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## **AC 2011-2129: DESIGN IN CONTEXT: WHERE DO THE ENGINEERS OF 2020 LEARN THIS SKILL?**

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## Design in Context: Where do the Engineers of 2020 Learn this Skill?

Increasingly, engineers must design engineering solutions that consider the contexts in which they are implemented. Examples like China's Three Gorges Dam, the development of next-generation fusion nuclear power, and the One Laptop per Child program illustrate the complexities and the stakes of current and future engineering projects. The National Academy of Engineering<sup>[1, 2]</sup> argues that the "Engineer of 2020" must not only be technically capable, but also be able to understand the contextual requirements and consequences of their work.

ABET program accreditation criteria<sup>[3]</sup> promote contextual engineering practice in several of its outcomes criteria [italics added]:

- (c) an ability to design a system, component, or process to meet desired needs *within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*
- (f) an understanding of *professional and ethical responsibility*
- (h) the broad education necessary *to understand the impact of engineering solutions in a global, economic, environmental, and societal context*
- (j) a *knowledge of contemporary issues.*

In this research, we define contextual competence as an engineer's ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions.

How can engineering programs best develop their students' ability to integrate context and design? This paper reports results from two national studies, funded by the National Science Foundation, which are exploring educational practices and outcomes at diverse institutions. *Prototype to Production: Processes and Conditions for Preparing the Engineer of 2020* (P2P) surveyed faculty members, students, alumni, program chairs, and associate deans of undergraduate education at 31 four-year U.S. engineering schools. A companion study, *Prototyping the Engineer of 2020: A 360-degree Study of Effective Education* (P360), developed detailed qualitative case studies of the engineering programs at six institutions empirically identified as leaders in producing graduates with at least some of the attributes specified by the National Academy's<sup>[1]</sup> report as import for the engineer of 2020.

### Literature Review

In describing the importance of integrating liberal and professional studies, Stark and Lowther<sup>[4]</sup> argued that "The capability to adopt multiple perspectives allows the graduate to comprehend the complex interdependence between the profession and society. An enlarged understanding of the world and the ability to make judgments in light of historical, social, economic scientific, and political realities is demanded of the professional as well as the citizen" (p. 23). In the two decades since that paper appeared, engineering educators and practitioners have increasingly come to embrace its principles. Bordogna, Fromm, and Ernst,<sup>[5]</sup> for example, argue that "contextual understanding capability" is an important component of engineering innovation, and this growing recognition is reflected in the emphasis reports by the National Academy of

Engineers,<sup>[1,2]</sup> the National Science Foundation,<sup>[6]</sup> and the National Research Council<sup>[7]</sup> place on contextual competence; in ABET's standards for engineering accreditation,<sup>[3]</sup> and in the growing body of research literature that explores students' contextual understanding and ways to incorporate contextual competence into the engineering curriculum.

Despite this increased national attention on contextual competence for engineers, Karnov, Hauser, Olsen, and Girardeau<sup>[8]</sup> found that engineering students were generally lacking in key aspects of this skill. Notwithstanding faculty reports of increased curricular emphasis on understanding the organizational, cultural, and environmental contexts and constraints of engineering practice, design, and research, a 2006 study reported that 48 percent of engineering employers found recent graduates to be inadequately prepared in these areas<sup>[9]</sup>. Efforts to remedy this deficiency have identified a number of approaches for integrating contextual competence into the curriculum. For example, students' immersion in a real-world community context is a key component of Purdue's NAE-recognized Engineering Projects in Community Service (EPICS)<sup>[10]</sup>, which involves students in long-term, real-world design projects. Similarly, evidence indicates that Smith College's TOYtech project<sup>[11]</sup>, in which students are tasked with designing toys that introduce children to the principles of technology, helps develop students' recognition of the importance of working well in teams and considering the societal impact of engineering practice.

The framework for conceptualizing contextual competence, and which underlies the P2P and P360 studies, rests on the proposition that, while solutions to engineering problems must first be technically sound (e.g., the bridge should not fall), solutions must also be practically feasible and desirable in the light of contextual constraints on the problem. When considering which of these constraints to address, engineers need to also determine the scope of the potential impacts of their solution. What kind of consequences will their solution have, for example, on the local, national, and/or global level? Some constraints may overlap, while others may supersede others (i.e., the local economic needs of the community may have to be reconciled with the solution's effect on the global environment). Thus, in studying contextual competence, we hypothesize two sets of "contextual" constraints: 1) a potential design solution's scope (local, national, and global), and 2) the potential constraints to which the solution may require attention (historical, social, economic, environmental, political, cultural, and ethical). In engineering, contextual competence will interact with the technical constraints and vice-versa. Further, we posit that a practitioner's contextual competence will influence two components of engineering problem-solving: 1) the process (e.g., being able to work with a diverse team), and 2) the solution.

## Methods

Quantitative Survey Methods. The *Prototype to Production* study (P2P) utilizes a cross-sectional survey design to assess engineering education programs and outcomes at 31 four-year U.S. institutions. The study team implemented a disproportional, stratified random sampling plan to provide a nationally representative sample of four-year engineering programs that offer two or more ABET-accredited programs in six engineering disciplines (biomedical/bioengineering, chemical, civil, electrical, industrial, and mechanical). All faculty members, program chairs, and sophomore, junior and senior students at participating institutions were invited to participate in web-based surveys. The student surveys solicited respondents'

background and demographic characteristics, self-assessments of selected learning outcomes, and future career plans. The survey also queried students' perceptions of classroom practices, out-of-class interactions with faculty, and extracurricular experiences. Chairs were asked questions about their curriculum, educational support programs, and promotion and tenure practices. Faculty members responded to questions (similar to those posed to chairs) about their programs. Faculty members also reported on the emphasis they give to the attributes specified in the National Academy's "E2020" report, the teaching practices they employ in a course they teach regularly, and on their level of agreement with the goals of the NAE report. Associate deans of undergraduate engineering responded to questions relating to their college/school's practices and policies as they align (or fail to align) with the recommendations of the NAE report.

