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Case Study of Prior Knowledge: Expectations and Identity Constructions in Interdisciplinary, Cross-cultural Virtual Collaboration*

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Before integrated design thinking in teams can occur, team members must create an environment in which collaboration is possible—a 'relational space' determined by the identities individuals construct for and of one another. As design collaborations expand across cultural and disciplinary boundaries, identity construction becomes more crucial and more difficult, especially in virtual environments. As a result, engineering educators need to understand and teach appropriate transferable practices that students can bring to team environments, particularly those that involve crossing boundaries—be they disciplinary, cultural or geographic. A case study based on cross-cultural, cross-disciplinary collaboration in a capstone design course shows that through instruction students become aware of the importance of collaborating across cultural and disciplinary boundaries, and through experience in actual projects they become aware of the complexities posed by such collaboration. Case study data, in conjunction with a substantial literature review, identify research questions to guide curricular development in engineering that combines instruction and hands-on experience to help students construct professional identities that support sharing design knowledge in cross-cultural, cross-disciplinary team environments.

Keywords: interdisciplinary; intercultural; collaboration; identity construction

THE GLOBAL MARKETPLACE

Need for interdisciplinary collaboration skills

IN THEIR EXTENSIVE EXPLORATION of design thinking, Dym *et al.* highlight 'design thinking in a team environment' as one of the core areas of research and exploration [1]. Citing the work of scholars such as Rittel, Bucciarelli and Minneman, they emphasize the social nature of design as engineers work together to develop, test and evaluate innovative solutions to complex problems. In the contemporary workplace, in particular, design involves practitioners from a range of fields within and beyond engineering, and often it involves collaborators from around the globe. Industry projects frequently involve multiple engineering specialties and require additional input from industrial designers, artists, economic experts, marketing specialists, manufacturers, and environmental consultants [1, 2]. Together, these cross-disciplinary and cross-functional teams negotiate workable solutions to design challenges—solutions that must be technically and economically viable, capable of being manufactured, and capable of being sold.

As early as 1996, ABET responded to this collaborative work environment with the introduction of the EC2000 engineering accreditation criteria [3] that include the ability to work on multidisciplinary teams. Recent calls such as *Educating the Engineer of 2020* [4], *Rising Above the Gathering Storm* [5], and *Facilitating Interdisciplinary Research* [2] also advocate preparing engineers and scientists who can work in creative, interdisciplinary environments. Their claims are echoed by popular texts such as Thomas Friedman's *The World Is Flat*, which paints a clear picture of the globally distributed, constantly shifting world of production [6]. Moreover, calls to more effectively address the contemporary workplace come not only from external sources but from within engineering programs. For example, Sheppard, Dominick, and Aronson argue explicitly for incorporating cross-disciplinary and cross-cultural teams into undergraduate education [7]. They argue that virtual teams involving participants in different countries and different fields are ubiquitous in the contemporary workplace, but our graduates are ill-prepared for the challenges of such collaborations.

To address this lack of preparation, engineering educators must do more than provide realistic

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interdisciplinary or cross-cultural design experiences; we must develop corresponding pedagogies to teach students how to collaborate in these multidimensional—and increasingly virtual—environments. Toward this end, the present study focuses on one specific element of such instruction: the need to help students construct professional identities that support, rather than hinder, the sharing of design knowledge in virtual team environments. That is, before design thinking in a team environment can occur, team members must create an environment in which collaboration is possible—and that environment depends heavily on the identities individuals construct for and of one another. Identity construction is crucial for establishing trust in cross-functional and global teams, where participants do not share common disciplinary or national cultures; it becomes even more critical in virtual environments, where participants have limited access to one another's larger contexts.

Elsewhere, we have identified broad areas of metacognitive knowledge that students need to effectively approach virtual collaboration [8, 9]; in this paper, we focus specifically on how students construct their own and their collaborators' identities, and how those constructions support or hinder collaboration. Following a constructivist approach to educational research, we identify guidelines for developing appropriate pedagogies by addressing 'prior knowledge' [10] with two key questions:

1) What expectations—about themselves, their collaborators, and the process—do students bring to interdisciplinary and cross-cultural collaboration?
2) How do the roles that engineering students adopt when establishing professional identities impact the way the team works?

LITERATURE REVIEW

Interdisciplinary collaboration in the engineering classroom: current practices, current gaps

In response to the need for interdisciplinary collaboration skills as identified by ABET, the NAE, industry, and academia, 'multidisciplinary' and 'interdisciplinary' design experiences have proliferated in engineering curricula, as even a brief survey of recent scholarship suggests [11–25]. From freshman through senior courses, engineering educators are creating innovative experiences that bring students from different disciplines together to address complex technology needs. Universities such as Stanford, MIT, Rensselaer and Rochester Institute of Technology have well-developed programmes supporting a range of projects, often with industry sponsors [22–25]. Other programmes involve a more limited number of departments or a specific project. Several programmes reach out beyond engineering. For example, Stanford's Institute of Design includes business, medicine, the humanities and education; similarly Howard University brings mechanical and electrical engineering students together with students in marketing and art to collaborate on industry-sponsored projects [21].

What these and similar programmes across the country share is a commitment to giving students opportunities to collaborate in design projects that cross disciplinary boundaries—the same kinds of collaborative projects they are likely to experience in the workplace. What they often appear to lack, however, are concrete, explicit learning materials and teaching practices that help students develop transferable skills to negotiate across these boundaries, particularly in virtual environments. As Shuman *et al.* point out in their recent review of state-of-the art teaching practices for the ABET professional skills (communication, teamwork, ethics, global/societal impact, lifelong learning and contemporary issues): '. . . too often educators incorporate student teams into their courses with little thought to their best use. Minimal guidance is provided on group development, soliciting members' input, consensus building, resolving conflict, and team leadership' [26]. This assessment echoes a broad-based 2000 study by Colbeck *et al.* of group projects in two predominantly black schools, one private school, three land-grant universities, and one urban commuter school. Their research found that although group projects are common, faculty generally provide students with little or no instruction on effective collaboration [27].

