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Expert View

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A Novel Paradigm for Engineering Education: Virtual Internships With Individualized Mentoring and Assessment of Engineering Thinking

Engineering virtual internships are a novel paradigm for providing authentic engineering experiences in the first-year curriculum. They are both individualized and accommodate large numbers of students. As we describe in this report, this approach can (a) enable students to solve complex engineering problems in a mentored, collaborative environment; (b) allow educators to assess engineering thinking; and (c) provide an introductory experience that students enjoy and find valuable. Furthermore, engineering virtual internships have been shown to increase students'—and especially women's—interest in and motivation to pursue engineering degrees. When implemented in first-year engineering curricula more broadly, the potential impact of engineering virtual internships on the size and diversity of the engineering workforce could be dramatic. [DOI: 10.1115/1.4029235]

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Introduction

The pool of engineers in the United States is neither large enough nor diverse enough to meet the needs of a growing high-tech economy, and student interest in engineering degrees is declining [1,2]. Overall, the largest decrease in enrollment in engineering degree programs occurs between the first and second years, especially among women [3]. While the percentages of women obtaining BS, MS, and Ph.D. degrees in Biomedical Engineering are second only to those in Environmental Engineering, graduation rates are not monotonically increasing over time; for example, the proportion of women graduating with BS degrees in Biomedical Engineering dropped steadily from 2004 to 2007 [4] and appears to be holding steady at just under 40% according to 2012–2013 data [5]. Compounding this problem, engineering degree programs receive few transfers from other majors, so the

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decline in enrollments after the first year has a significant effect on the total number of engineering degrees awarded [6,7]. First-year courses thus play a pivotal role in a student's decision to pursue an engineering degree, and current programs do not motivate enough undergraduates to become engineers.

Research has shown that engineering students who have meaningful experiences of engineering practice are more likely to persist beyond the first year of an engineering degree program than students whose first-year curriculum does not contain such experiences [8,9]. One way to provide meaningful experiences is through internships or other work-based learning opportunities, which help students begin to form the identity, values, and habits of mind of professional engineers. For example, Dehing et al. [9] found that workplace learning produced a "quantum leap" in identity development among undergraduate engineering students, helping them make the transition from "engineering student to student engineer." And O'Connor et al. [10] have shown that engineering students who make this transition are more likely to persist in engineering degree programs.

This presents a challenge, though, because first-year students lack the skills and knowledge to succeed in traditional internships or cooperative research programs, which are typically designed for more advanced undergraduates [11]. This lack of preparation is systemic; in a survey of 12 industrialized countries, for example, students in the United States spent the least amount of time learning in a professional context [12]. While many engineering programs offer cornerstone design courses for first-year students, these are typically not based on authentic practices or real-world data. In a developing body of work [13–18], we have designed and deployed *virtual internships*, which simulate authentic engineering problems and practices in an online environment and give students the opportunity to engage in realistic professional engineering work. Because these internships are offered in a constrained and fully mapped design space, many elements can be automated or semi-automated with artificial intelligence, including individualized mentoring [19,20]. All student and mentor actions and interactions are recorded automatically by the virtual internship platform, enabling us to analyze learning outcomes and processes and the extent to which students are developing, in addition to knowledge and skills, the identity, values, habits of mind, and other attributes of professional engineers.

We present this novel paradigm for early engineering education not as a hypothesis-driven empirical study but as a review of recent efforts to develop, implement, and test a novel virtual learning environment. Our aim is to show that engineering virtual internships can (a) give students the opportunity to engage in complex engineering problem solving in a mentored, collaborative environment and thereby develop the habits of mind and other attributes of engineering professionals; (b) give educators the opportunity to assess the presence and absence of key aspects of engineering thinking; and (c) provide an introduction to engineering experience that students enjoy and find valuable. Furthermore, the approach can be broadly disseminated and scaled to meet the needs of early engineering students and programs nationwide.

Virtual Internships as a Paradigm for Engineering Education

A virtual internship in engineering is a simulation of the experience a student might have in an idealized work experience at an engineering company. The idealized nature of the experience is critical in several ways. First, not all internships have attentive and engaged mentors. In a simulated experience, the quality of mentoring can be maintained at a consistently high level. Second, variability among internship experiences leads to variable achievement of learning outcomes. In a simulated experience, all students are given the same real-world problem to solve and identical resources with which to solve it. This approach levels the playing field and enables follow-on courses to build on a known foundation of knowledge and skills. Finally, in an actual internship, some previous engineering knowledge is typically required of the student so that companies benefit from their efforts to educate and train the intern. In a simulated internship, problems can be posed and scaffolded such that no prior engineering knowledge is required. In addition, no company resources are used, so no benefit to the sponsor—other than a positive student impression of that company for potential future recruiting purposes—is expected [17,21].

