Engineering Cultures: Expanding the Engineering Method for Global Problem Solvers

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Abstract

What does it mean for engineers to engage in global problem solving? What forms of knowledge or sets of capabilities characterize the effective global problem solver? What sorts of learning experiences are involved in gaining such knowledge and capabilities? The purpose of this paper is to present the design, initial steps, and preliminary assessment of the "Engineering Cultures: Building the Global Engineer" project which seeks to address the above questions through the development of a new undergraduate course called "Engineering Cultures." The first section of this paper briefly outlines ongoing efforts to internationalize engineering curricula, followed by a discussion of how the Engineering Cultures project connects to existing work while also attempting to extend the opportunity to become global problem solvers to a broader population of students. The final section presents an initial set of outcomes from ongoing assessment efforts.

I. Introduction

Engineering graduates from the United States increasingly travel to diverse locations and work side-by-side with peers with markedly different life histories and cultural experiences. In the arena of engineering education, it has become more common to assert that globalization is having a profound impact on the educational needs of engineering students and that engineers must become global problem solvers. Indeed, it is no longer controversial to assert that if engineering students are to function effectively in global communities their undergraduate curricula should prepare them to interact and problem solve in diverse settings. Accordingly, an increasingly widespread curricular policy in colleges of engineering is to "internationalize" the curriculum.

A key stimulus for efforts to internationalize engineering programs lies in the Accreditation Board for Engineering and Technology's (ABET) criterion 3h established in 2000. Criterion 3h asserts that "Engineering programs must demonstrate that their graduates have…the broad education necessary to understand the impact of engineering solutions in a global and societal context."[1] This criterion is somewhat ambiguous in that it could be interpreted as referring to the challenges of marketing engineered products to consumers in different countries rather than of engaging engineers in problem solving with co-workers from different countries. Nonetheless, since 'h' is the only criterion that includes a reference to the 'global,' it is frequently understood as a call to prepare engineers for problem solving in diverse contexts and, therefore, as a call to internationalize the curriculum.

In the spirit of EC 2000, engineering educators interested in altering current curricula should consider addressing some key questions about the desired outcomes of such changes. First, what does it mean for engineers to engage in global problem solving? In particular, is global problem solving the same as international problem solving? Second, what forms of knowledge or sets of capabilities characterize the effective global problem solver? Third, what sorts of learning experiences are involved in gaining such knowledge and capabilities?

The purpose of this paper is to present the design, initial steps, and preliminary assessment of the "Engineering Cultures: Building the Global Engineer" project, which is partially funded by the National Science Foundation (DUE-0230992). This project seeks to address the above concerns through the development of a new undergraduate course called "Engineering Cultures." The first section of this paper briefly outlines ongoing efforts to internationalize engineering curricula. This is followed by a discussion of how the Engineering Cultures project connects to existing work while also attempting to extend the opportunity to become global problem solvers to a broader population of students. The final section presents an initial set of outcomes from our on-going assessment efforts.

II. Ongoing efforts to internationalize U.S. engineering curricula

In the U.S., efforts to internationalize engineering curricula have minimally included affording students the opportunity to gain personal experiences beyond the geographical boundaries of the country. The primary approach at most institutions has been study-abroad programs, attractive in part because they serve as a device for recruiting and retaining quality students.[2] A prominent example is the Global Engineering Education Exchange (GE3), which is administered in the U.S. by the Institute for International Education. In operation since the mid-1990s, the GE3 successfully oversees study-abroad exchanges among 34 schools in the U.S. and 17 schools in other countries.[3] Also, since 1997, the University of Rhode Island has sponsored annual conferences on 'International Engineering Education' that have brought together increasing numbers of faculty, engineering administrators, and sponsoring agencies working to provide engineering students with study-abroad opportunities.[4]

Other proposed approaches to internationalizing engineering education call for changes within existing curricula. For example, the 2001 forum at the University of Illinois at Chicago, "International Engineering: Internationalism and Implications for Engineering Higher Education," called for an array of innovations that, taken together, would amount to a systemic shift in the content of engineering education:

1) team design projects involving students at different institutions;
2) training in non-native languages;
3) integration of international cases and content into engineering courses;
4) use of distance education to achieve international interactions;
5) greater emphasis on courses designed to teach students to "be sensitive to other cultures"; and

6) training in the "variety of ways in which local engineering practices, laws, and regulations, and intellectual property are managed across the globe."[5]

Not surprisingly, individual schools have developed and offered distinct configurations of approaches to internationalizing their engineering curricula. A prominent example is Georgia Institute of Technology (Georgia Tech), which is seeking to become "the primary U.S. producer of engineers graduating with significant international and global distance learning experience." Georgia Tech's engineering college has set the ambitious goal of having "one-half of its students graduate with a meaningful international education and global experience," ranging from "individual course offerings to develop a student's appreciation of a global perspective, to a semester of study and/or work abroad to provide direct international experience, to degree-long programs with intensive study and work abroad requiring proficiency in a foreign language."[6] In 2004, approximately 20% of the engineering student body at Georgia Tech, or 1,600 students, were enrolled in elective foreign language courses. Other schools, such as Embry-Riddle Aeronautical University, Northern Arizona University, University of Washington, University of Pittsburgh, and Worcester Polytechnic Institute, are also developing mixes of study-abroad and distance education programs.[7, 8] The National Science Foundation, in fact, now supports international education programs for undergraduate engineers under its program Developing Global Scientists and Engineers.[9]

Providing an overarching umbrella for efforts at individual institutions is the American Society for Engineering Education (ASEE), which has made significant efforts to build international connections among faculty and administrators in the engineering education community. One pathway has been through International Colloquia on Engineering Education, which have been held in Berlin (2002), Nashville (2003), Beijing (2004), and Sydney (2005). A more recent approach is to increase the international knowledge of engineering faculty by distributing to all its members the monthly *International Engineering Education Digest*, edited by Russel Jones and Bethany Oberst.[10] Jones has been a prominent advocate and activist for international engineering education since publishing "Educating Engineers for International Practice" in the journal *Liberal Education* in 1995.[11]

Despite these efforts to increase student participation in international experiences, the challenges they face are large, if not overwhelming, especially when programs require international travel. While study abroad can be both life and work transforming, as recently as 2001-2002 only 4% of engineering students in the U.S. participated in an "international academic experience."[6] In the best of cases, student participation reaches only 10% in the United States (e.g. University of Rhode Island), compared with 20% in Europe.[12] Furthermore, as the Open Doors 2004 report reveals, the number of foreign students entering the U.S. has decreased significantly in recent years, reducing opportunities through another longstanding method for introducing U.S. students to international perspectives.[13]

III. Engineering Cultures

Engineering Cultures uses a different approach to introduce students to the idea and practice of global problem solving. Minimally, the course seeks to provide international training for students unable or unwilling to face the financial, logistical, and emotional burdens of leaving their home institutions. But in addition, the course is built on the view that the key value added to engineering education from international experiences, and a defining feature of effective global problem solvers, is an enhanced ability to engage in activities of problem definition with people who are located differently than one is and are likely to define problems differently than one does. As such, Engineering Cultures focuses on and seeks to build student competence in "problem definition across differences," defined as a key step in global engineering work that typically occurs prior to the activities of mathematical problem solving that comprise engineering analysis.

In the next section, we discuss the genesis of the idea for the Engineering Cultures curriculum and pedagogy. We then describe the specific learning objectives, course design, and tests of both in-class and online formats.

A. Course origin

Gary Downey and Juan Lucena, two of the authors, developed the idea for this course based on observations they made while conducting an ethnographic study among undergraduate engineering students.[14] Through their research, Downey and Lucena discovered that a key feature of the engineering method, as it tends to be taught in engineering science courses, could have unintended effects at odds with an important dimension of effective global engineering practice. Through hundreds of exercises in core engineering science courses, the students they observed were learning that the key first step in engineering problem solving is to draw a boundary around the problem, after which mathematical theories of the engineering sciences must be brought to bear to find a solution, typically through the five-step process, "Given, Find, Equations, Diagram, Solution." While progressively coming to master mathematics-based engineering analysis, students also seemed sometimes to be practicing the view that engineering problem solvers, as people, were necessarily either right or wrong. In other words, the emphasis on drawing a boundary around a problem appeared to have the unintended effect for at least some students of predisposing them to divide the world of problem solvers into two parts, those who drew the boundary the same way that students were learning and those who did not. Those who did draw the boundary the same way became capable of being 'right' and those who did not were, by implication, 'wrong.'