There are, of course, exceptions. In identifying best practices, Shuman *et al.* reserved the highest praise for those few that intentionally guide students in developing personal, interpersonal and project management skills, rather than simply immersing them in a team experience [26]. In additional examples, Rutkowski *et al.* [28] delineate course management strategies to support virtual global collaboration; Fruchter and Lewis [29] describe a mentoring system to support virtual, global teams of graduate students in engineering, architecture and building construction; and Sheppard *et al.* [7] identify key factors student teams need to address to ensure successful collaboration, including cultural norms, team structure, objectives, team leadership behaviour, group process and performance.

Articles describing and evaluating such pedagogies, however, are the exception rather than the rule to date. In general, the current paradigm reflects positive efforts to incorporate collaborative experiences into the engineering curriculum. However, both the growing presence of interdisciplinary, and increasingly virtual, design teams in engineering curricula and the marked lack of pedagogy to support transferable interdisciplinary collaboration practices points to a clear need for research that identifies these transferable practices and demonstrates ways engineering educators can help students develop them.

Communication in virtual environments: the creation of relational space

To teach such practices engineering educators must first understand team dynamics, particularly as complicated by virtual environments. Within such collaborations, the ability to communicate across boundaries—disciplinary, cultural, and geographic—is critical. Central to such communication is the development of a shared discourse that enables collaborators to work productively together. This shared discourse is more than simply an agreement on common terms. Bucciarelli describes it as the 'web of tacit understandings of what is to be considered an honorable claim, a significant conjecture, a valid "proof", or a laughing matter . . . an accepted rhetoric for describing, proposing, critiquing, and disposing that girds all design conversation, fixing what constitutes a true and useful account' [30]. That is, when engineers work together, and when they work with colleagues from the sciences, natural resources, marketing, and finance, the work succeeds only when those involved form this web of tacit understandings. The further apart collaborators are—epistemologically as well as physically, the more challenging it is to develop that web.

Bridging disciplinary, cultural and geographical gaps involves an array of strategies, including effective technologies, communication practices, interpersonal skills and team building strategies; scholars from a range of fields are already addressing some of these issues. In this paper, we focus on one foundational aspect of the process: the need to create a meaningful social network in which collaboration—particularly virtual, cross-functional collaboration, takes place. Nardi and Whittaker provide a useful description of the function of this social network when they posit a 'communication zone' as the necessary social space in which effective collaboration can occur [31]. In examining this zone, Nardi and Whittaker's work focuses not on the process of information exchange (i.e., how people make their expertise known to one another), but rather on what they describe as "the social processes that scaffold information exchange" [31]—scaffolding that must be in place before participants on a cross-functional team can productively engage in collaborative design thinking.

Importantly, Nardi and Whittaker tie the creation of this communication zone very closely to face-to-face communication, noting that the body is a key source of information that facilitates social bonding. That is, we gain a great deal of information about people from their physical presence and our physical interactions with them—information that is much harder to achieve in virtual collaborations, but no less central to productive work. Nardi and Whittaker point to three key activities of face-to-face interaction that support the creation of this social space. First is physical touch—in US culture, the act of shaking hands, for example. Second is eating and drinking together; while research on cross-cultural communication suggests that the kinds of interactions expected over meals can vary widely [e.g., 32], sharing meals is very often a common source of social bonding, and helps significantly in facilitating collaborators' understanding of and engagement with one another. Third, shared physical space, be it co-located offices, a common meeting room (sometimes called a 'war room'), or attendance at the same conferences, also facilitates the communication zone.

The communication zone emerges as a result of various levels of social bonding that occur more naturally in face-to-face communication or co-located work. Recent research on design in global and/or virtual environments bears out the need for these sustained social networks and the communication zone Nardi and Whittaker posit. For example, Cross identifies the power of shared physical space in enabling a project team to coalesce [33]. Jarvenpaa and Leidner, Leinonen *et al.*, and Coppola, Hiltz and Rotter all describe the need for trust in virtual teams [34–36]. Keisler and Cummings underscore the need for shared social settings and a sense of presence [37]. Tavcar, *et al.*, in their study of students in a European Global Product Realization course, develop a series of requirements for global teams that includes 'Familiarization of project team members and building of trust', noting that 'a personal relationship and trust among team members are very important for creative dialogue and effective cooperation' [38]. Similarly, in a study of workplace global virtual teams, Leinonen *et al.* describe the 'difficulties in reaching shared understanding' as a critical problem [35], and they note the need 'to understand one's self as part of a social system' in order to effectively support individuals' awareness of collaboration and facilitate the development of shared goals and working processes [35]. In their comparison of face-to-face and computer-mediated (CM) student design teams, Whitman *et al.* reported that while both teams completed the project successfully and reported generally positive experiences, the CM teams consistently reported lower values when asked about the effectiveness of group processes (successful meetings, sense of making progress, all members participating, knowing expectations) and higher values with respect to the difficulty of making decisions [39]. When reporting on a four-year study of communication in global virtual student teams, Rutkowski *et al.* note that with effective communication technologies in place, the core challenges facing such teams are 'organizational and social', and they emphasize the practices of 'structuring group processes, building trust, and supporting decision-making' [28].

In these and numerous other theoretical and empirical investigations of virtual group design, the issue of creating and maintaining effective social networks—and particularly of team members' abilities to represent themselves, their work, and their processes to one another—repeatedly emerge as key challenges. In virtual collaborations, participants must construct one another and forge these social bonds without the benefit of physical cues. Collaborators construct themselves and one another through texts such as email exchanges, reports, or similar documents, as well as through phone video conferences. Video conferences do provide some degree of physical presence—or at least physical image—but in general, when the work of engineers and their collaborators in design projects is geographically distributed, team members often lack substantial mechanisms to come to know one another, and thus to create the scaffolding necessary for effective information exchange. As a result, the ways in which engineers construct their identities—for themselves as well as for their collaborators—can have a substantial impact on the formation of effective communication zones. The nature of engineers' self-representation and identity construction is thus a critical research area with respect to preparing engineers to collaborate successfully in the flat world.