The analyses reported in this paper used data from the student survey, supplemented with institutional characteristics obtained from the Integrated Postsecondary Education Data System (IPEDS), and academic minors/certificate data collected from the associate deans. Of the 32,737 students invited to participate in the survey, 5,249 (16%) responded. Such a low response rate (by historical standards), however, is not uncommon. Survey response rates have been in decline for several decades<sup>[12-15]</sup> and web-based surveys often have relatively low response rates<sup>[16,17]</sup>. Weights to adjust for response bias (at the campus level) and for differences in institutional response rates were applied, resulting in a nationally representative sample of students with respect to sex, race/ethnicity, class year, and engineering discipline. Missing student data were imputed using the Expectation-Maximization (EM) algorithm of the Statistical Package for the Social Sciences (SPSS) software (v.18). Twenty-nine associate deans for undergraduate education (or the equivalent) from the 31 participating institutions returned surveys.

Using the data collected from each group, the research team constructed scales that measure various curricular emphases, classroom and program experiences, and attitudes about education. Factor analytic techniques identified the number of latent constructs underlying sets of items in order to reduce the number of items necessary to adequately measure those constructs and to assess each factor's meaning.<sup>[18, 19]</sup> Principal axis factoring and direct oblimin oblique rotation with Kaiser normalization were used to identify factors. Principle axis factoring was chosen in order to establish the existence of the underlying theoretical constructs<sup>[18-20]</sup>. Oblimin oblique rotation was selected in the knowledge that any resulting factors may be correlated.<sup>[18]</sup> Examination of the factor correlation matrix to assess the level of correlation among the factors and the justification for their independent existence<sup>[21]</sup> indicated no serious problems.

Scales included only items with rotated factor loadings greater than .40. In the literature on factor analysis the minimum acceptable factor loading required to retain an item varies from approximately 0.4 to 0.7.<sup>[19, 21]</sup> Because an oblique rotation assumed that factors may be correlated, some items may load above .40 on multiple factors. In those instances, items were assigned to a factor based on the magnitude of the loading, the effect of keeping/discarding the item on the scale's internal consistency (alpha) reliability (see below), and on professional judgment. In some instances, items loading above .40 on more than one factor were discarded. Cronbach's alpha<sup>[22]</sup> is the most widely used measure of the internal consistency of a scale<sup>[23, 24]</sup>. Acceptable values for alpha vary from approximately 0.6 to over 0.9, with the most generally acceptable minimum value in social science research being either 0.7 or 0.8 – a standard met by

each of the scales used in this analysis<sup>[18, 23, 25, 26]</sup>. Factor scale scores<sup>[27]</sup> were formed by summing individuals' responses on the component items of a scale and then dividing by the number of items in the scale. Properties of the scales used in this analysis are given in Table 1.

**Table 1: Descriptive Statistics of Scale Variables.**

<b>DEPENDENT VARIABLE</b>	<b>Mean</b>	<b>Std. Dev.</b>
<b><i>Contextual Competence<sup>1</sup> (Alpha = .91)</i></b>		
Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem	3.33	0.97
Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	3.32	0.99
Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	3.19	1.08
Ability to recognize how different contexts can change a solution	3.45	0.96
<b>INDEPENDENT VARIABLES</b>		
<b><i>Program Emphases on Core Engineering Thinking<sup>2</sup> (Alpha = .85)</i></b>		
Generating and evaluating ideas about how to solve an engineering problem	3.80	0.89
Defining a design problem	3.78	0.93
Emerging engineering technologies	3.50	1.04
Creativity and innovation	3.72	1.03
How theories are used in engineering practice	3.72	1.00
<b><i>Program Emphases on Broad and Systems Perspectives<sup>2</sup> (Alpha = .84)</i></b>		
Understanding how non-engineering fields can help solve engineering problems	2.61	1.05
Applying knowledge from other fields to solve an engineering problem	2.86	1.06
Understanding how an engineering solution can be shaped by environ., cultural, econ., and other considerations	3.00	1.07
Systems thinking	3.23	1.07
<b><i>Program Emphases on Professional Skills<sup>2</sup> (Alpha = .88)</i></b>		
Leadership skills	3.33	1.09
Working effectively in teams	4.02	0.89
Professional skills (knowing codes and standards, being on time, meeting deadlines, etc.)	3.59	1.12
Written and oral communication skills	3.74	0.92
Project management skills (budgeting, monitoring progress, managing people, etc.)	3.32	1.06
<b><i>Program Emphases on Professional Values<sup>2</sup> (Alpha = .82)</i></b>		
Examining my beliefs and values and how they affect my ethical decisions	2.62	1.15
Ethical issues in engineering practice	2.99	1.12
The value of gender, racial/ethnic, or cultural diversity in engineering	2.54	1.15
Current workforce and economic trends (outsourcing)	3.15	1.10
The importance of life-long learning	3.67	1.02

<sup>1</sup> Question stem for items in scale from student survey: "Please rate your..."

<sup>2</sup> Question stem for items in scale from student survey: "How much have the courses you've taken in your engineering program emphasized..."

