solving problems. STEM learning does not end with the mastery of pertinent skills and knowledge; it must also include developing a sense of what kinds of judgments are in keeping with the values and practices of a field. Within a STEM discipline, there are particular ways of justifying decisions and developing solutions [14] . The *epistemic* *frame hypothesis* suggests that any community of practice has a culture [14-17] and that culture has a grammar: a structure composed of *skills* (the things that people within the community do); *knowledge* (the understandings that people in the community share); *values* (the beliefs that members of the community hold); *identity* (the way community members see themselves); and *epistemology* (the warrants that justify actions as legitimate within the community). This set of elements – the skills, knowledge, values, identity, and epistemology – forms the *epistemic frame* of the community [15, 16]. The elements of the epistemic frame that are specific to the profession of engineering are the engineering epistemic frame (EEF) elements.

Previous studies [18-21] have shown that participation in *epistemic games*—learning environments where young students begin to develop the epistemic frame of professionals (including architects, journalists, urban planners, and engineers)—increases students' understanding of science and their interest in the profession. For communities of innovation such as engineering, the key step in developing the epistemic frame is some form of *professional practicum* [11, 12]. 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. Examples include cornerstone and capstone courses in undergraduate engineering programs, medical internships and residencies, or almost any graduate program in STEM disciplines. By participating in authentic professional practices, students incorporate new ways of thinking and working into their sense of self [17]. They come to think of themselves, at least in part, as professionals. In more formal terms, these practica not only develop skills and knowledge, identity, values and epistemology, but also enable students to develop linkages between these elements as appropriate to solving a particular problem.

One authentic professional practice well-recognized to be important to engineering education is *engineering design*. According to Dym et al. [22],

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

In other words, activities in the design process critical to producing a quality product are gathering information, considering multiple alternatives and iterating through all the steps in the design process [23]. Learning how to design also requires learning to tolerate ambiguity, handle uncertainty, make and justify decisions, think as part of a team and communicate with both technical and non-technical audiences [22]. Our own work also suggests that interactions with both clients and mentors [24, 25] are key to the professional practice of engineering design.

Many aspects of engineering design in professional practice, including considering multiple alternatives, iteration, making and justifying decisions, working as a team and communicating with teammates, clients and supervisors, can be performed in a simulated environment - as a computer-simulated professional practicum or virtual internship. Computer-based simulations of real-life activities and experiences are an emerging and popular area of research and development in the learning sciences [26-29]. One advantage of the virtual learning environment, especially when role-play is involved, may be the immersive element of the activities [27]. In prior work by our group, the virtual internships *Urban Science* and *Digital Zoo* have been shown to successfully lead to the development of professional values and epistemology in urban planning and biomedical engineering, respectively, in K–12 students [19, 30]. An additional advantage of the on-line environment is that student communication and work output can be captured for later in-depth analysis of the learning process and progress.

III. Virtual Internship Design

As outlined above, our design criteria for an ideal first-year introduction to engineering course or module are that it must provide: (1) exposure to professional engineering practices, (2) exposure to the engineering design process as applied to a problem relevant to improving society and/or the quality of people's lives, (3) an engaging experience, (4) the opportunity to work in a team, (5) a positive image of a successful, practicing engineer to which women can relate, and (6) data that can be used to robustly assess student learning and motivation to pursue an engineering degree. Finally, it must do so (7) using minimal financial resources.

With regard to the design process in particular, we propose that the problem should incorporate six critical aspects of engineering design: individual research, design space exploration, client/stakeholder feedback, teamwork, selection of a preferred design and presentation of results. Each of these elements can be linked to the development to the engineering epistemic frame (EEF) through the five EEF elements: knowledge, skills, identity, values and epistemology (Table 1). This approach has many features in common with the STAR.legacy cycle, which is one method of challenge-based instruction that supports the *How People Learn* framework [31]. The STAR.legacy cycle also includes six activities: face a challenge, generate ideas, obtain multiple perspectives, research and revise, test your mettle and go public [32, 33]. An advantage of our approach is that we have recently developed robust mixed method (qualitative and quantitative) techniques by which the development of EEF elements and their linkages can be measured [34-36].

Table 1. Minimum set of activity elements required for an effective virtual internship, engineering epistemic frame (EEF) elements promoted by each activity, and representative tasks within a virtual internship that are the embodiment of each activity element.

Activity elements	EEF elements	Representative tasks
Individual research	Knowledge, skills	Technical reading, technical writing, graphing of data, interpreting graphs
Design space exploration	Knowledge, skills, epistemology	Developing and testing hypotheses regarding design alternatives, performance evaluation of design alternatives
Feedback	Values, identity	Interpreting performance in the context of stakeholder/client feedback, recognizing differences in client/stakeholder values
Teamwork	Skills, identity	Communicating with peers, conflict management, group decision making
Design selection	Skills, values, epistemology	Evaluating performance, valuing certain performance metrics above others, justifying a decision
Presentation of results	Skills, identity	Communicating in a professional context, answering questions about all aspects of the process including research, design, feedback, teamwork and design selection

A team-based design problem inherently satisfies two of our course design criteria: (2) exposure to the engineering design process and (4) the opportunity to work in a team. The remaining criteria were reconfigured into five guidelines for virtual internship development, which we call the *virtual internship framework*:

1. *Compelling Challenge*: The challenge posed in the virtual internship, i.e., the fiction of it, must be compelling to first-year undergraduates. It must be relevant to improving society and/or the quality of people's lives. Ideally, the challenge is attractive to a diverse group of students. This addresses criteria (2), a design problem relevant to society and (3), providing an engaging experience
2. *Large and Complex Design Space*: The virtual internship must include a multi-dimensional design space that is large and complex enough to preclude easy optimization. Any design space will have input parameters and output parameters (i.e., performance metrics). If the design space has too few dimensions, the task is trivial and uninteresting. If there are too many combinations of input parameters that generate good performance metrics, students will not be challenged. This aspect is critical to criterion (3).
3. *Competing Client Values*: It should be impossible to satisfy all clients/stakeholders in the virtual internship. Clients/stakeholders should value multiple performance metrics with no redundancy (i.e., no two stakeholders should value the same metrics to the same degree). In addition, the complex design space cannot produce output parameters that satisfy all stakeholders' valued performance metrics. This aspect addresses criteria (1) and (2).
4. *Web-based Access and Communication*: Making the virtual internship available in a web-browser environment is critical to broad access and potential for scale-up to large or multiple institutions with minimal increase in cost. Additionally, it is important that communication among students and between students and design advisors in the virtual internship are almost entirely web-based. This enables robust assessment of learning since it permits the capture of a rich data set of discourse. This aspect addresses criteria (1), (6) and (7).
5. *Existence of one or several Positive Female Role Models*: In a simulated environment, one has the opportunity to create a highly diverse leadership team. Ensuring that positive female role models exist addresses criterion (5).