Constructing engineering identities

Close examinations of engineering identities have begun to emerge from a number of different directions. *First*, the question of what it means to be an engineer has clearly come to the forefront in engineering education, both as a critical research question and as a mode of defining student outcomes for assessment. For example, in defining the broad research agenda for engineering education, the *Journal of Engineering Education* characterizes 'engineering epistemologies' as one of five core research areas for current scholars [40]; we need, that is, to understand who we are. In *The Engineer of 2020*, the National Academy of Engineering applied scenario thinking to develop the core characteristics for the next generation of practitioners [41]. Davis and Beyerlein characterize engineering as a profession 'entrusted with the well-being of people and society as a whole', but note that expectations for such service 'may not be defined consistently or be widely known' [42]. They took a highly structured empirical approach to defining key qualities, using iterative surveys of employers and educators to construct an 'engineer profile' that delineates performance expectations for 10 key roles (analyst, problem solver, designer, researcher, communicator, collaborator, leader, self-grower, achiever and practitioner) [42]. These reports and research projects, in addition to providing 'targets' for today's educators, also provide clear indications to our students of who engineers are and what they do. As described below, we adapted the work of Davis and Beyerlein in particular to assess student attitudes in our case study.

Second, studies have begun to emerge that examine how student and professional engineers construct themselves. In their recent work on the use of portfolios in engineering, for example, Turns and Lappenbusch explore the ways in which constructing professional portfolios helps engineering students articulate their professional identities [43]. Other studies examine the ways in which underrepresented groups—typically women—negotiate personal and professional identities, creating self-representations to facilitate acceptance into traditionally white male environments. Through a series of interviews, for example, Jorgenson examined the ways in which women positioned themselves vis-à-vis their work and constructed their professional identities—often in ways that elided gender from the equation [44]. A similar study of women students in engineering by Dryburgh examined the ways in which students both adapted to their professional culture and internalized their professional identities [45]. Such studies help us understand—and ultimately facilitate—the ways in which students become professional engineers; they also help locate gaps in student understanding that more explicit pedagogies can begin to remedy.

Few of these studies, however, consider the ways in which engineers' construction of themselves impact their collaboration with others both within and outside engineering. Two notable exceptions are Downey and Lucena's work on engineering identity across cultures [46] and Dannels' work on engineering identity in design classes [47]. Although not explicitly concerned with collaboration, Downey and Lucena, by examining the ways in which engineering is defined and constructed across different national cultures, implicitly raise important questions about the roles engineers play within cultures and organizations, and about the ways in which national variations in engineering identity might impact global collaborations [46]. More directly relevant to the present study, Dannels' work, which focused on students in a capstone design class, identifies the ways in which students' construction of both their own position within the course and their perceived sense of professional roles seriously affected their design work. Specifically, because students did not see themselves as 'real engineers'—even though they worked on a project for a real external industry client—and because in the students' views 'real engineers' did not directly interact with customers, the students completely discounted elements of the project that involved gathering information from end users. Through both interviews and observations, Dannels notes the ways in which students either made up or ignored those parts of the assignments that asked the design teams to gather customer data. Students identified themselves as students first, and getting a good grade by producing a design acceptable to the professor (not the client or the end users) was paramount. Their perceived identities, and the ways they constructed their identities to other members of their team, exerted a powerful influence on their design practice.

Our own work further supports the impact that identity construction has on collaboration. As we have reported elsewhere, identity became a crucial issue in a collaboration between U.S. engineering students and European digital media students [9]. In that case study, the students did not explicitly or intentionally represent their personal and professional identities to one another, and this gap led to significant breakdowns in collaboration and the absence of a functional communication zone. In particular, the engineers implicitly constructed themselves in very narrow terms (getting the technical work done) that did not facilitate collaboration outside those defined technical boundaries; at the same time, they constructed the work of those outside the boundaries as less valuable and saw a kind of 'dumbing down' process at work in collaborating with non-specialists. Both the engineers and the digital media students rested in preconceived stereotypes, failing to either explain themselves or ask identity-oriented questions of their collaborators; the absence of a social network was evident in student comments about the collaboration and in struggles that occurred through the process.

These initial studies suggest that, as engineering educators, we need to look not only at how engineers develop their identities, but at how they construct those identities in collaborative situations and how they represent their identities to one another.

METHODS

As the literature review demonstrates, existing scholarship on design collaborations in both workplace and educational settings suggests a clear need for engineering educators to understand and teach transferable practices that students can bring to team environments, particularly those that involve crossing boundaries—be they disciplinary, cultural, or geographical. We argue, based on this prior work, that the ability to create a flexible, engaged, collaborative professional identity is one such practice, and is at the heart of creating relational space, or the 'communication zone' and 'web of tacit understandings' that is the foundation of design thinking in a team environment.

To begin addressing the pedagogies needed to help students develop this practice, we offer a case study that provides insight into students' prior knowledge and expectations in this arena. Specifically, the case study:

a) describes students' expectations in two cohorts (control and treatment) as they approach boundary-crossing collaborations;
b) explores the ways in which these students implicitly and explicitly constructed their identities in the collaborative environment;
c) suggests ways in which these identity constructions influenced the design collaboration.

Importantly, the case study is not intended as representative of all engineering students' prior knowledge and practices [48]; rather, in examining one group of students closely, it raises important research questions and provides the basis for further inquiry in this key area of design team practice and education.

Research setting and prior work

The control cohort for the case study involved engineering students in a capstone design course at a U.S. university and digital media students in a technical communication course at a European university. With little instructional intervention other than assignments, required telephone conferences, and use of an online course management system, the students produced white papers and websites to promote the projects being completed in the engineering design courses. This baseline data for future interventions was collected in the forms of:

a) a pre/post survey to measure confidence in intercultural and interdisciplinary teaming,
b) collected email exchanges and conversations within the teams, and
c) focus groups based on responses from the surveys and exchange data. Findings [8, 9] indicated that students were ill-equipped to:
   - establish 'relational space' needed to manage and orchestrate virtual teams;
   - communicate their expertise to a variety of audiences; or
   - establish their own professional identities in contexts other than the technical academic classroom or laboratory [8, 9].