The simulated nature of the engineering virtual internship has significant advantages for learning assessment [22]. In addition to being able to assess students' final design proposals, integrated pre/postmeasures (entrance and exit interviews in the fiction of the internship) allow assessment of students' engineering learning, interest in engineering, and motivation to pursue an engineering degree, among other outcomes. The engineering virtual internships we have developed contain, for example, questions related to knowledge, skill, and practices in the target engineering domain and questions from the Pittsburgh Engineering Attitudes Scale [23,24], which measures first-year students' attitudes toward engineering. These measures have been validated and used to assess the effects of participation in a virtual internship on first-year students' engineering knowledge, interest in and motivation to pursue an engineering degree, and confidence in their ability to do professional engineering work [14–16,18].

In addition to *learning outcomes*, virtual internships also provide the ability to assess *learning processes*. The system automatically records students' (a) reports and other work products, (b) conversations with peers and mentors via email and instant message, (c) engineering notebook entries, and (d) final proposals or presentations. This allows for analysis of student learning both during and after the virtual internship using learning analytics tools designed to detect and measure the development of professional engineering thinking. These tools, which are described in detail below, quantify and visualize the extent to which students are learning to think like engineering professionals by operationalizing the learning science theory of *epistemic frames*.

Assessing Engineering Thinking

Learning to solve complex engineering problems comes from being part of a *community of practice* [25,26]: a group of people who share similar ways of framing, investigating, and solving problems. Engineering learning does not end with the mastery of pertinent skills and knowledge; it must also cultivate the ways of thinking and making decisions that reflect the values and practices of the engineering profession. The epistemic frame hypothesis [27–29] suggests that every community of practice has a culture and that each culture has a grammar: a network 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 network of skills, knowledge, values, identity, and epistemology forms the *epistemic frame* of that community.

Epistemic network analysis (ENA) [22,30–33] is a suite of statistical tools used to quantify the development of an epistemic frame. ENA collects in situ longitudinal data documenting the development of and linkages among elements of an epistemic frame. These data are represented in a dynamic network model that quantifies changes in the strength and composition of an epistemic frame over time. Specifically, ENA looks at *discourse* elements—the things an individual says or does—for evidence of one or more elements of an engineering frame. The association structure of the discourse is modeled with an adjacency matrix of frame elements based on their co-occurrence in discourse over time.

To identify the elements of an epistemic frame as they occur in discourse, we use *epistemic discourse coding*. This automated conjunctive keyword coding process has been validated by comparing utterances hand-coded by multiple, independent human

Table 1 Codes used to indicate different epistemic frame elements in *Nephrotex* and *RescuShell*

Epistemology	Data, engineering design, client, and stakeholders
Values	Client and stakeholders
Identity	Engineer and intern
Skills	Data, engineering design, professionalism, and collaboration
Knowledge	Nanotechnology, surfactants, materials, manufacturing process, attributes, design, data, and client (*Nephrotex*)
	Actuators, power sources, materials, range of motion, control sensors, attributes, design, data, and client (*RescuShell*)

coders and by comparing hand-coded utterances to the automated coding system. Cohen's kappa scores were 0.80–0.98 between the automated system and the human coders. These results compare favorably to human-to-human coder outcomes, and, in some cases, outperform them. Two coding schemes have been developed, one based on epistemic frame theory (see Table 1) and one adapted from Accreditation Board for Engineering and Technology (ABET) standards [34].

We describe ENA in greater detail elsewhere [33,35], but in brief, ENA models this coded data by grouping the utterances of a designated unit of analysis into *stanzas*, such that the utterances within a stanza are closely related and those in different stanzas are not. In a virtual internship, for example, stanzas are defined as all of the utterances that take place within a single activity such as a team meeting or specific design task. Once stanzas are defined, utterances in a stanza are collapsed, such that each stanza receives a "1" for every code that was present in at least one utterance from that stanza and a "0" for every code that was not present in any utterance from that stanza. Because we are ultimately interested in the *connections* between elements of complex thinking, ENA produces an adjacency matrix for each stanza to determine which codes co-occur (indicated by a 1 in the matrix) and which codes do not (indicated by a 0).[1]