We adopted hierarchical (blocked) linear regression procedures for these analyses. With this technique, the researcher chooses the number and order of predictors inserted into the regression model. One may “block” or group the predictors based upon a theoretical construct and/or to examine differences between groups of variables. Given this study’s interest in which variables have the greatest effect on students’ contextual competence, we entered blocks of variables in the following order: 1) student background and institutional characteristics (as control variables), 2) academic minors, 3) co-curricular activities, and 4) curricular emphases. Interpretation of results focused on the amount of variance in the outcome variable explained by the addition of each block.

**Qualitative Case Study Methods.** The P360 study, designed as a companion study to the quantitative P2P study, used case study techniques to examine exemplary engineering education practices at six four-year U. S. institutions of higher education. Cases were selected based upon a) empirical identification (using data from another study) of the institutions “out-performing” others in producing graduates with at least some of the attributes of “the engineer of 2020;” b) number of engineering degrees awarded in selected fields with particular reference to women and/or underrepresented minority groups and c) input from a national advisory board. Teams of educational researchers, engineering faculty members, and doctoral research assistants conducted two visits (2-3 days for each visit) to each of the six sites. Extensive document reviews to gather information about each engineering program augmented the interviews of students, faculty, and administrators at each site. Research teams utilized both one-on-one interviews and focus group conversations with administrators, faculty and students, as well as (in some instances) direct observation of classes and activities to form a comprehensive, triangulated view of engineering education at each campus. Each team conducted iterative analysis of their cases, and then the full research project team met to conduct a cross-case analysis. The results summarized below represent a distillation of more extensive and more comprehensive discussions of the activities at each of the case study institutions.

## **Results**

**QUANTITATIVE FINDINGS.** Students from our sample self-reported their level of contextual competence based on questions reflecting their ability to connect contexts to design solutions. The contextual competence scale consisted of five variables reflecting students’ assessments of their skills in each of the following areas: “use what you know about different cultures, social values, or political systems in developing engineering solutions,” knowing “the contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem,” knowing “the connections between technological solutions and their implications for the society or groups they are intended to benefit,” and “recognize[ing] how different contexts can change a solution.” Students rated their ability on each item using a 1-5 metric, where 1 = “weak/none” and 5 = “excellent.” The aggregated four-item scale, with an internal reliability (alpha) of 0.91, was the criterion measure in our analyses.

Examination of the factors influencing students’ self-reported contextual competence provides insights into effective educational practices. We examined the influence of curricular emphases, the minors or certificates available to students, and students’ co-curricular activities. The full blocked linear regression model was significant ( $F_{(37, 5087)} = 49.239, p < .001$ ) and explained 26%

of the variance in students' contextual competence skills. Graphs of the residuals indicate that the model is appropriately specified and that residuals are not related to the other variables in the model. The results from each of the blocks are given in Table 2.

Several findings are noteworthy. Higher levels of contextual competence were related to 1) curricular emphases 2) being active in particular clubs and activities, 3) participating in service work, and 4) the existence of an entrepreneurship minor or certificate. Of these important factors, curricular emphases had the largest influence. Surprisingly, certain variables one might expect to be positively related to contextual competence were not. These included curricular emphasis on professional skills, activity in certain engineering-specific organizations, student design projects, study abroad, and the availability of design, leadership, or sustainability minors. We describe these results in detail below.

Engineering curricular emphasis on core engineering thinking and broad perspectives are both positively related to higher levels of contextual competence. Students enrolled at engineering schools that offer an entrepreneurship or other type of minor, but not design, leadership, or sustainability minors reported higher levels of contextual competence than their counterparts at institutions not offering an entrepreneurship minor. Several co-curricular experiences had a positive influence on contextual competence, including being active in an engineering-related non-professional organization related to women or minority students (such as NSBE or WISE) or other non-engineering clubs and activities, participating in humanitarian engineering projects (such as Engineers Without Borders) or other non-engineering service work. Interestingly, being active in engineering-specific organizations and participating in study abroad had no effect.

All of these results are statistically significant after controlling for students' precollege characteristics (including various demographic characteristics and high school achievement), institutional characteristics, and engineering major. Students attending doctoral-granting institutions (compared to baccalaureate institutions) and those enrolled at large/medium sized institutions (compared to small ones) report higher levels of contextual competence. Both findings suggest that institutional resources and mission may play a part. Majoring in General Engineering (compared those who have not declared a major) was positively related to contextual competence. None of the other majors significantly influenced the outcome. Men and students from historically underrepresented racial/ethnic groups reported higher contextual competence than did women and White students. Maternal education was positive and significant, but paternal education was not. Scores on the SAT Critical Reading Test were also positively and significantly related to level of contextual competence, although math scores were not. Finally, both age and class standing positively affected contextual competence. Because the two variables are correlated, but not highly (0.28), we included them both as controls, the statistical significance of class standing (independent of age) strongly suggest that students gain in their level of contextual competence as they proceed through their programs. Finally, transfer students reported higher levels of contextual competence than non-transfers, even after taking into account age and class standing.