While the setting of a distributed workspace was perhaps novel to the students, as 'digital natives' (having used digital media since a very young age for educational, play, and social purposes) they were not new to communicating in virtual space. Also, as seniors they had previous experiences communicating their work to a range of audiences, and many had experience in professional workplaces as interns. However, when tasked with producing representations of their design work within a complex collaborative system, they did not bring all of these skills together.

Parallel to this course offering we offered a course section on the global marketplace and global communications to a *treatment cohort* of students in their junior year. The curriculum was situated within a Professional Development course designed to help students become aware of their potential roles in society as engineers. Assignments designed to support these outcomes included reading and discussion of Friedman's *The World is Flat* [6] and Linda and Frank Driskill's case study, "Risk-Based Design in a Pipeline Engineering Project for Colombia: First Do No Harm" [49]. The final assignment required student groups to develop a case-study scenario that involved cross-cultural communication issues that arise in engineering, and present ways of negotiating these issues. Groups submitted a written report and presented their work in the form of a skit. Learning outcomes stated that students should be able to:

- identify cross-cultural communication issues that arise in technologically mediated collaborations;
- describe work already undertaken by others on cross-cultural issues;
- summarize insights into the experiences of others;
- offer examples of practice that might be adapted for use by others;
- evaluate past initiatives.

At the conclusion of the course, all students achieved the objectives as measured by the graded case studies. A focus group conducted at the end of the semester revealed that students enjoyed the readings and the activities, felt they learned from the course, and believed that their roles as engineers would include some sort of global collaboration.

Following the instruction on global awareness, this treatment cohort of students entered their senior capstone design and completed the same intercultural, interdisciplinary collaborative project as the control cohort. However, the treatment cohort curriculum was enhanced with pedagogical strategies informed by the baseline data gathered during the control cohort project. Interventions included a variety of assignments designed to promote relational space and construction of broader, more collaborative engineering identities. For example, students in each team were required to write introductory emails to their counterparts overseas, including both social and work-related information about themselves, followed up by an 'ice-breaker' video-conference. Students also wrote self-reflections on their strengths and weaknesses as team members and then as a group assigned team roles [8, 9].

We hypothesized that, in contrast to the first cohort, the students in the second cohort would be better prepared to:

a) establish "relational space" needed to manage and orchestrate virtual teams;
b) communicate their expertise to a variety of audiences;
c) establish their own professional identities in contexts other than the technical academic classroom or laboratory.

Thus, we expected that the second cohort of students would have less difficulty in their cross-cultural and cross-disciplinary collaborations (Survey 1) and have more confidence in a broader range of engineering roles (Survey 2).

Data collection

To compare the control cohort and the treatment cohort, data was gathered using two methods:

1) a survey to students regarding their opinions on the difficulty of cross-cultural and cross-disciplinary collaboration and their assessment of their own levels of experience in such collaborations;
2) a survey to students regarding their confidence levels in fulfilling a range of engineering professional roles.

Survey 1: Student perceptions of difficulty and experience

Students from both cohorts completed pre- and post-surveys on their perceptions of the difficulty of cross-cultural and cross-disciplinary collaboration and their experience in each area (Table 1).

Responses to questions 1, 3, 5, and 7 were based on a 5-point Likert-type scale with 1 = very easy and 5 = very difficult. Questions 2, 4, and 6 were included to encourage students to add written comments to describe examples of their experience. This survey was distributed to the control cohort before (n = 19) and after (n = 16) the capstone design project. The treatment cohort completed the survey before (n = 19) and after (n = 19) the global marketplace instruction, and then again after the capstone design project (n = 11). Since no instruction on cross-disciplinary collaboration was given to the treatment cohort in their junior

Table 1. Survey on student perceptions of difficulty and experience

1. How would you rate the difficulty of collaborating with colleagues in another country?
2. What kinds of difficulties did you face based on the fact that you and your colleagues are from and working in different countries?
3. How would you describe your own level of cross-cultural experience?
4. What, if anything, has changed in your understanding of cross-cultural collaboration and communication as a result of this course?
5. How would you rate the difficulty of collaborating with colleagues from another discipline?
6. What kinds of difficulties did you face based on the fact that you and your colleagues have different disciplinary backgrounds?
7. How would you describe your own level of cross-disciplinary experience?
8. What, if anything, has changed in your understanding of cross-disciplinary collaboration and communication as a result of this course?

Table 2. Holistic behaviours of a comprehensive engineer profile (Davis & Beyerlein, 2005)

Technical Roles	Holistic Technical Behaviours
Analyst	When conducting engineering analysis, the engineer adeptly applies principles and tools of mathematics and science to develop understanding, explore possibilities and produce credible conclusions.
Problem Solver	When facing an engineering problem, the engineer produces solutions that properly address critical issues and assumptions and that are conceptually and contextually valid.
Designer	When facing an engineering design challenge, the engineer develops designs that satisfy stakeholder needs while complying with important implementation, societal and other constraints.
Researcher	When conducting applied research, the engineer designs and conducts studies that yield defensible results and answer important applicable research questions.
Interpersonal Roles	**Holistic Interpersonal Behaviours**
Communicator	When exchanging information with others, the engineer prepares, delivers and receives messages that achieve desired outcomes.
Collaborator	When working with others in joint efforts, the engineer supports a diverse, capable team and contributes toward achievement of its collective and individual goals.
Leader	When providing needed leadership, the engineer promotes shared vision to individuals, teams, and organizations and empowers them to achieve their individual and collective goals.
Professional Roles	**Holistic Professional Behaviours**
Self-Grower	Motivated for lifelong success, the engineer plans, self-assesses and achieves necessary personal growth in knowledge, skills, and attitudes.
Achiever	When given an assignment, the engineer demonstrates initiative, focus, and flexibility to deliver quality results in a timely manner.
Practitioner	Driven by personal and professional values, the engineer demonstrates integrity and responsibility in engineering practice and contributes engineering perspectives in addressing societal issues.

year, this cross-disciplinary question set was not repeated as a posttest until the end of their cross-disciplinary collaboration experience during their capstone design project. The mean and standard deviation for the control cohort and treatment cohort were calculated and compared graphically.