To identify patterns of connections in the data, ENA sums the adjacency matrices for each unit of analysis u into a cumulative adjacency matrix, C^u, where each cell C^u_{ij} represents the number of stanzas in which a codes i and j were both present. The set of cumulative adjacency matrices C for all units in the data are converted into vectors in a high-dimensional space, H, such that each dimension of H represents a unique pairing of two codes; the position of the vector representing cumulative adjacency C^u on dimension corresponding to the unique pairing of codes i and j in H is given by C^u_{ij}.[2] The vectors are spherically normalized, and resulting normalized vectors ^{N}C thus quantify the *relative* frequencies of co-occurrences independent of the number of stanzas in the model for any given unit.[3] Finally, ENA performs a singular value decomposition on the normalized vectors. This provides a dimensional reduction of the original high-dimensional space, called ENA space, such that the dimensions of the rotated space capture the maximum variance in the data. That is, for every unit u in the data, ENA creates a point P^u that is the rotated location of the normalized vector $^{N}C^u$ under the singular value decomposition.

To interpret the dimensions of this rotated space, ENA takes the codes in the original data—which correspond to the nodes of the networks of connections—and positions them in ENA space so that for any unit u in the dataset, the centroid of the network model corresponding the cumulative adjacency matrix C^u is in the same location as the point to P^u.[4]

The resulting data can then be represented as a network model in which each node corresponds to a code from the coded dataset and lines connecting nodes represent co-occurrences of codes in the data. Representative network models of engineering thinking created using ENA are presented in Results. In these models, each node corresponds to a code from the coded dataset and lines connecting nodes represent co-occurrences of codes in the data the thickness of the lines connecting pairs of nodes corresponds to the number of stanzas in which both codes occur. Thus, ENA allows for the quantification and visualization of cognitive networks, making it possible to characterize students' thinking, while they are engaged in complex problem-solving activities.

The Engineering Virtual Internships *Nephrotex* and *RescuShell*

We have reported previously on the engineering virtual internship *Nephrotex*, in which students work as interns at a fictitious company that designs and manufactures ultrafiltration membranes for the hemodialysis machinery used to treat end-stage renal failure. First, Chesler et al. [17] described the design criteria for creating a virtual internship in engineering and provided proof-of-concept data on the engineering learning that occurs with use of *Nephrotex* for first-year engineering education. Then, in a more in-depth study, Arastoopour et al. [18] demonstrated that women who participated in the virtual internship in engineering felt more confident in and committed to engineering than women who participated in a first-year engineering course with no design component. Arastoopour et al. also showed, using ENA, that men and women whose discourse was focused on engineering design were more committed to an engineering career. These positive results motivated us to design a second engineering virtual internship according to the design criteria already established [17].

In the engineering virtual internship *RescuShell*, students work as interns at a fictitious company, RescuTek, where they design the robotic legs for a mechanical exoskeleton to be used by search and rescue personnel in dangerous or demanding situations (see Fig. 1). Students begin the virtual internship by viewing a training video, completing an online entrance interview (presurvey), and creating an online staff page (short biography). During the 10-week internship (2 h per week), they work independently and in teams with other students to complete specific tasks related to the design project. In particular, after reviewing the existing literature, students propose their own designs, which they test and assess by submitting them to RescuTek's internal research and development staff. Various RescuTek stakeholders then comment on whether these designs meet existing standards. Each of the stakeholders considers different aspects of the design, including safety, cost, reliability, work capacity, payload, and agility. The virtual internship is designed so that no prototype exists that satisfies all of the stakeholders' requests. Therefore, each student must decide which stakeholders' interests are most important while meeting basic standards for all. Students are guided throughout the internship by a *design advisor*, a senior engineer in the company, who initiates and guides all activities through email, online chat, and regular team meetings integrated into the simulation. Design advisors are trained mentors (typically upper-level engineering undergraduates) who respond to students in the role of a senior engineer at RescuTek. One advisor can effectively mentor and guide design projects for up to 25 students at a time, allowing for large classes to engage in the simulation with limited staffing. In the final week of the simulation, students create posters and give conference-style presentations of their final designs to their peers and instructors. Each presentation includes a summary of the findings, data,

[1]Because ENA models the co-occurence of codes, the entries on the diagonal of the matrix are assigned a value of zero regardless of the presence of absence of the codes corresponding to the cells, since cells on the diagonal would represent codes co-occurring with themselves.

[2]The cumulative adjacency matrices are symmetric, because $C^u_{ij} = C^u_{ji}$ for all i and j.

[3]Spherical normalization is accomplished by dividing each vector C^u by its length. This is the equivalent of the cosine norm frequently used in natural language processing and automated content analysis.

[4]Technically speaking, ENA places the nodes so as to minimize the distance between P^u and the centroid of the network corresponding to C^u as represented in ENA space. The optimization typically results in a good fit of the model.