Finally, care was taken to ensure that student work could be assessed for evidence of students having achieved, to some degree, educational outcomes that correspond to ABET Criteria [37] (Table 2).

Table 2. Engineering curriculum educational outcomes, related ABET Criteria and student work that could be assessed for evidence of having achieved an educational outcome.

Educational Outcomes	ABET Criteria	Student Work
1: An ability to apply knowledge of mathematics, science and engineering.	(a)	Notebook pages, summaries of technical reading
2: An ability to design and conduct experiments, as well as to analyze and interpret data.	(b)	Notebook pages, device design plans, device performance analyses, and individual and team-based device selections
3: An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability	(c)	Assessment of individual and team-based device performance with respect to client requirements, non-technical issue impact statement
4: An ability to function on multidisciplinary diverse teams	(d)	Peer/self assessment
5: An ability to solve engineering problems	(e)	Final device performance and justification of final device selection
6: An understanding of professional and ethical responsibility	(f)	Justification of final device selection including commentary on relative importance of the five performance criteria
7: An ability to communicate effectively and professionally by oral, written and graphical modes	(g)	Chat-based interactions with design advisors, emails to internship supervisor (written), final presentation (oral) and analysis of device performance (graphical)
8: The ability to understand the impact of engineering solutions in a global, economic, environmental and societal context	(h)	Justification of final device selection, non-technical issue impact statement
9: A recognition of the need for and an ability to engage in life-long learning	(i)	Literature search results using the internet
10: Knowledge of contemporary issues	(j)	Non-technical issue impact statement
11: An ability to use some techniques, skills, and modern engineering tools necessary for engineering practice	(k)	Device performance comparisons using Excel, literature search results using the internet

IV. Example Virtual Internship: *NephroTex*

In the virtual internship *NephroTex*, students role play as early career hires in the fictitious company *NephroTex*. Students are personally welcomed by the CEO via video and email and then informed by their immediate supervisor (again via email) that their first task is to design a next-generation dialyzer membrane. During the internship, students interact most frequently with a design advisor who is available via email and chat and serves as an intermediary between the team (4 to 5 students) and their immediate supervisor. The chronological internship progression is shown in Figure 1; a version of this information is provided to students in the form of a Gantt Chart (Appendix 1).

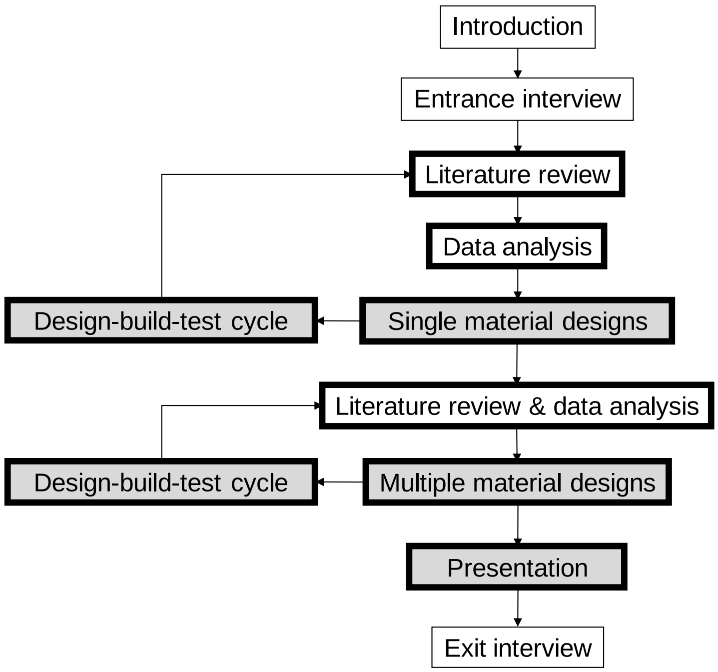

Figure 1. Flow chart for virtual internship progression. Thin borders denote individual activities; shaded boxes with thick borders denote team activities; unshaded boxes with thick borders can be individual or team activities.

In terms of incorporating the activity elements required for an effective virtual internship, the virtual internship can be described as follows:

Individual Research. Literature for review is provided to students in the form of fictionalized corporate technical reports based on the actual scientific literature. Reading and understanding these materials builds knowledge and skills. These technical reports are part of virtual internship framework aspect 4: web-based access and communication. A representative *NephroTex* technical report is included as Appendix 2. Students are also prompted to learn more about the company, its employees, mission, vision, history, etc. through short assignments that require students to explore the *NephroTex* website including, for example, viewing and creating staff pages.

Design space exploration. First individually and then in teams, students develop hypotheses based on their research regarding which combination of parameters will yield the best dialyzer membrane performance. In teams, students test these hypotheses by proposing design alternatives to the *NephroTex* Research and Development group and then analyze the design performance results that are returned to them. All design alternatives available to the students fall within a constrained design space, the complexity of which is determined by the number of input parameters, the number of output parameters, and the relationships between the input and output parameters. *NephroTex* has four input parameters – material, percent carbon nanotubes, processing method and surfactant – and 5 output parameters – biocompatibility, marketability, reliability, ultrafiltration rate (or flux) and cost (Figure 2, which is not provided to students). The mapping of input parameters to output parameters is defined by the simulation kernel; this key piece of virtual internship design is virtual internship framework aspect 2.

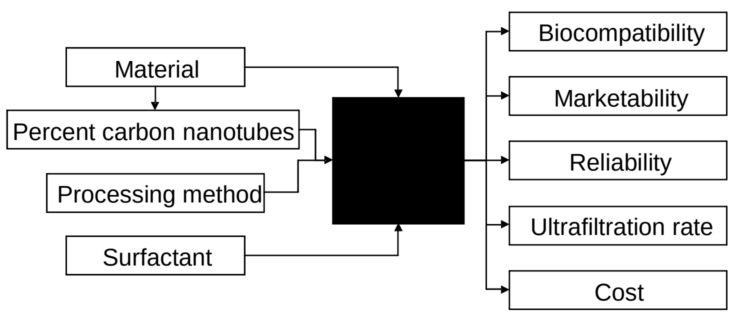

Figure 2. Design space in *NephroTex*, which has four input parameters and five output parameters or performance metrics.