Survey 2: Student confidence in engineering roles

Another survey was designed to elicit the confidence levels for various roles as self-reported by engineering students, based on the attributes of an "engineer profile" as defined by Davis & Beyerlein [42]. Using data from a study that included industry and academic professionals, Davis & Beyerlein defined ten roles that were agreed to be critical for a complete 'engineer profile' in the global marketplace. The roles include: Analyst, Problem Solver, Designer, Researcher, Communicator, Collaborator, Leader, Self-Grower, Achiever and Practitioner. The roles in the Davis study were further classed 'holistically' as either 'technical, interpersonal, [or] professional behaviors desired in engineers' (see Table 2, reproduced from their article). All of the roles in the engineer profile were created based on 'broader expectations of engineers' performance', classifying engineers as 'people in professions entrusted with the well-being of people and society as a whole' [42].

Students were asked to rate their confidence in each of these roles on a 5-point Likert scale, with 1 = not confident and 5 = fully confident. Students were also asked to list the sources of learning that caused these variations. Since each role is defined in detail in the survey, the task of completing the survey was intensive, so students were given 20 minutes to complete the survey in class. Only students in the treatment cohort were asked to complete the survey, so there is no control data for this survey. The survey was completed by the treatment cohort students at the beginning (n = 16) and end (n = 11) of their capstone design project. The experiment was a within-subjects design aimed at minimizing the threats of selection. Five students did not respond to the posttest and hence there may be effects of mortality. For statistical analysis α was predetermined to be 0.05 as the cut-off for significant differences.

To determine if the mean confidence levels for the roles were statistically significant, a two factor fixed effects ANOVA where the participants are crossed within roles and test time was conducted in JMP 6. The results of this analysis were compared with a graphical analysis of mean confidence levels between roles and within the pre- and posttest for each role to verify the interpretation of statistical tests. Qualitative data, in the form of comments and responses to open-ended questions, were coded and are discussed below in the context of the literature review and the curricular interventions.

RESULTS

Survey 1: Student perceptions of difficulty and experience

To test if the project and instructions made a difference in the cross-cultural and cross-disciplin-

Table 3. Control cohort perception differences

	Difficulty in cross-cultural collaboration		Experience in cross-cultural collaboration		Difficulty in cross-disciplinary collaboration		Experience in cross-disciplinary collaboration	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std.dev.
Pre-project	2.89	0.57	3.4	1.3	3.5	0.8	2.6	1.1
Post-project	2.68	0.7	2.87	0.88	3.37	1.27	3.25	1.06

Table 4. Treatment cohort perception differences

	Difficulty in cross-cultural collaboration		Experience in cross-cultural collaboration		Difficulty in cross-disciplinary collaboration		Experience in cross-disciplinary collaboration	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std.dev.
Pre-instruction	2.87	0.93	2.39	0.98	–		–	
Post-instruction	2.85	0.81	2.62	0.92				
Pre-project	2.87	0.93	2.39	0.98	2.56	0.7	3	0.97
Post-project	3.45	0.68	3.27	1.00	3.00	0.94	3.18	0.75

ary collaboration among teams, the difficulties and experiences of the treatment cohort were compared with that of the control cohort. The differences in perceptions of difficulties and experiences as reported by the control cohort are summarized in Table 3. The results of the treatment cohort are summarized in Table 4.

Comparison of the results from the control cohort and the treatment cohort show that there is a marked difference in the mean perception of difficulty and experience levels between the treatment and control cohort. The histogram in Figure 1 demonstrates these differences.

At first glance, the results appear confounding: Figure 1 shows that the control cohort, compared to the treatment cohort, reported less difficulty in cross-cultural and cross-disciplinary collaboration after the team project. Also, the control cohort considered themselves more experienced after the project than the treatment cohort. Yet the open-ended questions and focus groups suggest that while the treatment cohort reported more difficulties and less experience, they were more conscious of, and had a more sophisticated understanding of, problems in cross-cultural collaboration. The control group, on the other hand, remained unaware of complexities though problems were reflected in their struggles in collaboration. The results thus indicate an important gap between students' self-assessment and their actual performance.

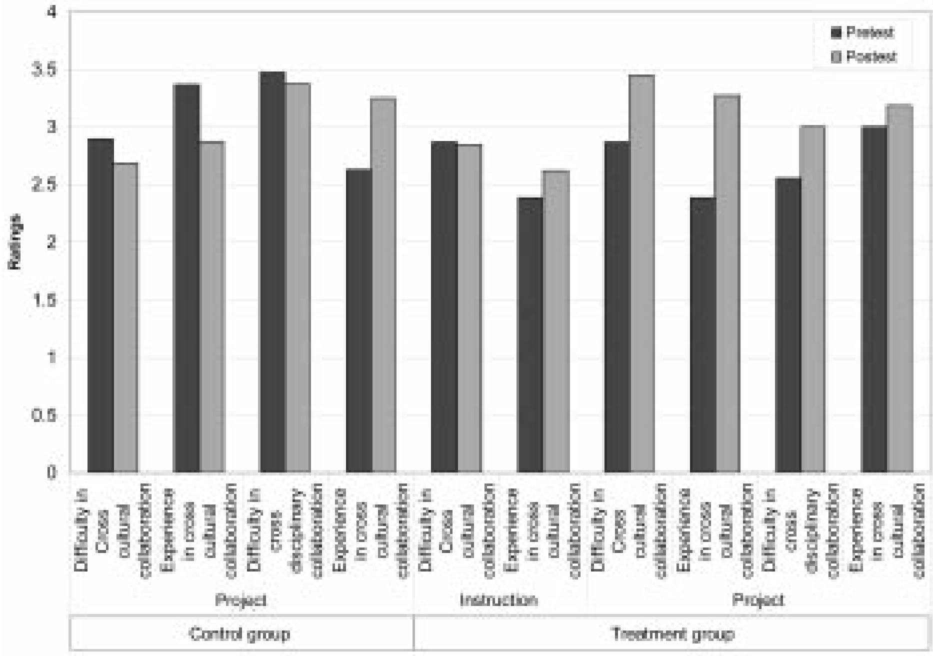

Fig. 1. Depicting the effects of the instruction and project on the perception of the difficulty levels and experience between the control and treatment cohort.