Yet coming to expect worlds of problem solvers to be divisible into two groups, the right and the wrong, could be problematic in an engineering career where encounters with people who define problems differently than one does are arguably a regular condition of engineering work, especially as engineering work goes global and diversity becomes a more obvious characteristic of the engineering workplace. Following the experiences of engineering students in engineering science courses thus raised the question that the very rigor of the engineering method, while establishing and enhancing the competence of engineers in mathematical problem solving, could also be limiting or inhibiting the development of the competence of engineers in effective problem definition, especially when working in collaboration with others.

Downey and Lucena responded to these concerns by creating and pilot testing the Engineering Cultures course at Virginia Tech in 1994-1995. After a regular course was approved and offered in Spring 1996, requests for the course quickly increased to 250-300 students per semester. To balance the twin goals of active learning and maximum reach, the class was ultimately limited to

150 students and taught regularly by a team that includes three graduate teaching assistants managing weekly oral and written discussion sessions. Seven of these assistants, including co-authors Thomas Bigley, Chris Hays, Brent Jesiek, Liam Kelly, Jane Lehr, Jonson Miller, and Amy Nichols-Belo, went on to offer their own versions of the course, in class sizes ranging from 25-40 students. Lucena transferred a variation of this course to Embry-Riddle Aeronautical University in 1997 and Colorado School of Mines in 2001. Enrollments at these smaller institutions have been in the range of 25- 30 students.

B. Course Learning Objectives

Engineering Cultures seeks to expand the engineering method by helping students build competency in problem definition with co-workers who might hold different perspectives. The key learning objectives are that, by completing course assignments, students will be able to demonstrate that they:

(1) understand and are able to analyze the locations and contents of different perspectives involved in a given engineering problem;

(2) understand and are able to analyze the locations and contents of the perspectives they hold themselves as engineers; and

(3) are able to forge agreements in problem definition, in part by accommodating their own perspectives to those of other engineering problem solvers.

C. Course Design

Engineering Cultures helps students pursue the first objective, learning to map different engineering perspectives, by surveying through discrete substitutable modules the emergence of engineering as a professional practice in different countries. Downey and Lucena have developed modules on engineers in France, Great Britain, Germany, Japan, Soviet Union/Russia, and the U.S. Efforts are currently underway to create similar modules on engineers in Brazil, China, Colombia, Egypt, India, Korea, Mexico, and Taiwan.

Each module addresses four questions:

a. How did the nation state evolve?
b. How have engineers emerged in this country?
c. What is a typical career trajectory for an engineer?
d. What are key emerging trends for engineers and engineering?

Addressing the first question involves identifying those geographical, historical, and demographic dimensions of the country that provided the context for the emergence of engineers. An important issue to follow concerns what came to count as national progress in each case. For example, it matters that the French had an absolutist state before the Revolution and that what came to count as national progress were activities that enhanced social order and helped society advance toward a future state of perfection. By contrast, Great Britain early on developed a strong parliament and activities that counted as progress were those that improved material comforts, with material comfort defined in terms of distance from manual labor. In Germany, achieving national coherence has always been a significant problem for a country that has long been a diverse collection of states, and what came to count as progress were activities that emancipated German *geist,* which is to say the distinctive mix of mind and spirit thought to be shared by all Germans.

An additional important dimension to pursue is the influences that countries have had on each other. For example, former colonies of Britain and France have unique mixes of influences on engineers from both colonial and domestic sources. Understanding the emergence of engineering in the United States, for example, requires understanding the influences Americans felt from British and French sources mixed with indigenous images of the "American people" as they formulated a novel commitment to progress as activities that increased the production of low-cost goods for mass consumption. Likewise, in Egypt one finds influences from the French, British, Germans, Soviets, and Americans mixed with indigenous yearning to recreate the past glory of Egyptian civilization and work toward an economic union of Arab states.