To select their design alternative input parameters, students use a custom membrane design interface (Fig. 3). This tool allows students to visualize their proposed designs, make changes, and record their design process. Changes to the proposed designs can be readily visualized through the dynamic visual representation without having to use complicated professional modeling software.

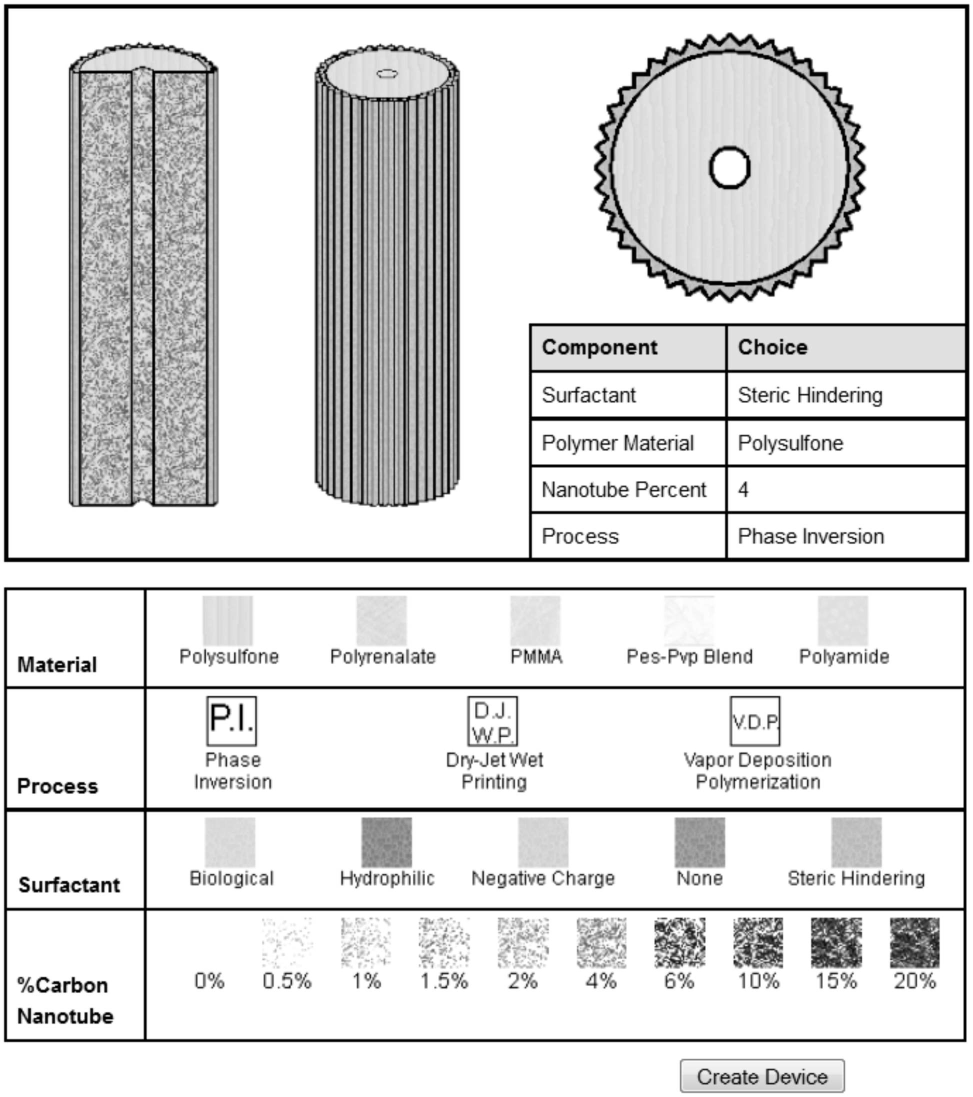

Figure 3. Custom membrane design interface students use in *NephroTex* to select input parameter values for their proposed design alternatives, i.e., to explore the design space.

Student teams perform two design-build-test cycles throughout the virtual internship. During the first cycle, students create “single material designs” (Figure 1) using a subset of the design space. Students are assigned a single material and can vary percent carbon nanotubes, processing method and surfactant. In the second design-build-test cycle, students create “multiple material designs” (Figure 1) as they explore the full design space which includes the option to use any of the five materials (Figure 3). In order to constrain the exploration of the design space, each student team is only permitted to submit five design alternatives to the *NephroTex* Research and

Development group per design-build-test cycle. Student teams are informed that this realistic constraint exists because cost is a barrier to testing mutliple design alternatives.

Feedback. After students send their design alternatives to the *NephroTex* Research and Development group, the performance metrics for their devices are sent back to them in tabular and graphical format (Figure 4). To interpret the performance criteria, students must return to the *NephroTex* staff pages (first visited during individual research) to learn which employees are stakeholders in the performance of the design and what levels of biocompatibility, marketability, reliability, ultrafiltration rate and/or cost they find acceptable. Each stakeholder is designed to value two performance metrics differently from the others. That is, no two stakeholders value the same metrics to the same degree (internship framework aspect 3). To ensure different degrees of value, each stakeholder has a strict threshold as well a preferred level for the performance metrics they value. These levels may overlap but are not identical for two stakeholders. The stakeholders' valued performance metrics as well as their strict and preferred thresholds are given in Table 3.

Table 3. Stakeholder valued performance metrics and threshold levels

Performance Metric	Stakeholder	Threshold
Biocompatibility*	Clinical engineer	Strict: 90 nanograms/mL
		Preferred: 45 nanograms/mL
	Focus team leader	Strict: 110 nanograms/mL
		Preferred: 55 nanograms/mL
Ultrafiltration rate	Clinical engineer	Strict: 10 m^3/m^2 per day
		Preferred: 15 m^3/m^2 per day
	Product support	Strict: 12 m^3/m^2 per day
		Preferred: 13.5 m^3/m^2 per day
Marketability	Marketer	Strict: 330,000 units per year
		Preferred: 550,000 units per year
	Focus team leader	Strict: 250,000 units per year
		Preferred: 650,000 units per year
Cost*	Marketer	Strict: $150 per unit
		Preferred: $100 per unit
	Manufacturing engineer	Strict: $160 per unit
		Preferred: $75 per unit
Reliability	Manufacturing engineer	Strict: 3 hours
		Preferred: 5.5 hours
	Product support	Strict: 1.5 hours
		Preferred: 4.7 hours

*Lower cost and lower beta-thromboglobulin level (biocompatibility) are desirable

Batch Details

Name	Title	Created	Material	Process	Surfactant	Nanotube
homer	Device 2	1:22 pm, Jan 20	polyrenalate	dry	biological	2
homer	Device 1	1:22 pm, Jan 20	polyrenalate	phase	hydrophilic	1.5