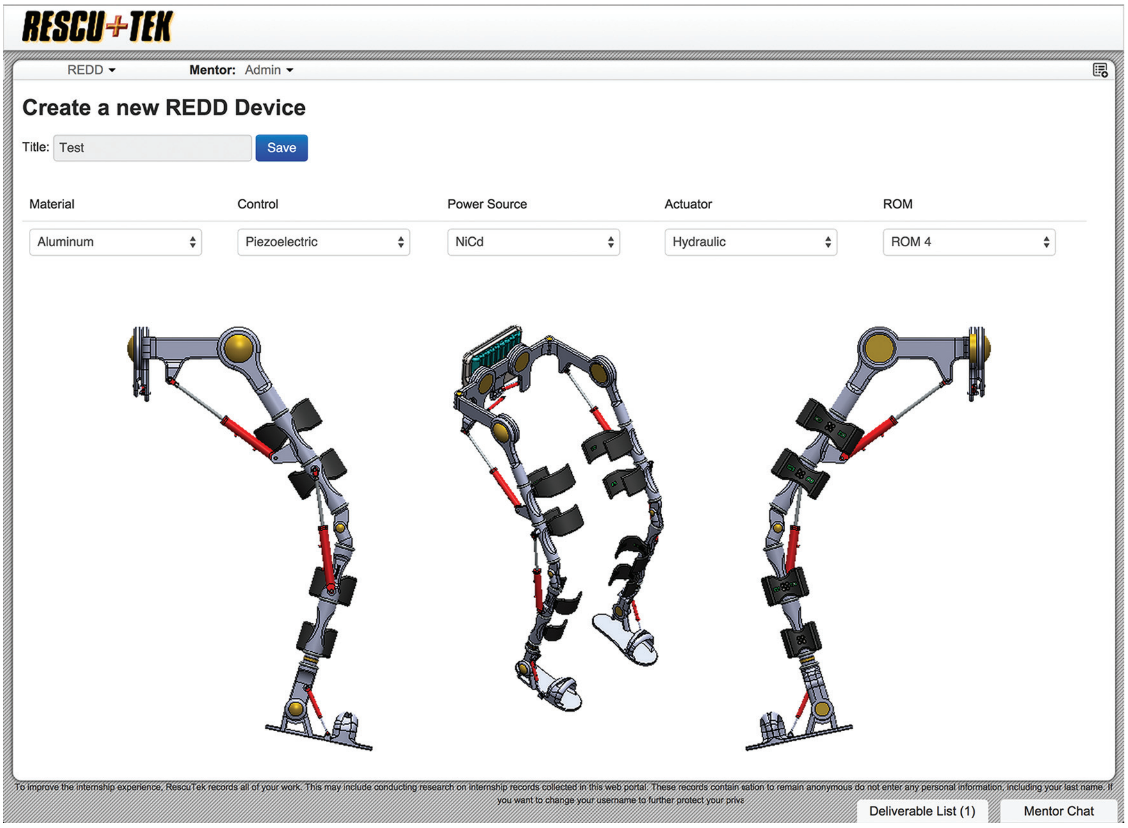

Fig. 1 In *RescuShell*, students use a simulated design tool to create prototypes of their exoskeletons. Students make decisions concerning the material, control sensors, power source, actuation, and range of motion of the robotic legs.

and references to the literature that helped them select their final design, and their goal is to justify their design decisions to their peers and to the company. Students then complete exit interviews (postsurveys) that are used in conjunction with the presurvey and discourse data (students' emails, chats, engineering notebooks, etc.) to measure the effects of the virtual internship on student learning, interest in engineering, and motivation to persist in an engineering degree program.

Nephrotex and *RescuShell* are similar in length, activities, scope, and structure, and they differ only in content. That is, the design problems are different between the two virtual internships but the complexity of the design space is similar; the details of the design advisor communications are different but their frequency is the same; the content of resource materials are different but the number and sophistication and comparable. The parallels between the two virtual internships enabled us to use them to test hypotheses regarding the impact of participation in one or two virtual internships in a first-year course on the development of engineering thinking and student interest and satisfaction.

Previous studies [13–18] have shown that engineering virtual internships help students learn domain-relevant skills, knowledge, and practices, develop interest in engineering careers, and build confidence in their ability to do engineering work. In what follows, we present some preliminary findings from a course entirely based on engineering virtual internships.