**Table 2: Blocked Regression Results (n = 5,124)**

	<b>Block 1: Individual &amp; Institutional Controls</b>	<b>Block 2: Availability of Academic Minors</b>	<b>Block 3: Student Co- Curricular Activities</b>	<b>Block 4: Curricular Emphases</b>
	$\beta$	$\beta$	$\beta$	$\beta$
Research institution <sup>1</sup>	0.121 ***	0.145 ***	0.138 ***	0.100 **
Masters institution <sup>1</sup>	-0.023	0.012	0.015	0.009
Large institution <sup>2</sup>	-0.223 ***	-0.243 ***	-0.223 ***	-0.112 ***
Medium institution <sup>2</sup>	-0.171 ***	-0.156 ***	-0.144 ***	-0.060 *
Biomedical/bioengineering <sup>3</sup>	-0.003	-0.011	-0.015	-0.029
Chemical engineering <sup>3</sup>	-0.040	-0.054	-0.048	-0.035
Civil engineering <sup>3</sup>	0.013	-0.003	0.005	0.010
Electrical engineering	-0.045	-0.059	-0.041	-0.033
General engineering <sup>3</sup>	0.007	-0.015	0.043	0.155 ***
Industrial engineering <sup>3</sup>	0.054 *	0.042	0.043	0.008
Mechanical engineering <sup>3</sup>	-0.003	-0.022	0.002	0.001
Other engineering <sup>3</sup>	-0.015	0.003	0.016	0.015
Class standing	0.154 ***	0.149 ***	0.141 ***	0.131 ***
Age	0.046 **	0.056 **	0.063 ***	0.058 ***
Men	0.043 **	0.042 **	0.085 ***	0.069 ***
Underrepresented ethnicity	0.057 ***	0.060 ***	0.060 ***	0.043 **
Father's education	0.015	0.011	0.002	0.002
Mother's education	0.026	0.028	0.020	0.038 *
SAT critical reading score	0.017	0.023	0.021	0.066 **
SAT math score	0.080 ***	0.070 ***	0.079 ***	0.023
Transfer student	0.023	0.024	0.038 *	0.043 **



**Table 2: Continued**

Minor/certificate in entrepreneurship	0.060 **	0.058 **	0.042 *
Minor/certificate in design	-0.038 *	-0.036 *	-0.017
Minor/certificate in leadership	-0.030	-0.049 *	0.000
Minor/certificate in sustainability	-0.004	0.001	-0.006
Minor/certificate – other	0.072 ***	0.082 ***	0.066 ***
Active in an engineering club/ student chapter of a professional society		0.048 **	-0.006
Active in other engineering- related clubs or programs for women and/or minority students		0.089 ***	0.051 ***
Active in other clubs or activities (hobbies, civic or church orgs, student government, etc.)		0.061 ***	0.033 *
# of weeks at study abroad/ on an international, school- related tour		0.012	0.014
# of weeks on humanitarian engineering projects (Engineers Without Borders, etc.)		0.126 ***	0.140 ***
# of weeks doing non- engineering related community service or volunteer work		0.067 ***	0.056 ***
# of weeks on student design project(s)/competition(s) beyond class requirements		0.016	0.006
Core engineering thinking curricular emphasis			0.110 ***
Professional values curricular emphasis			-0.017
Professional skills curricular emphasis			0.020
Broad perspectives curricular emphasis			0.334 ***
<b>Adjusted R<sup>2</sup></b>	0.070 ***	0.075 ***	0.116 ***
<b>Change in R<sup>2</sup></b>		0.005 ***	0.043 ***

Notes.  $\beta$  = Beta, the standardized regression coefficient

1. Reference group is Bachelors' Institutions

2. Reference group is Small Institutions

3. Reference group is Undeclared Majors

\*p < .05 \*\*p < .01 \*\*\*p < .001

As noted earlier, the study is also interested in the collective effect of curricular emphases, co-curricular activities, and academic minors on levels of contextual competence, particularly when other potential influences (such as students' precollege characteristics and academic achievement) are accounted for. To estimate the independent effects of each block, the blocks (as noted previously) were entered in the following order: 1) individual and institutional characteristics (as control variables), 2) academic minors, 3) co-curricular activities, and 4) curricular emphases.

Analyses indicate that curricular emphases on core engineering thinking and on broad perspectives had the largest (and independent) effect on students' contextual competence (delta  $R^2 = .142$ ), almost twice as much as the control variables (adjusted  $R^2 = .074$ ). The effect of co-curricular activities was almost as large as that of the control variables (.043), whereas the change in R-square for academic minors was essentially zero (.005). The pattern was similar when the curricular and co-curricular blocks were reversed in their order of entry into the model (curricular = .156 and co-curricular = .028). This finding suggests that programmatic emphasis on both core and broad engineering-thinking (versus co-curricular engagement) may be among the primary venues for promoting students' contextual competence. One possible explanation for this finding might be that, in the curriculum, the importance of contextual competence is specific and explicit, and students may, consequently, give it more attention. On the other hand, engagement in co-curricular activities may offer only serendipitous exposure to this skill area.

QUALITATIVE FINDINGS. These quantitative findings align to some degree with the results from the P360 qualitative case studies. We first briefly describe unique findings from our six case study sites: Arizona State University, Harvey Mudd College, Howard University, Massachusetts Institute of Technology, The University of Michigan, and Virginia Tech. We then summarize across these cases in a brief cross-case analysis.

*Arizona State University* (Tempe and Polytechnic Campuses) is located near the large urban community of Phoenix and has benefited from connections with the many corporations that are located nearby. The University's (ASU) Fulton Schools of Engineering and particular engineering departments have deliberately enhanced connections with industrial partners. The Polytechnic campus also worked closely with industry partners as they designed their unique technical degree programs. Industry partners have provided many benefits for ASU and have demanded a particular focus on contextualizing engineering education. The multitude of potential employers in the vicinity also provides full- and part-time work for students. According to one faculty member:

The students are going to challenge you on the relevance of things. And [you better] be able to bring real world problems into the classroom. So I think that influences what we are as well. A large part of the student body does have work experiences before they graduate, and so that also brings a practical component to things.