Analysis

Name	Title	Reliability	Marketability	Flux	Biocompatibility	Cost
homer	Device 2	6	800000	17	43.33	140
homer	Device 1	7	400000	21	76.67	110

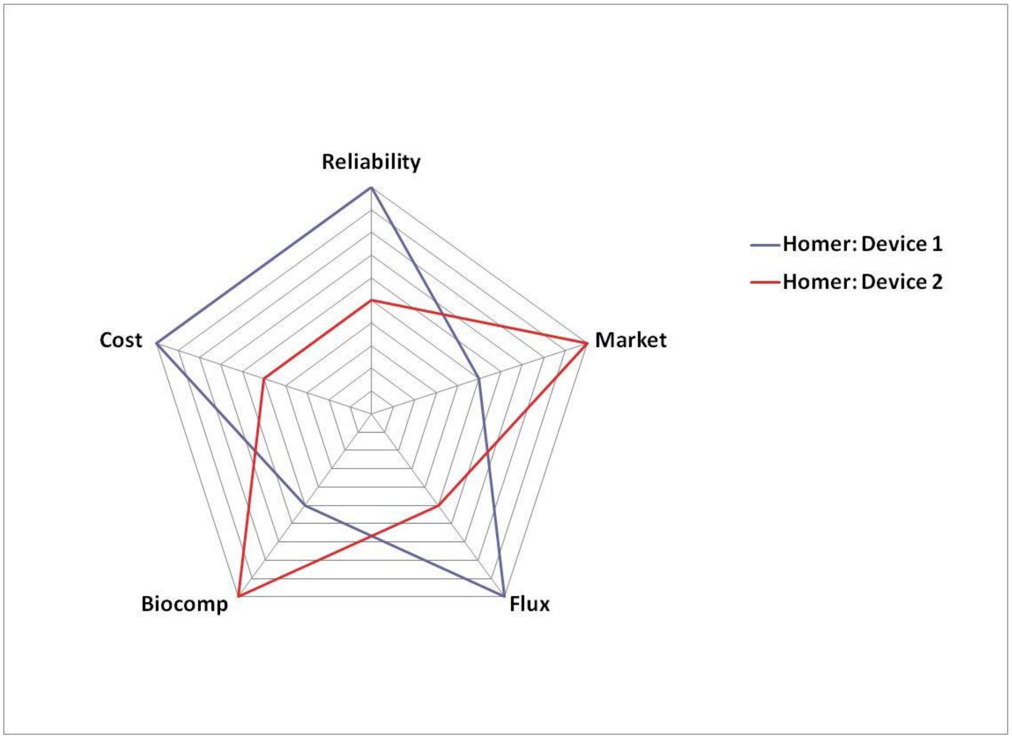

Figure 4. Sample student "Batch" input to *NephroTex* Research and Development group (top panel), returned performance metric "Analysis" results in tabular format (middle panel) and returned graphical representation of rankings of performance metrics (bottom panel).

Teamwork. While some internship work is completed individually, such as reading the literature, writing in notebooks, and graphing data, much design work is done in teams (Figure 1; thick lines). Team interactions are facilitated during class-time by design advisors through on-line, web-enabled chat. However, team interactions can also take place outside of class through the web-enabled chat or face-to-face.

Design selection. After the final design-build-test cycle, each student team must identify an optimum device that meets as many stakeholders' requests as possible. The design of the simulation kernel does not allow for an outputted device that satisfies all stakeholders' requests. Thus, each student individually justifies this design selection in their electronic design notebook and describes why he/she chose to meet certain stakeholders' requests and not others.

Presentation of results. Student teams present the final design selection and justifications to the class, design advisors and the instructor. This "going public" aspect forces students to articulate their decision-making process, justification and values. This activity is not web-based.

V. Implementation

Thus designed, *NephroTex* was implemented into a *professional practice simulator* (2PS), a Web-based PHP application and MySQL database, which is a shared workspace that simulates the technologies and workflow of a professional office. Using a web-based client, 2PS allows student players to interact through simulated e-mail and a live chat interface. The e-mail interface, linked to the Web-based PHP application and database, controls the flow of game activity. Since all activities are web-based, students can access the game from any Internet-accessible location.

Students attend a total of 11 50-minute class sessions and are required to be on-line during class.. Nearly all *NephroTex* student work occurs during class and no material outside of *NephroTex* is presented to students during class. Design advisors (upper level undergraduate or graduate students with approximately 12 hours of training) are also on-line during every class period and check the site frequently between classes to answer student e-mails and assess student work for grading purposes. However, while design advisors are virtually present (i.e., on-line), they are not physically present in the classroom and do not interact face-to-face with students until the final presentation.

The course instructor may be present in the classroom during class sessions. This person does not need to have specific expertise or training. Typically, the course instructor role plays as an employee of *NephroTex* responsible for ensuring that interns remain on task. Any questions directed to the course instructor during class are re-directed to the on-line design advisors.

The training for design advisors includes participating in an accelerated version of the virtual internship as a student, discussing epistemic frame theory, and most importantly participating in a guided version of the virtual internship as a design advisor. This training prepares design advisors to answer students' questions, understand how the virtual internship system functions, help with troubleshooting, guide students in reflection discussions, and at all times maintain a professional persona in the virtual internship. One trained design advisor can mentor up to 3 teams of 5 students simultaneously.

Brief videos describing *NephroTex* and other epistemic games are available on www.youtube.com/epistemicgames.

VI. Assessment of the Virtual Internship for Student Motivation and Learning

In Fall 2010, 120 students enrolled in an introductory engineering class with a modular design that allowed us to implement *NephroTex* with two sets of students over the course of the semester. At the beginning of the semester, faculty instructors described all the modules and students listed their preferred (top 3) modules. Based on these preferences, 45 students (13 women, 32 men) were selected to participate in *NephroTex*; of these, 29 self-identified as prospective biomedical engineering majors. The course met twice per week over the course of the semester so we could implement *NephroTex* two times (i.e., with two sets of students: 25 and then 20) over the course of a 13-week (26 contact-hour) semester.

NephroTex sessions were held in a computer lab where each student worked at his or her own computer. Some students met virtually through the chat program or in person outside of class to finish assignments or plan for upcoming tasks. Frequent e-mail and chat communication between students and design advisors occurred; expectations regarding professional communication styles were made clear at the outset and reinforced frequently. One assignment required students to conduct a literature search and summarize findings in their design notebooks; many other assignments required students to read pre-selected material and summarize the content in their notebooks. The engineering disciplines were introduced via staff pages that students were required to read. Also, at one point students were asked to add current staff members to their team based on their expertise in another discipline and describe how that person's skills and training would contribute to a particular aspect of future product development. The entire virtual internship was an introduction to how practicing engineers work and do engineering. Students received no explicit training in the engineering design process but were guided through two design-build-test cycles in which they had to justify the designs they sought to test.