Preliminary Results From an Introductory Engineering Course Based on Virtual Internships

In the fall of 2013, we implemented both *Nephrotex* and *RescuShell* in a new first-year undergraduate course at the University of Wisconsin–Madison College of Engineering. To our knowledge, this was the first-ever course based entirely on simulations of authentic engineering practice [36]. The course enrolled 50 students: half the students ($n = 25$) were randomly selected to participate in *Nephrotex* first and *RescuShell* second, and the other half ($n = 25$) used the simulations in the opposite order. This crossover study design effectively doubles the sample size because each student serves as both a treatment case and a control case. All students completed all activities in both simulations. Data were collected from pre- and postsurveys integrated into each simulation, and the virtual internship system automatically recorded students' chats, emails, notebook entries, and work products.

Result 1: Experience With a Second Virtual Internship Leads to More Advanced Engineering Thinking. The results of ENA performed on two groups of students in the virtual internship *Nephrotex* are shown in Fig. 2. Students in one group used *Nephrotex* without any prior experience with an engineering virtual internship; students in the other group used *RescuShell* immediately before using *Nephrotex*. Student utterances from *Nephrotex* were coded for engineering epistemic frame elements (see Table 1). The two groups were significantly different on the second dimension ($\text{mean}_A = 0.301$, $\text{mean}_B = 0.159$; $p = 0.002$, $t = 3.266$, and Cohen's $d = 0.369$). Each point in Fig. 2 is the centroid of a student's epistemic network. To determine which elements account for the difference between the two groups, we compared their mean epistemic networks (see Fig. 3). Students using an engineering virtual internship for the first time had a higher mean on dimension two because those students made connections mostly among basic skills and knowledge. Students who had already participated in a previous engineering virtual internship made additional connections with epistemological elements of engineering and knowledge of the client, elements that are indicative of thinking like an engineer.

Result 2: Students Concerned With Client Requirements Were More Highly Valued by Their Design Teammates. We investigated the aspects of engineering thinking that were

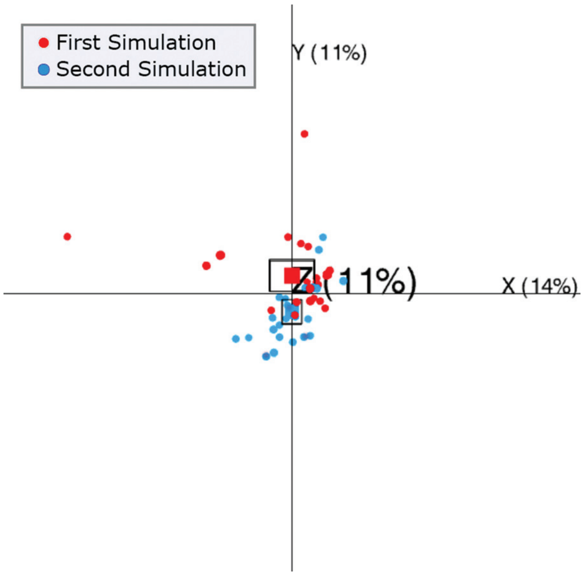

Fig. 2 ENA scatterplot showing two groups of students who used the virtual internship *Nephrotex*. One group had no prior exposure to an engineering virtual internship (first simulation). The other group used *RescuShell* prior to using *Nephrotex* (second simulation). The points are individual students; the squares are the means for the two groups; the boxes are the 95% confidence intervals. The numbers in parentheses indicate the percentage of variance in the data accounted for by that dimension.

correlated with positive peer evaluations. At the end of each internship, students distributed virtual bonuses to their teammates based on the perceived quality of their teammates' engineering design contributions. We then compared the top quartile (students given the highest bonuses for design collaboration by their peers) with the bottom quartile (students given the lowest bonuses for design collaboration by their peers) in *RescuShell*. Student utterances from *RescuShell* were coded based on ABET criteria [34]. There were significant differences between the discourse of students who received low bonuses and those who received high bonuses (see Figs. 4 and 5). The means are statistically different with a moderate effect size ($p < 0.02$ and Cohen's $d = 0.44$) even though the 95% confidence intervals overlap in this case. It is important to note, however, that the significant difference between most-valued teammates and least-valued teammates was *not* in the extent to which students were focused on *teamwork* and *communication* (ABET criteria 3d and 3g), as might be supposed. Rather, students who were perceived by their peers as deserving of high bonuses were more likely to consider the *context of the client* and *ethics* (ABET criteria 3f and 3h) in their design work.

Result 3: Experience With a Second Virtual Internship Increases Student Satisfaction. At the conclusion of each virtual internship, students were asked to evaluate their experience (free response), and student responses were coded as positive, negative, or mixed/neutral. Student satisfaction with the course was predominantly positive, and no students felt that their experience was negative (see Fig. 6). Furthermore, the proportion of positive responses increased after students used the second simulation, and the proportion of neutral or mixed responses decreased.