(b) In order to understand how engineers emerged in each country, Engineering Cultures considers the following questions within each module: What has it meant to be an engineer? What sorts of knowledge have engineers valued? How and why has a given national emphasis in engineering changed over time? Pursuing these questions trains students to anticipate and be able to understand differing patterns of social position and status among engineers in different countries. For example, much existing research by historians of engineering[15] suggests that French engineers have tended historically to value mathematical theory and aspire to work in government where those who make it constitute the highest-ranked occupation in the country.[16] British engineers, on the other hand, have tended to value craftsmanship and work in the private sector, where they have constituted a comparatively low-ranked occupation.[17, 18] German engineers have exhibited yet another pattern, attaining the status of highly-valued workers only after German unification in 1870 and then later becoming model German citizens through their commitment to precise, high-quality technics.[19, 20] In Japan, although never a European colony, one finds evidence of British and German models influencing engineering education beginning in the Meiji period and a strong American influence after World War II, yet a distinctive pattern that located the most important training in a lifetime employment system within the firm.[21, 22]

(c) Following typical career trajectories for engineers requires examining in greater detail both what has emerged to count as engineering education and where engineers have typically worked. Differences within a given country can be significant. For example, in Mexico engineering training at Universidad Nationale Autónoma de México in the capital city became the key pathway to high-status positions in government while training at Monterrey Tech became the key pathway to high-status positions in private industry. To this day, students within Mexico must carefully consider their career ambitions before they enter a particular college.

By understanding such differences as these, students learn to ask intelligent questions about co-workers and make reasonable predictions about their career goals and desires. Thus, for example, knowing that the most elite French engineers are tracked into government may help one better understand a French engineering co-worker whose career has been wholly in private industry.

(d) Following key emerging trends typically involves exploring how the country involved is grappling with images of industrial competitiveness and what counts as globalization. Pursuing this question prepares students to anticipate more general concerns, fears, and senses of opportunity among co-workers. For example, where responding to globalization may challenge French engineers to seek ways of placing higher value on activities in private industry, German engineers may find themselves struggling to maintain a commitment to engineering precision while having to compete more on the basis of low price.

A conceptual feature of Engineering Cultures that has proven helpful is that the course treats cultures not as something shared by all the members of a given group but rather as sets of 'dominant images' that challenge people in a given location with their meanings and expectations. The purpose of this emphasis is to enable engineering students to recognize and analyze differences among people responding to a given culture as well as differences in cultures.

As described in objective 2, students must also be able to understand and critically analyze their own perspectives and how these might influence them in activities of problem definition. Students learn that differences in what counts as engineers and engineering knowledge can have implications for practices of problem definition in at least two ways. One way is that the scope of what counts as a relevant problem for engineers may vary from place to place. For example, although one must be aware of the significant differences that exist among engineers within France and the U.K., an informed student can reasonably expect French engineers to embrace the mathematical dimensions of a given problem to facilitate planning, leaving more practical problems to lower-status workers, while expecting British engineers to consider practical dilemmas and, hence, mid-course corrections as central to their responsibility and effective engineering practice. A second way that differences can affect problem definition is by varying the implications that particular types of work might have for one's identity, and hence one's career, as an engineer. For example, whereas one can anticipate a French engineering career to benefit most from work that advances and improve national infrastructures, one can expect a British engineering career to benefit most from work that advances and improves private sector production.

To engage in effective problem definition across differences, global engineers must thus know with whom they are working. Since engineers have unique life histories and may not fit dominant national patterns, the effective engineer must sort out the particularities of each case. But the sophisticated sorting of particularities is premised upon a solid understanding of how co-workers are likely to be positioned and what they are likely to know and want.