Students completed pre- and post-surveys on the first and last days of the virtual internship approximately six weeks apart. They answered two multiple choice and seven short answer isomorphic content questions. Content question topics included experimental setup, general design decisions, strategies to prevent membrane fouling, kidney functions, reliability of membranes, diffusion and hemocompatibility. These matched-pair questions were coded for correct responses (1 = correct, 0 = incorrect or incomplete). In the post-survey only, a series of engagement questions was asked to determine students' level of immersion and engagement in the virtual internship. These questions were adapted from Green and Brock's *transportation index* that measures a readers' immersion in a fictional world [38]. The four point scale ranged from 1 (strongly disagree) to 4 (strongly agree) with a higher score indicating more engagement in the virtual experience. Content question data were analyzed using Student's *t*-test with $p<0.05$ considered significant. The responses to the engagement questions were analyzed using a one-sample *t*-test (compared to a population mean with a neutral response of 2.5 on a 4 point scale) with $p<0.05$ considered significant.

Engineering Content Learning: The survey results demonstrated that *NephroTex* significantly increased engineering content learning. Students had an overall mean score of 39% (SD = 24%) correctly answered pre-survey content questions and 69% (SD = 22%) correctly answered post-survey content questions ($p<0.05$). Two central concepts in this virtual internship were experimental setup and strategies to prevent membrane fouling. The largest gains from pre- to post-survey were for the responses to these questions (Figure 5; $p<0.05$ for both).

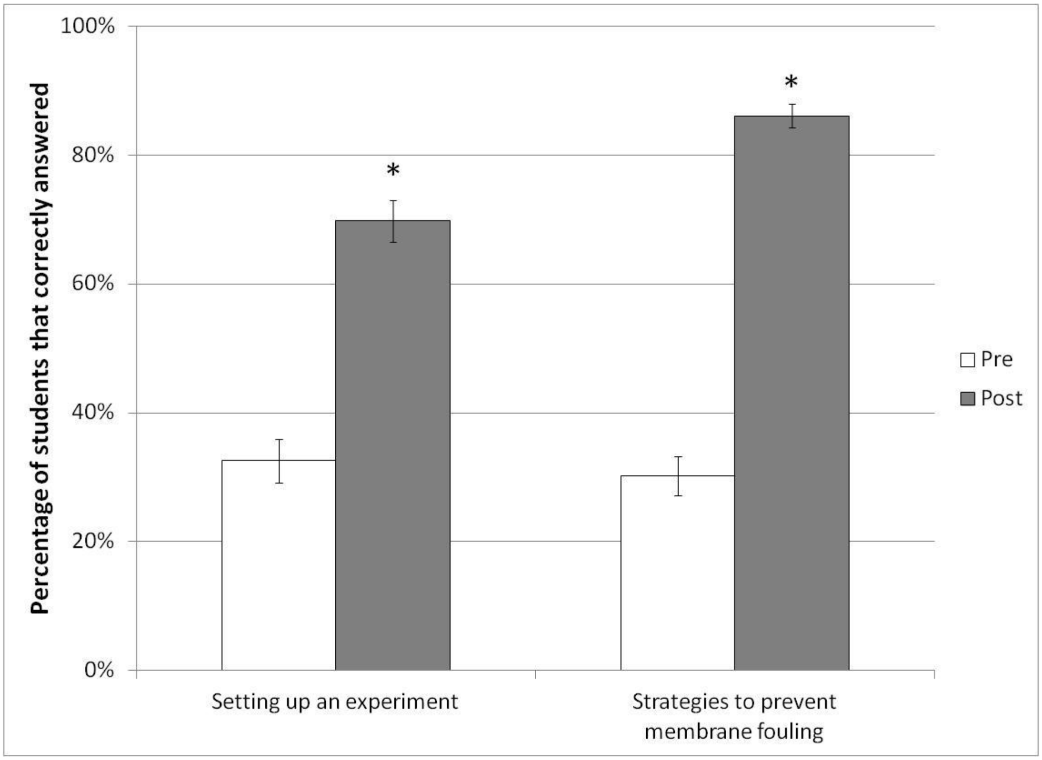

Figure 5. Percentage of students in *NephroTex* who correctly answered two of the engineering learning content questions in the pre- and post-surveys. Bars represent mean + standard error; * $p<0.05$.

For example, in response to a question about membrane fouling, a representative student had the following pre- and post-survey responses:

> *Pre:* I am not sure, but [carbon nanotubes] may allow blood to flow through easier.
>
> *Post:* 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.

Engagement: The survey results also demonstrated that students were significantly engaged in the virtual internship. Students responded particularly positively to “I was mentally involved in the *NephroTex* internship while it was going on” and “I wanted to learn how the new *NephroTex* device would turn out” (Figure 6). Student responses to these two questions are statistically significant compared to a neutral score of 2.5 on a 4 point scale. The question “The *NephroTex* experience changed my life” evoked a neutral response, as one might expect.

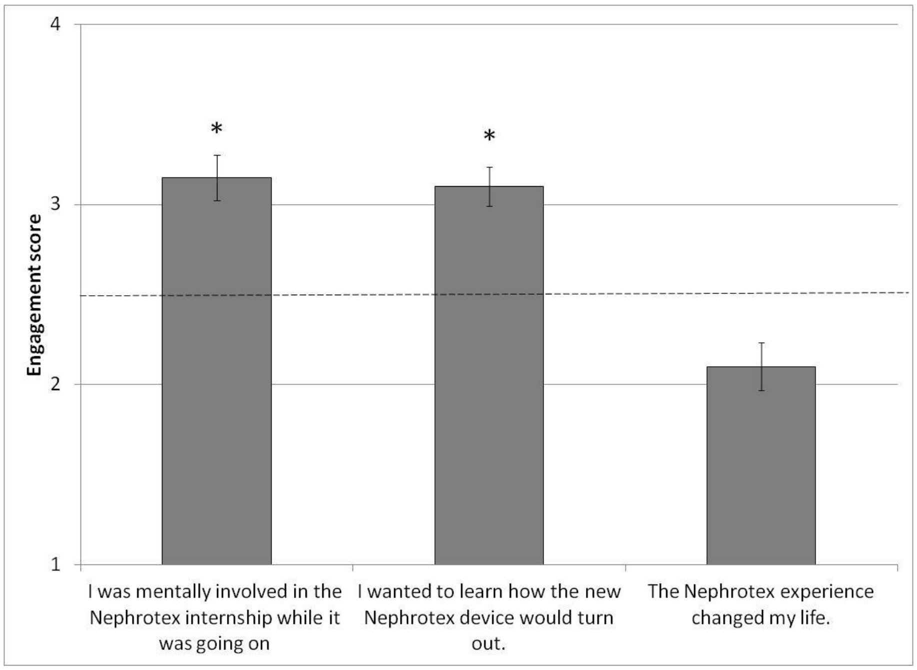

Figure 6. Student responses to three questions adapted from Green and Brock’s transportation index. The four point scale ranges from 1 (strongly disagree) to 4 (strongly agree). Bars represent mean + standard error; * $p<0.05$. The line at 2.5 indicates a neutral response.