Entrepreneurial initiatives within the Fulton Schools include an interdisciplinary curricular program, entitled Innovation Space, and the Entrepreneurial Program Office. In September 2004, the Fulton Schools created The Entrepreneurial Programs Office to coordinate curriculum

at both the undergraduate and graduate levels. The introductory course in entrepreneurship enrolls more than 100 students per year, and students may also find specialized entrepreneurial-focused classes within their home departments. Innovation Space is a smaller, specialized program in which a multidisciplinary team of students from business, design, and engineering work together for a year to develop a product prototype. The focus on entrepreneurship at ASU permeates the entire campus. The [Entrepreneurs at ASU](#) web page<sup>[28]</sup> provides a listing of over 50 potential courses and over 30 programs supporting entrepreneurship across the university.

Another major goal of the current university administration is to promote both diversity and global awareness. While appreciation of diversity and global awareness are often separate objectives on university campuses, ASU has integrated these two concepts into a singular focus. The demographics of ASU and the surrounding community may contribute to this unique vision of diversity awareness. The global emphasis is exemplified by the creation of the Office for Global Engagement within the Fulton Schools of Engineering. The mission of this office<sup>[28, 29]</sup> is to “structure an integrated and comprehensive portfolio of opportunities, programs, and partnerships that provide students and faculty the resources needed to become leaders in the global and professional arena”. Faculty members are also finding ways to integrate students’ hands-on global design experiences in the curriculum. Currently, several departments offer senior capstone experiences which include a global component. Mechanical/Aerospace, for example, has developed a senior capstone experience in which students work in multidisciplinary design teams with students in Singapore.

ASU has also, over many years, created a culture which values and promotes interdisciplinary ventures. The current university president actively supports new organizational structures which capitalize on the cutting-edge research made possible by crossing traditional disciplinary boundaries. In the Fulton Schools of Engineering, both Bioengineering and Sustainability are excellent examples of how interdisciplinary work is fostered. A new school focused on growth in urban areas combines faculty from Civil and Construction Engineering and offers both undergraduate and graduate degrees. “The School of Sustainable Engineering and the Built Environment (SSEBE) was created in July 2009 to provide a nexus within the Fulton Schools of Engineering for education and research addressing the critical infrastructure needs of our society in an environmentally sound manner . . .”<sup>[30]</sup>

The *ASU Polytechnic Campus* has developed specific general engineering degrees with practical engineering as one of the focal outcomes. The undergraduate curriculum is structured so that, at each level of the curriculum, students work on applied design problems that complement the more theoretical content. Many of these design projects are “contextualized” with an industry, sustainability, and/or global focus. From the beginning, the faculty and administrators at the Polytechnic campus have encouraged industry involvement in planning their unique curricular programs. One administrator described the process: “So, almost across the college and even across the campus, we engaged local industry to the extent that we could in different areas and brought them in to begin, in our view, kind of a partnership of how we develop different programs.”

These “practical” engineering experiences are integrated into theoretical concepts. For example, one faculty member described a project which involved multiple classes over a lengthy period of time. Students first became involved in the project during their first-year engineering core. “We also went and put up a wind instrumentation tower on the Hopi Nation, an Indian reservation. We are doing assessment for them right now as to whether or not they have enough wind to power their Nation with wind power. [Most] of our freshmen students, our first cohort, went up to install [the project]. We installed the tower, put an instrumentation pack on, get the data beamed back here, did analysis of the data and you are able to tie it to some degree into your courses.” Two years later, students were still retrieving data from this wind energy project to use within a statistics course.

**Harvey Mudd College** (HMC) fosters its engineering students’ contextual competence in through at least four mechanisms: 1) the College’s mission statement, 2) the formal curriculum, 3) the co-curriculum, and 4) activities with both curricular and co-curricular elements.

The College’s mission statement specifies that “Harvey Mudd College seeks to educate engineers, scientists, and mathematicians, well versed in all of these areas and in the humanities and the social sciences so that they may assume leadership in their fields *with a clear understanding of the impact of their work on society*” [italics added] <sup>[31]</sup>.

Interviews with HMC faculty, students, and staff make clear that *this* mission statement permeates the campus culture and provides the philosophical underpinnings for the curriculum, co-curricular activities, and administrative decision-making of the College. Faculty refer to it in discussions of curriculum review and reform; students allude to it in response to questions about their education and what they are learning; and it guides administrative resource planning and allocation. One wonders on how many other American campuses can faculty and students speak knowingly about their institution’s mission statement.

The mission is nowhere more evident than in the College’s “one-third, one-third, one-third” curriculum. Engineering (and all HMC) students complete a third of their coursework in “The Common Core” (courses in mathematics, physics, chemistry, and the humanities and social sciences). The goal is students’ acquisition of knowledge and techniques across disciplinary areas and increased understanding of the interdisciplinarity of technical work and its linkages with society. The second third of the curriculum is in the humanities and social sciences. Students pointed consistently to the value of their humanities and social science courses in developing an awareness of the importance of contextual competence, as well as the disposition and skills needed to think beyond the purely technical aspects in engineering design. The final third, the major field-specific portion, mixes theoretical principles and their intensive, hands-on application. Students also noted their introduction to contextual issues, ethics, and systems and life-cycle thinking both early and throughout their coursework.

In addition to the Common Core, engineering (and other HMC) students take “Clinic,” the signature curricular feature of the College’s engineering program. Clinic is a required, five-semester, experiential-learning capstone course that is essentially an adaptation of medical education’s clinical experience. Students work in teams on meaningful, industry-specified and

sponsored, engineering problems. Each clinic team must address the project's contextual aspects and their implications.