Engineering Cultures relies heavily upon oral discussions and written exercises, especially role-playing exercises, to help students practice adopting different perspectives. For example, students may be asked to imagine themselves as Japanese engineers working with Americans on a given project, produce a dialog among German, French, and British engineers analyzing a design situation, describe the likely contemporary conflicts among Mexican engineers trained at three different types of institutions, or even draft historically-informed poetry that captures the dreams of early Soviet engineers.

Achieving objective 3, demonstrating the ability to forge agreements in problem definition, tends to be most difficult for students because such requires moving beyond the recognition and sophisticated analysis of differences to the actual practice of formulating alternative responses, depending again upon the particulars of the case. The Engineering Cultures curriculum and pedagogy help students make this move by formally expanding the engineering method to include a four-step process for collaborative problem definition prior to the activity of mathematical problem solving. This process includes identifying perspectives, identifying who owns which definitions, mapping what alternative definitions mean to different participants, and adapting one's own definitions to accommodate other perspectives. Further details regarding each step are displayed in Table 1.

Table 1 Collaborative Problem Definition

Step 1	Identify each perspective that is involved in the decision you face. Remember that problems often mean different things in different perspectives. Relevant differences might include national expectations, organizational positions, disciplines, career trajectories, etc. Consider using the mnemonic device "Location, Knowledge, and Desire.' *Location*: Who is defining the problem? Where are they located or how are they positioned? How do they get in their positions? Do you know anything about the history of their positions, and what led to the particular configuration of positions you have today on the job? Where are the key boundaries among different types of groups, and where are the alliances? *Knowledge*: What forms of knowledge do the representatives of each perspective have? How do they understand the problem at hand? What are their assumptions? From what sources did they gain their knowledge? How did their knowledge evolve? *Desire*: What do the proponents of each perspective want? What are their objectives? How do these desires develop? Where are they trying to go? Learn what you can about the history of the issue at hand. Who might have gained or loss ground in previous encounters? How does each perspective view itself at present in relation to those it envisions as relevant to its future?
Step 2	As formal problem definitions emerge, ask "Whose definition is this?" Remember that "defining the problem clearly" may very well assert one perspective at the expense of others. Once we think about problem solving in relation to people, we can begin to see that the very act of drawing a boundary around a problem has non-technical, or political dimensions, depending on who controls the definition, because someone gains a little power and someone loses a little power.
Step 3	Map what alternative problem definitions mean to different participants. More than likely you will best understand problem definitions that fit your perspective. But ask: does it fit other perspectives as well? Look at those who hold Perspective A. Does your definition fit their location, their knowledge, and their desires? Now turn to those who hold Perspective B. Does your definition fit their location, knowledge, and desires? Completing this step is difficult because it requires stepping outside of one's own perspective and attempting to understand the problem in terms of different perspectives.
Step 4	To the extent you encounter disagreement or conclude that the achievement of fit is insufficient, begin asking yourself: How might I adapt my problem definition to take account of other perspectives out there? Is there some way of accommodating myself to

	other perspectives rather than just demanding that the others simply recognize the inherent value and rationality of mine? Is there room for compromise among contrasting perspectives?

D. Available course formats

To date, Engineering Cultures has been taught in 35 semester-length versions. Downey (12) and Lucena (5) have offered the course in lecture/discussion formats in both large and small classes, at both a research institution and smaller teaching institutions. Lehr (1) and Miller (1) have also offered their own versions of the course using the lecture/discussion format. In order to make course modules available to other institutions and to working engineers, Downey and Lucena have worked with Virginia Tech's Video Broadcast Services to develop and pilot test multimedia versions of course modules. Bigley (4), Hays (2), Jesiek (5), Kelly (1), Lehr (1), Miller (1), and Nichols-Belo (2) have all offered 100% online versions of the course using a combination of the multimedia module presentations and synchronous class meetings via CentraOne software, whose tools include audio-based interactions and a shared whiteboard.

As indicated in Table 2, all versions of the course require considerable reading and writing. Because no textbooks exist, readings for each module include a combination of academic and popular publications, woven together with content gathered and organized through extensive original research. Informal writing has included student responses through online threaded discussions, memos, autobiographical statements, dialogs, proposals, admission and exit tickets, poetry, and essay exams. Formal writing has included research reports, essay summaries and responses, and reflections assignments.