VI. Discussion and Conclusions

Here we present the design of a virtual internship for first-year engineering curricula that includes six activity elements: individual research, design exploration, client/stakeholder feedback, teamwork, selection of a preferred design and presentation of results and five additional criteria that make up the virtual internship framework.

In this study, we focus on the theoretical basis for the design of a virtual internship for first-year engineering curricula and on developing a virtual internship framework for successful implementation. We identified two criteria for success: educating and engaging students. Our results suggest that *NephroTex* had a positive impact on engineering content learning and engaged students.

A potential limitation is selection bias in the population of interest. That is, because of the format of the course in which *NephroTex* was implemented, more students who participated in this virtual internship were interested in biomedical engineering than other disciplines. While we anticipate that some of the benefits of a virtual internship are not discipline-specific, and that even students interested in, say, civil engineering, might benefit from participating in a virtual internship in biomedical engineering, confirmation of this must await future work.

VII. Summary and future work

In constructing the virtual internship, or engineering epistemic game, *NephroTex*, we have identified a set of six activity elements that we hypothesize are required for engineering learning and specifically for development of an engineering epistemic frame in first-year undergraduate engineers. Robust, quantitative analysis of the discourse collected in *NephroTex* using established methods [39, 40] will allow us to test aspects of this hypothesis in future work. In addition, we have identified five aspects of the game design, which act as design constraints, that we believe ensure an engaging, challenging, and ultimately positive educational experience especially for women that can be implemented at small and large institutions and multiple institutions simultaneously with minimal financial cost. Finally, we implemented *NephroTex* in a large first-year undergraduate course at our institution and successfully demonstrated both learning gains and high levels of engagement.

In addition to field testing with students at different institutions, from more diverse backgrounds, and with different disciplinary interests, our future work will include constructing virtual internships in different content domains. Our vision is to create a suite of virtual internships for each of the core engineering disciplines that could be implemented in parallel or series in an introduction to engineering class to give all students an early and realistic exposure to a range of engineering professional practices, which we anticipate will increase retention in engineering curricula. Indeed, as a novel approach to engineering education and one that emphasizes teamwork and communication, *NephroTex* may preferentially increase retention of women and underrepresented minorities. Testing this hypothesis will be another area of future work. Another promising future direction is altering the internship such that it is appropriate to high school or middle school-aged students to promote exploration of engineering careers in the pre-college years.

NephroTex is an example of an engineering professional practice simulation for first-year undergraduate students. This virtual and collaborative environment is based on learning theories that support students learning particular ways of justifying decisions and developing solutions unique to a domain. Incorporating an engaging virtual internship like *NephroTex* exposes students to professional practice, engineering design, and may motivate more students, specifically women and underrepresented minorities, to persist in engineering.

VIII. Acknowledgements

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Biographical Sketch for each author

Naomi C. Chesler is an Associate Professor in the Department of Biomedical Engineering at the University of Wisconsin-Madison with affiliate appointments in the Departments of Medicine, Mechanical Engineering and Educational Psychology. She graduated with a BS in general engineering from Swarthmore College before obtaining her MS in mechanical engineering from MIT and her PhD in medical engineering from the Harvard-MIT joint program in Health Sciences and Technology. Professor Chesler not only seeks to improve diagnoses and prognoses for heart failure by studying vascular biomechanics and hemodynamics, but also investigates mentoring and curricular change strategies for improving the recruitment and retention of women and underrepresented minorities in engineering. She has been collaborating with the Epistemic Games group in the Wisconsin Center for Educational Research since 2009.

Golnaz Arastoopour is a graduate student in the Epistemic Games research group at the University of Wisconsin-Madison. She is interested in how new technologies are effective and increase student engagement in STEM fields. Before becoming interested in education, Golnaz studied Mechanical Engineering and Spanish at the University of Illinois at 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. Golnaz has always been involved and interested in how technology can be used as an effective and engaging teaching tool.

Cynthia D'Angelo is a post-doctoral fellow with the Epistemic Games group. Dr. D'Angelo has a background in physics and science education. She has always been interested in improving science instruction and most recently, using simulations and games to help facilitate learning. Among other things, she is interested in how students make use of multimedia representations of scientific concepts in games. Her doctoral dissertation work involved looking at how students' understanding of vectors, vector addition, and Newtonian mechanics was mediated by representations and scaffolding questions in a specially designed game.

Elizabeth Bagley is a postdoctoral fellow in the College of Education at the University of Illinois at Urbana-Champaign. Dr. Bagley is particularly interested in the design, assessment and implementation of virtual STEM education experiences. Her doctoral work in Educational Psychology and Environment and Resources at the University of Wisconsin-Madison examined face-to-face and virtual mentoring conditions in a virtual environmental education experience called Urban Science. Before coming to the University of Illinois, Elizabeth taught 8-12th grade science in South Louisiana and conducted sea turtle and coral reef research with the World Wide Fund for Nature on the Kenyan coast.

David Williamson Shaffer is a Professor at the University of Wisconsin-Madison in the Departments of Educational Psychology and Curriculum and Instruction, and a Game Scientist at the Wisconsin Center for Education Research. He leads the Epistemic Games group. Before coming to the University of Wisconsin, Dr. Shaffer taught grades 4-12 in the United States and abroad, including two years working with the Asian Development Bank and US Peace Corps in Nepal. His M.S. and Ph.D. are from the Media Laboratory at the Massachusetts Institute of Technology, and he taught in the Technology and Education Program at the Harvard Graduate School of Education.