Discussion

Here, we reviewed recent efforts to develop, implement, and test a novel approach to first-year engineering education—virtual internships—and presented some preliminary results from an implementation of two of these virtual internships in a single course at a single institution. We have previously reported on the design and use of one virtual internship in engineering at a single institution [17] and at multiple institutions [18]. To date, over 700 students at three U.S. institutions of higher education, one European institution of higher education, and one high school have used *Nephrotex* or *RescuShell*. In general, these implementations are designed to educate students about engineering content and practices. We demonstrate here that our approach gives students the opportunity to engage in complex engineering problem

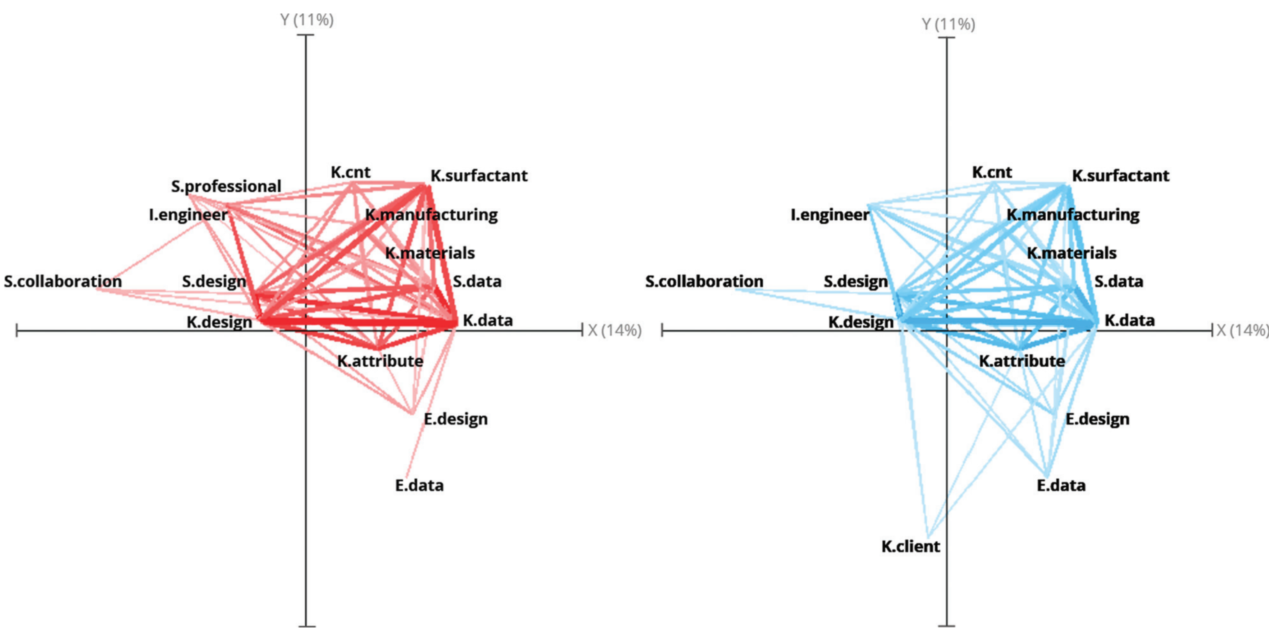

Fig. 3 Mean epistemic networks of the two groups of students described in Fig. 2, thresholded to reveal the most prominent connections. Students with no prior experience of an engineering virtual internship (left) made connections primarily among basic skills and knowledge and collaboration. Students with prior experience of an engineering virtual internship (right) made more connections to epistemological elements of engineering and to knowledge of the client. S = skills, K = knowledge, I = Identity, V = Values, and E = epistemology.

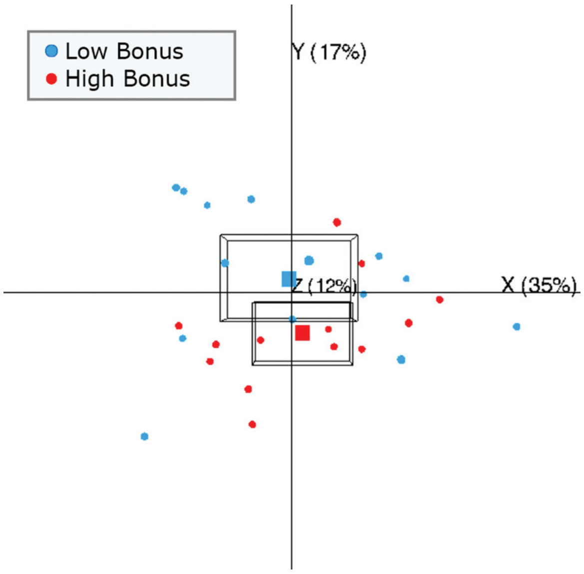

Fig. 4 ENA scatterplot showing two groups of students who used the engineering virtual internship *RescuShell*. At the end of the virtual internship, students assign their teammates virtual bonuses based on the perceived quality of their engineering design contributions. The points are students who received either low (bottom quartile) or high (top quartile) bonuses from their peers; the squares are the means for the two groups; the boxes are the 95% confidence intervals. The numbers in parentheses indicate the percentage of variance in the data accounted for by that dimension.