The “Integrated Experience” (IE), another key curricular element, is a required one-semester, interdisciplinary, team-taught course specifically intended to promote students’ understanding of the contextual and interdisciplinary dimensions of engineering. IE specifically investigates the interactions among science, technology, and society. In the view of two engineering faculty members, failing to consider the economic, social, and political context of a project would be “backwards-thinking.”

The mission is also apparent in the pedagogical approaches faculty members use to design and deliver the curriculum. Clinic is the most conspicuous example of “real-world,” hands-on experiential learning, but that approach to teaching threads through much of students’ other coursework. Students report faculty members’ frequent reliance on case studies drawn from personal experience in industry and on making connections between class topics and contextual and societal issues (e.g., the historical, cultural, economic, and societal impacts of China’s Three Gorges Dam; a discussion in a quantum mechanics and relativity course of the ethical, environmental, and societal implications of the development of nuclear energy and the atomic bomb).

HMC students also develop their contextual competence in several co-curricular venues. One program frequently cited in faculty and student interviews is the Nelson Distinguished Speaker Series, which brings to campus a wide range of nationally and internationally prominent individuals to speak on dimensions of a common topic. The 2010-2011 Series theme was “Powering the Planet – Sustainability.” Speakers explored potential solutions to the global climate and energy crisis – including a comprehensive look at the future of solar power. Speakers’ visits include meetings and in-depth discussions with students and faculty members. Students also participate in the student chapters of eight professional engineering and engineering education societies, although one faculty member noted that engineering at HMC relied less than other schools on the co-curriculum to develop students’ “soft” skills because the curriculum, as delivered, promotes those skills.

Efforts to stitch a seamless engineering education experience at HMC is visible in a growing number of joint curricular and co-curricular venues for developing engineering and scientific contextual competence and to internationalize the engineering curriculum and students’ experiences. A “Global Clinic” initiative augments the basic clinic model through projects involving Mudd engineering student teams in collaborative projects with student teams from institutions in Central and South American, Asia, and Europe. Global Clinic includes basic language instruction, cultural immersion during a three-week visit to the partnering country, and collaboration between teams throughout the year via audio/video conferencing and team reviews and presentations at the sponsor’s site. Other opportunities for students to gain international experience and develop cultural competence include institutional arrangements to support students’ practice/research-oriented study-abroad, nascent exchange programs with engineering schools in Japan and Turkey, and student-faculty research projects with international topical or locational dimensions to them.

**Howard University** is a federally-chartered, historically Black institution, located in Washington, D.C.. Howard University's approach to education stresses the creation of leadership within a community of people who were historically excluded from many facets of American life; this approach is referenced in Howard's motto, *Veritas et Utilitas*, "Truth and Service." Howard's core values are: excellence, leadership, service, and truth. Within this mission, the university prides itself on "building the nation through a culture of excellence in leadership, scholarship, and service"<sup>[32]</sup>.

Given Howard's history and mission, it is not surprising that leadership is stressed in coursework. In particular, this aspect of contextual competence is predominant even in the way faculty approach curricular design. For example, one faculty member states,

We continuously try to upgrade and update our curriculum. Basically it is driven by the university vision and then by the college vision, and then our vision. Howard University is about leaders. It is about building or adding to the students who come here, the characteristic of what a leader should be. And not only local, but global for the global community...so that is really, the general starting point for us in our curriculum.

The notion of leadership is related to the larger responsibility to society that a Howard student is expected to contribute. That is, Howard students, through their leadership, are expected to make a "bigger footprint" in the world. Among the engineering faculty, this responsibility and focus on leadership is translated into developing an acute awareness of the context of technological challenges.

They have to look at the project and approach the project not just from the technical perspective but they also have to research and discuss the social, economic, the environmental, and other issues that might be part of a really holistic approach to thinking about the project that they were focused on, so I make that a component of their course... and ethical issues, so that comes into play as well.

Contextual competence is a dominant theme among the Howard engineering faculty. For example one faculty stated:

I start off by asking the question, you know, 'Just because you can, should you?'...the leaning tower of Pisa I say 'Just because we can fix it, should we?'...what would happen to the poor politician who comes up with this bright idea, to the economics of the town you know all the money that's coming in now because tourist's are coming there to...so, whatever design they do for me from that point on they always have to incorporate what I call the 'social factors' and we're not just talking environmental. Usually you'll think you're talking about environmental when you say social but what about the history of the area? What about the politics of the area?

Furthermore, the engineering curriculum embeds a range of contextual issues into the academic experience for student as a mechanism to enable students to apply and reinforce their knowledge.

Mainly they will take stuff directly from class and apply it to this project. So last year I had them work on [how to] make people participate in recycling programs. This year, we were interacting through the computer science department to design human powered devices. So they come up with a bench warmer for sporting events. Someone sits there and pedals, warms up the other people on the bench. There was another person proposing a pitching machine for baseball. So instead of having an electrically powered automated pitching device, you have somebody pedaling, and it throws different pitches.

Contextual features are embedded into the learning experience for Howard students in order to not only prepare students for engineering practice, but also adhere to the overall mission of the institution. Context helps motivate students to apply their knowledge in ways that increase the likelihood they will have the “bigger footprint” and contribute in meaningful ways to society.

**Massachusetts Institute of Technology** (MIT) is located in Cambridge, Massachusetts and is known as a pre-eminent institution of research, teaching, and learning in the sciences and technology. As an institution founded to impart applied knowledge, MIT implements education from a laboratory approach, stressing hands-on experimentation. This approach is congruent with the Institute’s motto, *Mens et Manus* – “Mind and Hand.” The mission of MIT is to advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the nation and the world in the 21st century. MIT is dedicated to providing its students with an education that combines rigorous academic study and the excitement of discovery with the support and intellectual stimulation of a diverse campus community.