Appendix 1: Gantt chart made available to *NephroTex* interns on the first day of the internship to inform them of upcoming tasks and deadlines.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Administrative Internship Deliverables									
Entrance Interview	■								
Staff Page Creation	■								
Colleague Assessments								■	■
Exit Interview									■
Research									
Background Research	■								
Surfactant Analysis		■							
Internal Consultant Research			■						
Material Research			■						
Design Proposals/Testing									
Brainstorming/Individual Designs				■					
Isolated Material Team Designs					■				
Final Batch of Design Proposals						■			
Analyzing Results					■		■		
Final Design Deadlines									
Final Design Decision							■		
Presentation of Final Design								■	

Appendix 2: An example of a technical report about the effects of a surfactant on a filtration membrane made available during the *individual research* portion of the internship

Nephrotex Experimental Device Testing Report No. 2008-1

August 2008

Effect of PEO on Cellulose Acetate Membrane Fouling and Biocompatibility

Victor Montino
Research & Development Team Leader
Nephrotex, Inc.

Jared McComb
Hannah Chang
Research & Development Team Members
Nephrotex, Inc.

Nephrotex Experimental Device Testing Reports are available at http://www.nephrotex.com

Recommended citation:

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Effect of PEO on cellulose acetate membrane fouling and biocompatibility

Abstract
This paper details experiments on the effects of *polyethylene oxide* (PEO) on fouling reduction and biocompatibility. PEO has been shown to increase membrane *hydrophilicity*, which could help reduce the effects of membrane *fouling* and increase biocompatibility. A more hydrophilic membrane will attract water more strongly to the membrane surface than a less hydrophilic membrane. Foulant molecules in the solution will then be less able to displace water molecules and reach the membrane (Figure 1).

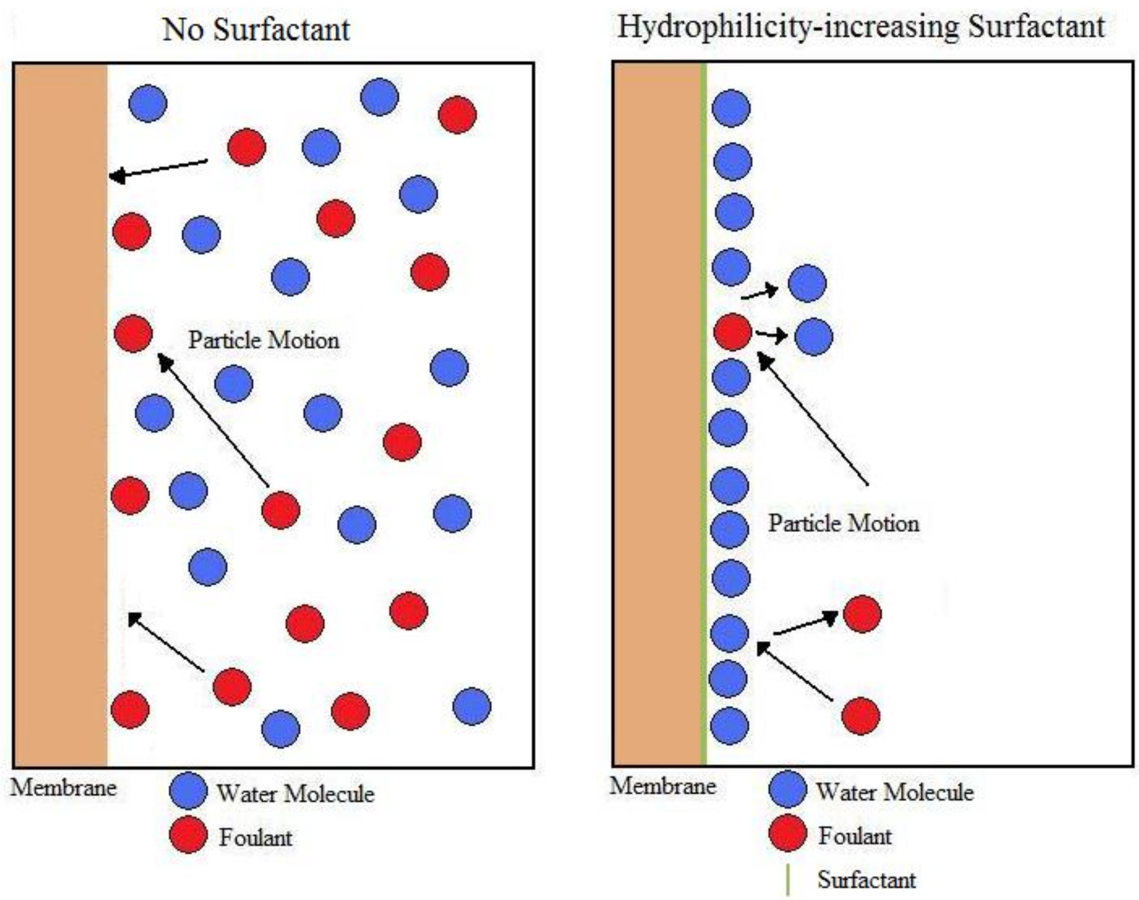


Figure 1: Foulant interaction with polymeric membrane without hydrophilic surfactant (left). Foulant interaction with polymeric membrane with hydrophilic surfactant (right).