Table 2 Reading and Writing Assignments

Instructional format	**Instructor**	**# sections taught**	**# pages reading**	**# pages informal writing**	**# pages formal writing**
Lecture/discussion Classroom	Downey + TAs	12	384	21	16
	Lucena	5	379	26	18
	Lehr	1	587	6	17
	Miller	1	437	0	13
CD/web/online	Jesiek	3	275	34	8
	Jesiek/ Nichols-Belo	2	275	34	8
	Bigley	2	276	11	13
	Bigley/Hays	2	277	26	12
	Downey + TAs	1	428	25	13
	Kelly	1	276	11	13
	Lehr	1	297	29	8
	Miller	1	409	10	16

IV. Informal formative investigations

Table 3 provides a timeline of informal pilot investigations conducted of both the classroom and online versions of the Engineering Cultures course. The purpose of these investigations, which went beyond normal course evaluations, was formative in nature. In other words, assessment data were collected, analyzed, and used in reformulating learning experiences for students.

Table 3 Informal Formative Investigations

Fall 1998	Downey solicited multiple paragraph assessments of the in-class course.
Spring 2001	Downey and three teaching assistants conducted a beta test of the multimedia Japanese module, with follow-up evaluations
Summer 2001	Downey and Lucena offered a two-week version of the course at the International Institute for Women in Engineering in Paris. 30 women students from 17 countries used the multimedia modules to prepare for the on-site experience.
Fall 2001	Downey and three teaching assistants conducted a full-semester pilot test of a 100% online version using the multimedia modules for content and Blackboard for assignments and asynchronous communications.
Summer 2002	Jesiek and Nichols-Belo conducted full-semester test of synchronous communications in the online version using CentraOne.
Summer 2003	Lehr introduced short-answer evaluations comparing assignments, modules, and media of learning (e.g., CD, etc.)
Spring 2004	Lucena assessed French and British CD modules in classroom version; Bigley and Miller collected aggregate pre/post-test data
Summer 2004	Lehr expanded short-answer evaluations comparing assignments, modules, and media of learning

Based on this assortment of formative evaluations, we found that the course has been working well in all three formats and, therefore, continued to develop and expand the curriculum. Based on the pilot studies, roughly 60% of participating students reported that the course experience was of major significance in their professional training. Of this total, approximately half indicated that they were profoundly transformed, viewing themselves as much better prepared to engage different perspectives in engineering work. The remaining half indicated that the course was well worth the effort in that it enabled them to have deeper insights into engineering problem solving and the world of a working engineer.

Of the remaining 40% of participating students, roughly half have been moderately positive, indicating they had learned things that would be useful in their professional careers. The majority of the remaining half expressed concerns that the workload for the course was too great. One student wrote, "It was an awful lot of reading and writing . . . ." Fewer than 5% of the students in the course have been more strongly negative about the experience, indicating either that it was irrelevant to their futures or, in the most extreme case, was "one of the worst experiences" of the student's college life.

V. Formal summative assessments

In Fall 2003, Barbara Moskal, an assessment specialist, joined the research team to assist in the development of more formal methods for evaluating content and learning outcomes in Engineering Cultures. The instruments developed include (a) an end-of-semester survey for summarizing overt student evaluations of a given course; (b) a multiple-choice learning assessment for measuring student learning through a pre/post-test; (c) a module survey for comparing student evaluations of different modules and modes of delivery; and (d) a content evaluation inventory for collecting peer evaluations of the knowledge contents of online modules. In this paper, we report data from (a) and (b) that pertain to the learning objectives outlined above, saving comparative and content evaluation data for a subsequent analysis. All assessments were administered via Blackboard. Although sections of both in-class and online versions of Engineering Cultures were taught during Spring and Summer 2004, technical difficulties resulted in the collection of unusable data for the online versions. This paper reports results from the in-class implementations of the course.