solving and leads to the development of professional engineering thinking. Moreover, it appears that engaging in multiple engineering virtual internships has some additive effects. Our initial findings suggest that the serial use of two virtual internships is even more effective than one on the development of engineering thinking and student satisfaction.

Engineering thinking was measured using ENA, a novel psychometric technique. This method identifies and quantifies the cognitive connections that students make while engaged in complex problem solving and creates network models of their patterns

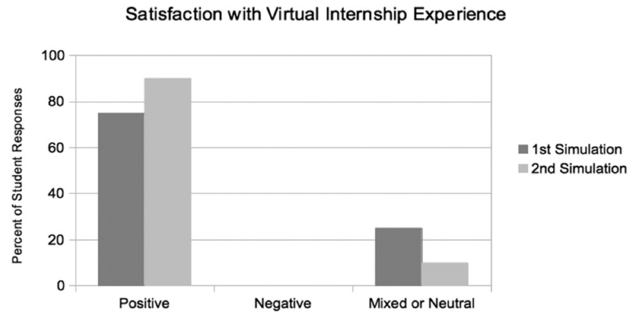

Fig. 6 Percentage of students who reported a positive, negative, or neutral/mixed experience after participating in a first or a second engineering virtual internship.

of connections. Typically, individuals who have denser epistemic networks are thinking in more complex and sophisticated ways about the problem. In addition, ENA makes it possible to correlate aspects of students' epistemic frames with their actions in the simulation, including their design choices, bonus assignments, and other aspects of participation in virtual internships. For example, our results indicate that students who made more connections with client- and context-centered elements were more highly valued by their teammates. To date, we have not collected longitudinal data on students who have participated in virtual internships in engineering at any of the institutions at which they have been implemented. A critical next step is to follow up on the self-reports of increased motivation to persist in engineering [18] and correlate them with graduation rates. Longitudinal studies would also allow us to assess the impact of authentic engineering experiences in the virtual internships with performance in an engineering degree program.

In addition, further implementations will need to include a more racially diverse student population. In academia, the educational benefits of diversity and inclusivity are concrete and significant [37]. Experience with diverse peers early in an undergraduate program fosters increased frequency and more positive cross-racial interactions later [38]. Students with the most classroom experience with diversity and the most diverse friends and experiences on campus are more engaged in learning and self-reported more gains in critical thinking, problem solving and self-