1. Testing

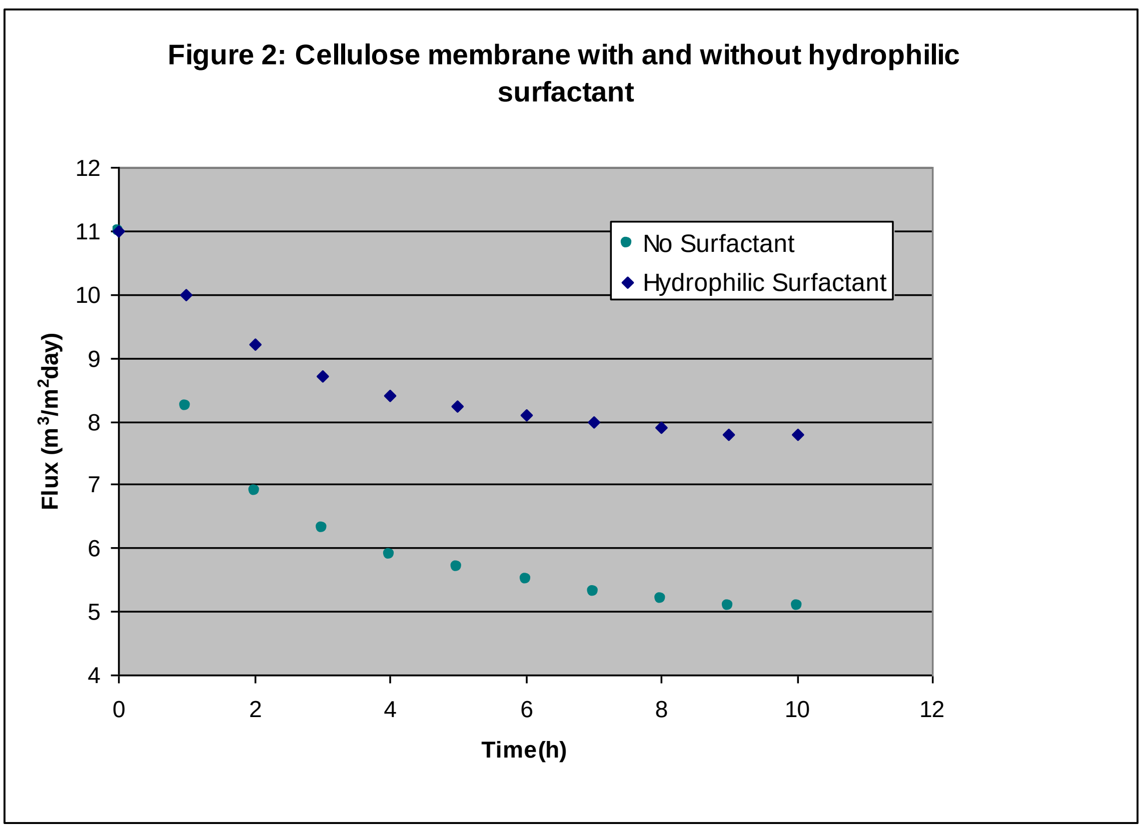
In order to determine the effect of this surfactant on reliability and biocompatibility, we used the standard company experimental setups detailed in the documents, "Reliability and Flux Benchmark Test" and "Biocompatibility Benchmark Test", respectively. The membrane material used for these experiments was Cellulose.

2. Results

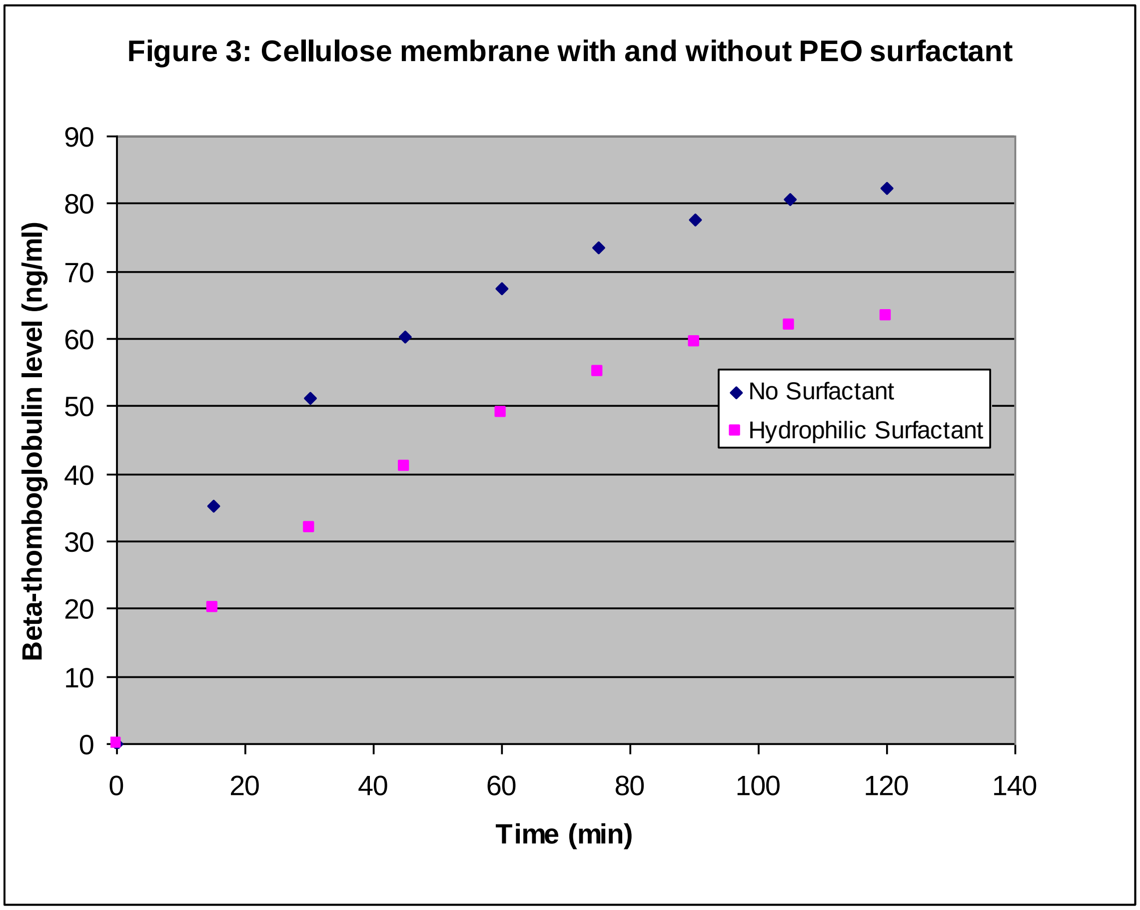
The Cellulose samples treated with PEO maintain operational flux rates longer than untreated Cellulose samples (Figure 2). Whereas the flux rate for untreated membrane fell to 75% of its original flux after 1 hour, the flux rate for the treated membrane still operated at 75% of the original flux after 5 hours of exposure to the fouling solution.

Time (h)	No surfactant (m^3/m^2-day)	Hydrophilic surfactant (m^3/m^2-day)
0	11	11
1	8.25	10
2	6.9	9.2
3	6.3	8.7
4	5.9	8.4
5	5.7	8.25
6	5.5	8.1
7	5.3	8
8	5.2	7.9
9	5.1	7.8
10	5.1	7.8

Table 1: A comparison of the flux through a dialysis membrane when using no surfactant versus when using a hydrophilic surfactant.



The beta-thromboglobulin levels were higher when blood was exposed to untreated Cellulose (Figure 3). After two hours, the beta-thromboglobulin level in the blood exposed to the untreated membrane was 82.3 ng/ml versus 63.2 ng/ml for the blood exposed to the sample treated with PEO.



3. Conclusion

PEO had a positive effect on both membrane fouling resistance and biocompatibility. The effect of hydrophilicity on membrane fouling resistance was significant, increasing the time to 75% performance from 1 hour to 5 hours. The effect on biocompatibility was less significant, decreasing the beta-thromboglobulin level after a 2 hour exposure by about 20 ng/ml.