At MIT, contextual competence and design are often intertwined. Design provides the context for learning, and, at the same time, optimal design solutions must take into consideration the “bigger picture” and how contextual factors influence decision-making. The quotes below illustrate the interwoven and tightly connected MIT mindset of “doing stuff” to “follow one’s passion” in order to “make a difference” in the world--all features central to MIT’s approach and to contextual competence. Our analyses suggest that the MIT community sees the value of providing context as beneficial in the following five areas:

Providing context to help learn the subject matter. One faculty member noted that “When [students] solve engineering problems, they have to use the material that they’ve learned, and so, the problem becomes the context in which they learn it.” A participant in a student focus group explained that:

...at MIT they integrate everything. . . For instance, in some mechanical engineering classes, you will actually be working with the biological systems. Like how much torque do your muscles have to put onto your arm in order to lift up so much weight? . . . They teach how everything interacts, you know, how your bones . . . are basically a lattice structure that translate all the forces back into a different direction, and that gives you biological aspects, and then the chemistry aspect and everything is just like, you can talk to a chemistry major perfectly, and you’ll understand what the hell they are talking about.

Providing context to motivate and engage students. As one faculty member, put it: “By working on projects, you develop self-efficacy because it is by the application of knowledge that you can see what you’ve applied and is successful.” Another faculty member estimated that:

Ninety percent of the classes are active exercises . . . In other words, we are trying to learn a bunch of things, but we are not doing ‘make believe.’ . . . First of all, things that are [students’] ideas, but that are real products and have chance to have real impact, [are] hugely motivating and confidence building. . . we are trying to learn, but we are trying to give back, and that is incredibly motivating, actually, in confidence building. And the other key idea is active.

Providing context to develop professional skills. An MIT administrator stated:

Well, I think the project-based learning, which we’ve started to call ‘project-centered learning,’ . . . [has] started to infiltrate not just the first-year courses but also courses down the line and with again, the idea that you can teach both disciplinary knowledge and broader teamwork skills, communication skills, a whole variety of those kind of things being the context of the problem-based learning and then it models more effectively, more realistically, what goes on for a real engineer.

A student in one focus group, commenting on the link between context and other aspects of engineering, confessed:

I just choked ‘cause I didn’t look at [the topic] in depth enough. I didn’t take the time to really plot it in a way that would make sense to me, present the data to myself in a way that made sense. And so that taught me a lot about how an engineer communicates with people to get their point across really effectively. Instead of just trying to get people to do things, it also made me understand just how much responsibility we carry, as people who are building things that the rest of the world is going to use.

A faculty member also noted the connectedness of contextual competence and other engineering skills: “That you have active learning and that you have dual impact learning experiences so you combine together the learning of engineering science along with other personal and interpersonal skills, teamwork, communications, ethics and so forth.”

Providing context to technical solutions. Interviewees indicated clear recognition of the fact that one needs to take into account social, environmental, global, political, and business factors when considering technical solutions. A faculty member commented:

One of the things that we tried to do when we redid our curriculum . . . it seemed to us that the civil engineers who build things ought to understand more about their environmental implications, and the environmental engineers ought to understand sort of the context that was creating environmental problems, and you think, for example, that urban sprawl is an environmental problem, the environmental engineer needs to know enough about what motivates transportation system, or why do people prefer to drive cars than take subways or trains.



One faculty member explained an approach to opening a design course:

So when I start our version of the design course, one of the very first things we do is talk about the types of information that are required, and we put them into various boxes. There is a technical box, and there is a market box, and there is a profitability and sales box, and there is a safety, environment, community box. So we are trying to have that context – business to community, and things in between all the way through it. Necessarily you spend most of your time, though, worrying how to get a computer program to converge on some result. I hope by making it all the way through and asking about it at the beginning, asking in the middle, asking at the end, that that context is never too far from their mind.

Providing context to enable students to be an engineer. A departmental administrator explained that MIT tries to:

. . . give [students] a set of circumstances and the needs of some customer . . . and then say[s] ‘Define what this problem is so that person’s needs are met.’ That means [students] have got to wrestle with the context of what they are doing. The quality to which they were able to invite and compose a product that meets that, is a measure of their professionalism, and so then we judge it. . . . These are things that I’m looking for . . . when they graduate. The more that I can tell them about that, in that context, the more that I think they have a chance to go out to the first job and be a little bit ahead.

Putting students in the position of thinking like a “real” engineer makes the nuanced connection between contextual context and professionalism. That is, the primary point at MIT is not just to provide the context for how a particular theory applies to a given application, but rather that the context is the opportunity to develop the knowledge and skills to make decisions as an engineer or professional.

*The University of Michigan’s* emphasis on helping students develop their contextual competence is evident in three general areas: 1) a succession of far-sighted administrative and faculty leaders in the College of Engineering who recognize the importance of these skills; 2) the curriculum, particularly its emphasis on international experiences; and 3) the co-curriculum.

Interviews with engineering faculty members and administrators indicate that contextual competence as an important learning outcome emerged from bi-directional, administrative and faculty leadership. Over the past 30 years, the College named a series of engineering deans and associate deans who initiated or sustained administratively skillful “top-down” processes of curricular and cultural change. According to one long time veteran faculty member, “[T]hese guys had remarkable visions of not only what engineering was going to become, but how it interacted with other disciplines, [and] what its role in society should be.” Their ideas found fertile ground among a few faculty members who responded with “bottom-up” support and a willingness to suggest and lead new programmatic initiatives. The emerging reforms also included College-wide curricular revisions in the mid-to-late 1990s and again in the latter half of

this decade. These programs and processes drew support from, and played out against a backdrop of, similar philosophical and curricular reforms underway at the University and national levels.