A. Assessment Instrument Development

An end-of-semester survey is a self-report instrument designed to acquire student feedback concerning experiences and learning during the Engineering Cultures course. This instrument contains a combination of structured response and open-ended questions and was administered to all sections during the last week of classes. The questions that comprise this instrument are provided below in the results section. All participating classes completed the end-of-semester survey.

In creating the learning assessment, Downey and Lucena first outlined key components of the Engineering Cultures curriculum that they expected to be common across sections. Next they developed multiple-choice questions that were designed to measure students' knowledge with respect to these components of the course. The instrument was then reviewed by Moskal, using as a guide literature that concerns the development of multiple-choice assessments.[23, 24] When appropriate, Downey, Lucena, and Moskal revised questions in a manner that is consistent with the literature on valid assessment.[25] Since this research investigation is on-going, the final version of this assessment is being maintained as confidential. The researchers will, however, share this instrument with other researchers upon request with the agreement of confidentiality (please contact Barbara Moskal at bmoskal@mines.edu).

The multiple-choice content assessment was administered as a pre-test within the first week of classes in each of the sections of the Engineering Cultures courses. This same instrument was administered as a post-test in the last week of each of these classes.

B. Assessment Results

The end-of-semester survey includes a list of questions that require students to respond as to whether they Strongly Disagree (SD), Disagree (D), Agree (A), or Strongly Agree (SA) with a set of five statements about the content of their learning. Each of these questions was constructed to directly address the stated objectives of the Engineering Cultures course. Table 4 displays the questions and the percentages within each class to select a given category.

As the table suggests, within and across four participating classrooms, the majority of students either agreed or strongly agreed that the course made a significant difference in their engineering education. On average, 93% indicated that they "gained significant knowledge about engineers in the world" and 95% indicated they are "better prepared to meet and work with engineers from different countries." Ninety-one percent indicated they "have a better understanding of how my perspective as an engineer is different from other of engineers from other countries" and 83% indicated they will now be "better at working with people who define problems differently than I do." Finally, 76% indicated they "will now be more likely to have a satisfying career as an engineer."

Table 4 End-of-semester Survey

	Course	n	SD	D	A	SA	NR
I gained significant knowledge from this course about engineers in the world.	VT, Sp 04, Sec 1	39	5.13	2.56	61.54	28.21	2.56
	CSM, Sp 04, Sec 1	26	3.85	0.00	50.00	46.15	0.00
	VT, Su 04, Sec 1	14	0.00	7.14	71.43	21.43	0.00
	VT, Su 04, Sec 2	27	3.70	0.00	51.85	44.44	0.00
	Average		3.17	2.43	58.70	35.06	0.64
I am better prepared to meet and work with engineers from different countries.	VT, Sp 04, Sec 1	39	5.13	5.13	53.85	33.33	2.56
	CSM, Sp 04, Sec 1	26	3.85	0.00	57.69	38.46	0.00
	VT, Su 04, Sec 1	14	0.00	0.00	85.71	14.29	0.00
	VT, Su 04, Sec 2	27	3.70	0.00	74.07	22.22	0.00
	Average		3.17	1.28	67.83	27.08	0.64
I now have a better understanding of how my perspective as an engineer is different from those of engineers from other countries.	VT, Sp 04, Sec 1	39	5.13	5.13	51.28	35.90	2.56
	CSM, Sp 04, Sec 1	26	3.85	0.00	61.54	34.62	0.00
	VT, Su 04, Sec 1	14	0.00	14.29	57.14	28.57	0.00
	VT, Su 04, Sec 2	27	3.70	0.00	59.26	37.04	0.00
	Average		3.17	4.85	57.31	34.03	0.64
I will now be better at working with people who define problems differently than I do.	VT, Sp 04, Sec 1	39	5.13	17.95	58.97	17.95	0.00
	CSM, Sp 04, Sec 1	26	3.85	7.69	69.23	19.23	0.00
	VT, Su 04, Sec 1	14	7.14	14.29	71.43	7.14	0.00
	VT, Su 04, Sec 2	27	0.00	11.11	70.37	18.52	0.00
	Average		4.03	12.76	67.50	15.71	0.00