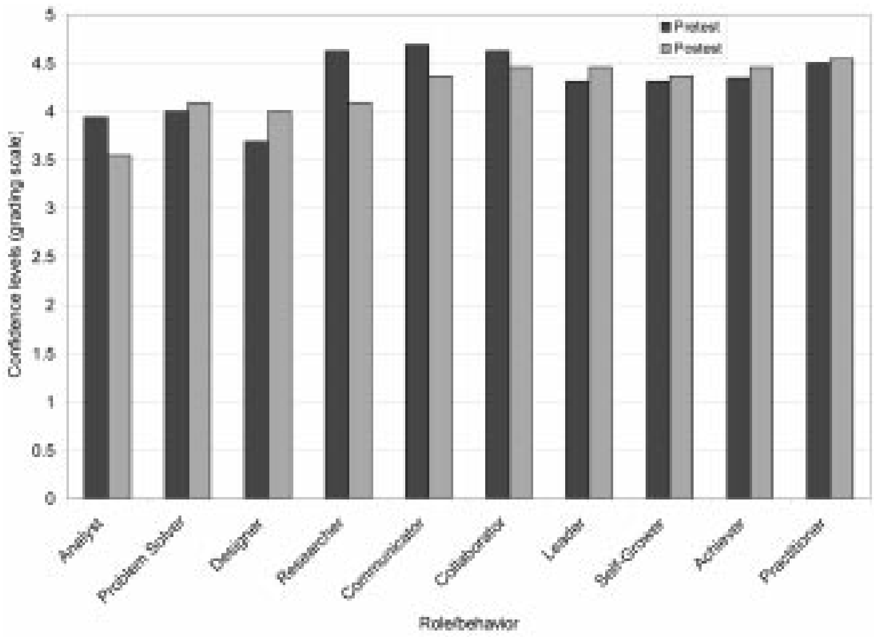

Fig. 2. Analysis affirming difference in mean confidence levels for the roles of analyst, problem solver and designer.

Survey 2: Student confidence in engineering roles

Figure 2 displays the results from the pre- and post-instruction surveys eliciting students' confidence levels for various engineering roles. The two factor ANOVA for the pilot data indicated that mean confidence levels for the roles of analyst, problem solver and designer were statistically different from the mean confidence level for all roles. These results correspond to an adjusted power of 0.4 to 0.8. However, there was no statistically significant difference in the mean confidence levels within each role between the pretest and posttest. These results correspond to a very low power of 0.05 to 0.2.

These responses, from the treatment cohort of senior engineering students at the end of their cross-cultural, cross-disciplinary project, show that averaged pre-project and post-project confidence levels are significantly lower in the Technical Roles of Analyst, Problem-Solver and Designer than in the Interpersonal and Professional roles. The fourth technical role, Researcher, decreased in confidence in the post-test. Although not significant, responses also show that there were decreases in confidence in the roles of Analyst, Researcher, Communicator and Collaborator, and increases in confidence in the roles of Problem-Solver, Designer, Leader, Self-Grower, Achiever and Practitioner.

Figure 3 displays the sources of learning that students identified as supporting each engineering role. Another one-factor fixed effects ANOVA was

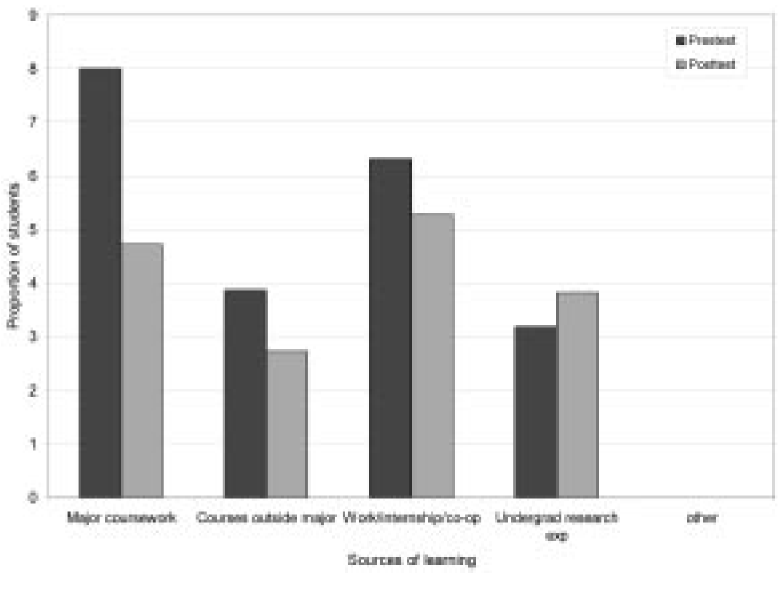

Fig. 3. Analysis illustrating increased application of undergraduate research experience.

conducted to determine statistically significant differences in the mean confidence levels of students for each of the sources of learning. There was no significant difference with a very low power of 0.05 to 0.08. The low power values indicate that there may be differences in the confidence levels for each role (pre to post) resulting from the project and that these would be observable with a larger sample size of 35.

Responses in Figure 3 show that students lowered their ratings of all sources for learning the roles of the engineer profile except for Undergraduate Research Experiences. Almost all of the students put comments in the 'Other' category, which was not tabulated numerically. 'Other' comments include experiential sources, such as Congressional visits (a class trip to Washington, DC), conferences, life experience, childhood values, parents, talks with co-workers, extracurricular activities and engineering organizations. The final distribution of sources of learning for roles shows that experiences in Work/Internships/Co-Ops leads as a factor students see as most helpful by the end of their senior year, followed by major coursework, Undergraduate Research Experiences and then finally courses outside the major.