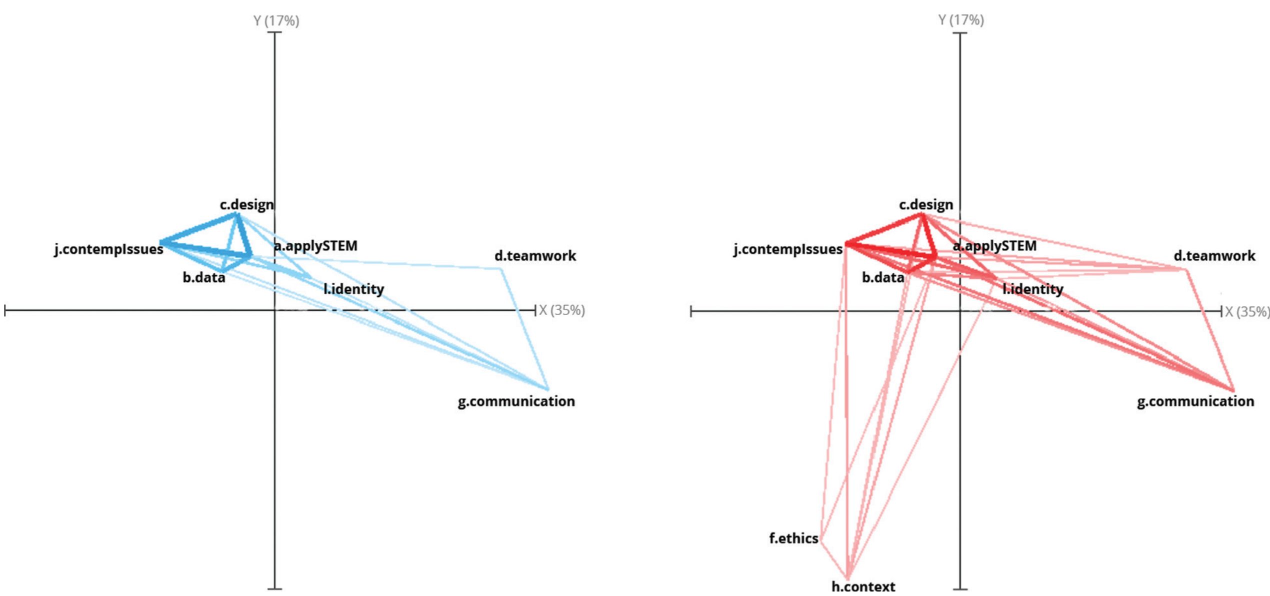

Fig. 5 Mean epistemic networks of the two groups described in Fig. 4, thresholded to reveal the most prominent connections. Students who received lower bonuses (left) made connections primarily to design and data issues and to teamwork and communication. Students who received higher bonuses (right) also made connections to the context of the client and ethics.

confidence [37]. Motivation to consider multiple perspectives, which is an important skill in team work as well as interdisciplinary research, has been shown to be related to classroom and campus experiences with diversity [37,39]. The literature on diversity also suggests that a more inclusive workforce is more innovative and more productive [40–42]. Implementing virtual internships with more diverse populations would allow us to explore whether the positive effects of participation that we have documented among women [18] are also observed in other underrepresented groups in engineering.

Another future goal is to create more virtual internships with application to other engineering disciplines. *Nephrotex* draws on material science, biomedical engineering, and chemical engineering fundamentals; *RescuShell* draws on mechanical engineering, biomedical engineering, and ergonomics. We are currently designing authorware that will enable other educators to create their own virtual internships with minimal effort; at that point, we anticipate that new internships could be created for electrical engineering, civil engineering, and other disciplines while still meeting the design criteria.

This support for simulation design would allow creation of more virtual internships suitable for precollege students as well. Many middle schools and high schools have adopted programs, such as Linked Learning [43,44] and Career Pathways [45,46], which aim to ground education in professional experience and connect students with high-quality, work-based learning opportunities. However, there are not enough out-of-school opportunities for students interested in science and engineering; of those that do exist, many do not give students the opportunity to engage in authentic tasks [47]. After a pilot implementation of *RescuShell* with high school students, the participating teachers praised the experience. "The kids take away a sense of accomplishment, that they've taken this entire product from a design all the way through to a presentation," one teacher observed. "Working in teams, and getting … real time feedback. And even though it was high pressure and very fast paced, they get so much out of it and that is truly a work experience. And the fact that they're getting a chance to have an internship is so important because we don't have enough internships to go around." When asked how the technology could best be used in education, one replied: "I would want it everywhere. It's so great! I want it in my classroom, I want it in my extra-curricular clubs that I do that are oriented around engineering. I want [the students] to experience that so then we can model off of that when I work with them." Another said, "I would love for every student to have the opportunity to do this."

Conclusions

Virtual internships in engineering provide first-year undergraduates (and even younger students) with meaningful experiences of engineering practice. They provide an environment in which students with no prior engineering training can frame, investigate, and solve realistic engineering problems and engage in authentic engineering practices [13–18]. Through these internships, students learn basic engineering knowledge and skills, but they also begin to form the identity, values, and habits of mind of professional engineers—that is, they learn to think like engineers. Because all the activities occur in an online environment, virtual internships allow educators to assess the presence or absence of key aspects of engineering thinking, such as client- and context-centered thinking, which our results suggest is highly valued by members of student design teams. Finally, while participation in one virtual internship was not considered a negative experience by students, participation in two was a notably more positive experience, which suggests that first-year engineering courses that offer multiple virtual internships may be not only effective but also enjoyable, potentially encouraging more students to persist to an engineering degree.

A 2011 report issued by the National Research Council [48] recommends increasing the use of games and simulations for learning concepts and practices in science and engineering. With the increased emphasis on practice- or project-based instruction and transdisciplinary approaches in science education [1,2,49–53], we must develop tools that enable instructors to provide meaningful, realistic engineering experiences without prohibitive costs, excessive institutional buy-in, or impractical scheduling. Virtual internships address this need, and participation in multiple virtual internships can enhance learning and student interest still more. Considering the previously demonstrated [18] effects on the motivation of women students to persist in engineering, the potential impact of virtual internships in engineering on the size and diversity of the engineering workforce could be dramatic if implemented in first-year engineering curricula nationwide.

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