After learning about engineering and engineers in the world, I will now be more likely to have a satisfying career as an engineer.	VT, Sp 04, Sec 1	39	5.13	10.26	66.67	15.38	2.56
	CSM, Sp 04, Sec 1	26	3.85	34.62	50.00	11.54	0.00
	VT, Su 04, Sec 1	14	14.29	7.14	78.57	0.00	0.00
	VT, Su 04, Sec 2	27	3.70	14.81	77.78	3.70	0.00
	Average		6.74	16.71	68.25	7.66	0.64

SD: Strongly Disagree, D: Disagree, A: Agree, SA: Strongly Agree, NR: No Response

One of the four sections did not successfully complete both versions of the pre and post learning assessment. For the other three sections, a two-tailed paired t-test was used to determine whether students displayed a significant change in average performance from pre to post assessment. As Table 4 suggests, a significant positive change in students' knowledge took place in each classroom, for the students' average score on the post test was higher than that which was witnessed on the pretest.

Table 4 Pre/post Learning Assessment

School	Number of Respondents	Pre-mean	Post-mean	p-value
CSM, Sp 04, Sec 1	20	12.84	19.69	.00*
VT, Su 04, Sec 1	10	12.88	17.58	.00*
VT, Su 04, Sec 2	25	13.08	16.33	.00*

V. Conclusions

The results of this initial study suggest that the in-class Engineering Cultures course is enabling students to advance toward the desired learning objectives for global problem solvers. By gaining significant knowledge about engineers in the world, students arguably become better able to understand and analyze the locations and contents of different perspectives involved in an engineering problem, especially in international contexts. By preparing to meet and work with engineers from different countries, students are gaining experience in understanding and analyzing the locations and contents of the perspectives they hold as engineers. Finally, by practicing an expanded method of engineering problem solving that grants importance to collaborative problem definition as a precursor to mathematical analysis, a significant majority of students at least claim that they will be better at working with people who define problems differently than they do.

Despite these positive results, much work remains to be done both in scaling up the course for use by others and in assessing student learning. To scale up the benefits of this course, the most obvious need is for new modules. Many students express interest in learning what counts as engineers and engineering knowledge in a wider range of countries. As described above, Downey and Lucena are currently developing new modules on engineers and engineering in Brazil, China, Colombia, Egypt, India, Korea, Mexico, and Taiwan.

To increase the number of practical experiences that students have in applying and assessing the expanded module of engineering problem solving in cases of collaborative problem definition, Downey and Lucena, working in conjunction with the Carnegie Foundation for the Advancement of Teaching, have initiated development of a corpus of case studies. Under the general label "Engineering Encounters," these case studies provide students with examples of engineers encountering and working with people who define problems differently than they do.

Finally, to increase the reach of the multimedia version of the course, Downey, Lucena, and programmers at Virginia Tech are currently involved in restructuring existing modules to transfer them from a CD-based to a web-based format, with the goal of making them available online.

In the assessment of student learning, Moskal is leading an effort to introduce an essay evaluation and accompanying rubric. For a course experience that seeks to expand the reasoning processes that engineers use in their work, a multiple-choice assessment can provide only limited evidence of significant change or improvement. Performance assessments, of which essays are a subset, are far better suited to the measurement of advanced skills, but unfortunately require a more extensive assessment process.[26, 27] Another ongoing effort is to compare evaluation of the effects of the learning modules in different formats. A survey has already been developed for this purpose. In the planning phase is a longitudinal study of long-term effects on student learning and identities, based on a survey of alumni five years after graduation. Finally, Downey and Lucena were recently named Boeing Company Senior Fellows in Engineering Education at the National Academy of Engineering, where their responsibilities include surveying and facilitating efforts to introduce problem definition into the pedagogy of the engineering sciences.

In sum, Engineering Cultures appears to have taken an important initial step toward preparing a broader range of students for global problem solving by helping them gain the self-understanding and analytical skills necessary to work effectively with people who define problems differently than they do. The concept and pedagogy are having positive effects. The main outstanding question concerns the extent to which this model can be scaled up for effective long-term use in the highly diversified arenas of engineering education.

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