DISCUSSION OF RESULTS

Survey 1: Student perceptions of difficulty and experience

With respect to difficulty and expertise, the case study results suggest that participants from both cohorts entered collaborative projects with relatively naïve views of potential problems, often centered on narrow constructions of non-technical collaborators. Instruction in their junior year increased the ability of students in the treatment cohort to identify potential differences before entering the collaborations while the impact of actual experiences varied from control to treatment cohort. The treatment cohort displayed a higher sensitivity to differences during the actual experience, and their sense of the difficulty increased throughout the project while the control cohort showed a decreased sense of difficulty as a result of the experience. Open-ended survey responses and focus group results suggest that the control cohort constructed a reductive technical/non-technical identity boundary throughout the collaboration that never became more complex. The treatment cohort, in contrast, although they also perceived this binary, developed a richer sense of their collaborators' identities as well as of their own roles, and displayed a greater willingness to work across those boundaries—even as they found them increasingly challenging. From an educational perspective, in this case decreased confidence reflected increased learning on the part of the treatment group: they more fully understood what they didn't know.

Cross-cultural perceptions

Over the course of instruction on the global marketplace in their junior year, students in the treatment cohort reported very little change in their assessment of the difficulties of cross-cultural communication (average of pre = 2.87, post = 2.85), but assessed their own level of cross-cultural experience as increasing (average of pre = 2.39, post = 2.62). In response to the open-ended question, 'What, if anything, has changed in your understanding of cross-cultural collaboration as a result of the work you've done for this course?' 18 of the 19 students indicated that they were more aware of cultural differences. They also cited finer distinctions regarding barriers and behaviors in collaborative settings. For example, in response to another open-ended question, 'What kinds of difficulties do you expect to face based on the fact that you and your colleagues are from and working in different countries?' students in the post-survey changed the way they referred to cultural and language differences and provided more specific examples. In addition to 'language barriers' more students used the word 'communication' and cited examples such as 'speech', 'idioms' and 'analogies'. Regarding cultural differences, after instruction the students distinguished and compared 'business practices' and 'social interactions', noting that both are important. Also, more students in the post-survey cited motivation and differing expectations and goals as a problem, specifically pointing out that 'staying motivated' and 'maintaining goals' is difficult. The results demonstrate, not surprisingly, that targeted instruction provides students with a clearer understanding of the range of issues involved in boundary-crossing collaboration.

Importantly, as the treatment cohort students' experience increased, so did their impressions of the difficulties associated with cross-cultural collaboration (Table 4). At the end of the capstone project, seniors rated the difficulties of collaborating with colleagues in another country higher than before and after their studies on the global marketplace during their junior year (pre-instruction junior year: 2.87, post-instruction junior year: 2.85; pre-project senior year: 2.87, post-project senior year: 3.45). Students again showed further refinement in their responses, describing communication difficulties in terms of differences in lexicons, the use of slang, 'translating' through technologies that prevented 'back and forth conversations', and overcoming lack of eye contact with all team members (even when using a visual medium). Both their assessments of the difficulty of cross-cultural collaboration and their own level of cross-cultural experience increased over the course of the instruction. This finding may suggest that students' sense of their own and their collaborators' identities grew more complex, as noted above, highlighting an area for further study.

In contrast, students in the control cohort rated themselves as having less experience in cross-cultural collaboration after their experience in the project (pre = 3.40, post = 2.87), but also indicated a decrease in their perception of the difficulty of cross-cultural collaboration (pre = 2.89, post = 2.68). In response to the open-ended question, "What kinds of difficulties did you face based on the fact that you and your colleagues are from and working in different countries?" the students cited a range of problems, including difficulties communicating through virtual media, differing goals, technical backgrounds, and time zones. Also, two students noted that they didn't work much with the students in the partner team. Responses to the open-ended questions, coupled with focus group findings, suggest that this seemingly confounding response may have resulted from a very limited construction of their collaborators' identities. That is, the control cohort appeared to enter the collaboration with a dichotomous sense of 'technical' versus 'non-technical' identities, narrowly defined as those with and those without expertise, and with little sense of cultural variations. Without instructional scaffolding, they did not move out of those narrow constructions, and although all students achieved their assignment goals, few considered the collaboration a productive experience [9].

Cross-disciplinary perceptions

The responses about cross-disciplinary work from the treatment cohort parallel their responses on cross-cultural collaboration: as students' experience increased, so did their impression of the difficulties of actual practice (Table 4). Their comments again show increasing sophistication and relate largely to communication issues: they cited jargon, vocabulary, terminology, and rhetoric as confounding factors. Also, almost every student commented on social factors that relate to how team members presented themselves and/or their knowledge, including differing 'approaches to problems' and 'styles of work'; having to exert more effort in 'having to explain concepts and ideas', 'having to be careful not to use technical jargon', and having to get past the idea that 'they don't think like we do and they have different goals—they have knowledge of other things'. One student even wrote 'sense of humour' as a possible place for misunderstanding. By the end of the project, as seniors the engineering students were still struggling with different understandings and interpretations, commenting that their non-technical counterparts 'skewed information', 'wanted to assume more than is stated', and 'stretched the truth'. Notably, however, these collaborations proceeded much more smoothly than in the control cohort based on instructor observations, email exchanges, and document reviews; students in the treatment cohort exhibited a marked willingness to work through conflicts that arose, and the US students even worked during their semester break to insure that the digital media students would complete their projects on time. Thus the technical/non-technical binary remained to some degree, but the collaborators displayed a greater willingness to work through the barriers.

In contrast, Table 3 shows that students in the control cohort indicated a decrease in their perception of the difficulty of cross-disciplinary collaboration (pre = 3.50, post = 3.37) but rated themselves as having more experience after their cross-disciplinary collaboration project (pre = 2.60, post = 3.25). In response to the open-ended question, 'What kinds of difficulties did you face based on the fact that you and your colleagues have different disciplinary backgrounds?' 12 of the 16 students cited communicating technical information as the main problem (two did not respond, and two cited differing expectations). Only three of the 16 students responded to the open-ended question, 'What, if anything, has changed in your understanding of cross-cultural collaboration as a result of the work you've done for this course?'—two emphasizing the importance of being 'clear' and one commenting that it is 'very important to understand who you are working with before you collaborate'. Little in the responses or observation data suggested that the students had, in fact, sought to know their collaborators at the outset or come to know them during the collaboration. The dynamic in the control cohort was narrowly constructed along work lines, and the engineering students demonstrated little willingness to engage with their collaborators beyond the minimum requirements.

Survey 2: Student confidence in engineering roles

Overall, as shown in Figure 2 above, students in the treatment cohort indicated lower confidence in technical roles than in Inter-Personal and Professional roles. It is important to note that Davis & Beyerlein's descriptions of the technical roles are heavily embedded in professional skills. For example, the role of Analyst requires that students be able to 'extract desired understanding and conclusions consistent with objectives and limitations of analysis'; a Problem Solver should be able to 'validate results, interpret, and extend the solution for wider application'; and the Designer should be able to 'assess and meet stakeholder needs by finding, creating, evaluating and synthesizing alternatives that efficiently result in products'. The fourth technical role of Researcher, in which student confidence decreased, includes the ability to 'interpret and validate results to offer answers to posed questions and to make useful application' [42]. It is no surprise that students realize over the course of actual practice that bringing their technical work to meet application and stakeholder needs is an extremely complex process requiring them to fill multiple roles.

The slight decreases in Communicator and Collaborator roles reflect the responses to the previous survey focused on the difficulties and experiences in collaboration—an ambiguity perhaps indicating knowledge of complexity more than confidence of expertise in practice after participating in actual cross-cultural, cross-disciplinary collaborations.

The sources of learning data in Figure 3 above show that students look to major coursework and actual experience as valid and useful sites for learning various roles in the engineering profile. An inroad for productively changing students' construction of their own and their collaborators' identities thus may be in influencing how students value courses outside of major, where professional skills such as communication are specifically targeted. Work on establishing links between non-engineering curricula and engineering roles has been initiated in a partnership with the English department, focusing on making explicit to both instructors and students the many areas of overlap in different disciplines' learning outcomes [50].

SUMMARY

Unexpectedly, the results of our case study groups were, on the surface, unaligned with the original hypotheses. According to self-reports, the treatment cohort did not report less difficulty in multi-dimensional collaborations and did not report more confidence in a broader range of engineering roles. We argue that because their open-ended responses display more complex understandings of multi-dimensional collaborations, these more experienced students are still better prepared to establish 'relational space' needed to manage and orchestrate virtual teams, communicate their expertise to a variety of audiences, and establish their own professional identities in contexts other than the technical academic classroom or laboratory. Encouragingly, responses to both surveys point toward a growing awareness that social skills are a genuine part of the job an engineer faces when representing their technical work to colleagues across cultural and disciplinary boundaries. Although a loss of confidence may not necessarily be the outcome sought in curriculum planning, we believe that a sense of ambiguity or uncertainty may be an indication that students are actually more realistically aware of the complexities that await them in their careers outside the classroom and the laboratory—and perhaps specifically more aware of the complex identities at work in the collaborative social network. This awareness, though not in the traditional form of 'expert' knowledge, may be good preparation and practice for agility with professional skills that will be a valuable resource for students as engineers in the 'flat world'. It may, in fact, create an important zone of proximal development [51] that prepares students for developing flexible, transferable skills for design thinking in team environments.

CONCLUSIONS: AREAS FOR FUTURE RESEARCH

Engineering design, as practiced in the workplace, is an increasingly complex collaborative process, involving multiple disciplines, multiple global cultures, and constantly emerging technologies to support virtual distributed work. In preparing students to succeed in this environment, engineering educators must increasingly attend to appropriate transferable professional practices. We argue that the ability to construct identities that support such collaboration is one such practice—and a practice currently under-explored in engineering education research. Existing research on distributed work, cross-cultural and cross-disciplinary collaboration, and engineering identity provides key starting points for new research in this area; the case study discussed here suggests that students' preliminary expectations, as well as their constructions of their own and their collaborators' roles and identities, are critical factors. Both the literature review and the case study suggest at least three critical questions to further explore both prior knowledge and appropriate interventions:

1) What roles do engineering students adopt when establishing professional identity in interdisciplinary contexts?
2) How do these roles impact collaboration?
3) What pedagogical strategies encourage students to expand their range of roles?
4) What pedagogical strategies best support transferable practices that enable students to cross a range of boundaries in workplace design collaborations?

The case study described here suggests that without explicit attention to creating a collaborative relational space, the participating students constructed narrow binary versions of their own and others' identities that inhibited successful collaborations. Yet when students were given meta-knowledge and skills for facilitating 'relational space' that provided a fuller context (rather than simply 'getting down to work'), conflicts were negotiated more productively while participants developed a stronger sense of the complexities involved in collaborating across boundaries. This case, however, represents a small sample population, and definitive conclusions require additional study on a broader range of students to identify prior knowledge, impact on collaboration, effective teaching practices, and transferability.

Moreover, the existing scholarship and the case studies suggest a series of additional questions engineering education research can address to better facilitate design thinking in a team environment, including:

1) What unconscious behaviors enhance or impede relational space in design collaborations?
2) How does enhanced relational space affect design team performance?
3) In collaborative design environments, how do engineering students communicate technical content across disciplinary and/or cultural boundaries?

4) What behaviours facilitate or impede effective information transfer across such boundaries, in both co-located and virtual environments?

Design thinking in team environments is clearly a critical practice for contemporary engineers. By more fully understanding how engineers approach such environments, how those approaches impact the collaboration, and what strategies best facilitate the work at hand, engineering education researchers can make marked strides in better preparing new graduates for the flat world.

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