Several curricular mechanisms at Michigan also contributed to the emergence of contextual competence as a valued educational outcome. *Curriculum 2000*, one of two significant curriculum review efforts of the past decade, recommended several structural and credit-related changes, including the “systemic treatment of non-program topics,” including communication, the humanities and social sciences, “and other important topics not generally treated in separate courses”.<sup>[33]</sup> Although the effects of a second, more recently completed review are not yet known, the report specifically notes that “Where once we hoped that our graduates would analyze thermodynamic efficiency, now our graduates must also help analyze the ethical and social impacts of their technologies”.<sup>[34]</sup>

Three new programs also emerged, each with contextual competence as a core element. Faculty and administrator interviewees noted that these programs grew in part from student interest in international experiences and engineering coursework relevant to national and international topics (e.g., alternative energies, the environment). The International Minor is a 16-20 credit-hour program requiring demonstration of foreign language skills; coursework on non-U.S. countries, intercultural communication, and global trends in engineering and business; and a practical international experience through study, work, or volunteer activities abroad. In the 15-credit Multidisciplinary Design Minor, students get hands-on experience designing, building, and testing technology systems working in interdisciplinary student teams. Its inaugural specialization is in Global Health Design, which emphasizes an interdisciplinary and comprehensive design process, experiential learning, intercultural training, and in-depth exposure to a specific global health theme. In the Program in Entrepreneurship, students learn business methods, skills in writing business plans, obtaining venture capital and other funding, intellectual property rights, and identifying market niches that may be domestic or international.

The curriculum emphasizes contextual competence early and late in students’ programs. One student reported that “we talked about [contextual competence and] social issues [in] one . . . [of] my very first engineering classes, ‘Engineering 100’ they call it here, and the title of the section was ‘Engineering Design in the Real World.’” Other sections of “Engine 100” also address issues extending beyond the technical, but the focus and emphasis appears to be variable. Some departments (e.g., Civil and Environmental Engineering) offer courses which specifically address contextual competence. Students also encounter contextual diversity issues and thinking in their senior capstone design courses. Interviews suggest, however, that the degree of capstone projects’ emphasis on contextual competence probably varies across departments and projects. The importance of thinking beyond the purely technical elements of a design project, however, arises frequently in interviews with both students and faculty members, though its emphasis appears to be given early and late in students’ programs.

Faculty and students speak frequently of the value of an international experience. According to one faculty member:

I can tell when our students have that experience. I can tell in class. . . . I actually don’t think it matters exactly what it is. You know, it could be that trip to China; it could also

be that it's a trip to Africa to help a village do [unintelligible] education system, or it could be doing an internship, help getting a company off the ground. . . . [I]f you get them back in class, you know they're different.

The College has a goal of providing in the next few years an international experience for half of all undergraduate engineering students (vs. about one-third currently). The College's Office of International Programs in Engineering (IPE) oversees a variety of study- and work-abroad programs (including the International Minor) specifically for engineering students. IPE also collaborates with the campus-wide International Center to expand the number and variety of international opportunities for engineering students.

The value Michigan's College of Engineering attaches to developing students' contextual competence is apparent in several co-curricular mechanisms, many carried out jointly with the Office of Undergraduate Education. The College's Office of Student Affairs consciously, and with demonstrable success, builds alliances between the formal curriculum and classrooms and other aspects of campus life. The Office includes the College's recruiting and admissions functions and student-support services, including an Advising Center (in which faculty are actively engaged), a Career Resources Center, and a Learning Center – all specifically for engineering students. The College relies heavily on the co-curriculum to promote students' "soft" skills. One faculty member noted that "We tend to rely on the . . . professional societies and student chapters." Faculty and administrators note the uncommonly close collaboration among the College's faculty and its academic and student affairs offices. According to one administrator:

This more expansive model of curricular integration also works for us . . . our dean . . . will be the first to say or to talk about all the learning that takes place outside the classroom. Entrepreneurship, multidisciplinary, and the international, they are all outside the classroom. So making it part of the engineering experience, I guess, is what we are trying to do.

The College and University also support a broad array of engineering-related student organizations (e.g., WISE, NSBE, SHPE SWE, IASTEE, and the Society of Global Engineers). The student-founded "BLUElab" (inspired by Engineers Without Borders) was frequently cited as a venue where students can develop their contextual awareness and skills. BLUElab is a student-run organization that coordinates project teams working at home and abroad trying to develop environmentally, culturally, and economically sustainable solutions. Asked about where students develop contextual competence, one student replied:

I think that has been a really big deal in the past year or so here. We have had a couple of groups like BLUElab, . . . IAESTE. . . . I think that those two are really great in giving engineering [students] a sense of responsibility and people are pretty aware that those exist. So even if you are not a member, you do know that you could be and those are fairly well supported by college. There is also the [IEP Office and the International Minor]. I felt especially in the past year [international experience] has just been emphasized more by the administration [and] that, you know, as a Michigan engineer you

are going to go out and make a difference responsibly and you will be working with engineers from all over the world and you will be able to do that.

*Virginia Polytechnic Institute and State University* (Virginia Tech) began as a land grant institution focusing on engineering and agriculture, with a strong military influence (in prior years employing retired military personnel as instructors). Consequently, there has always been an emphasis at Virginia Tech on the practical aspects of engineering. The initial focus on practical engineering seems to have created an institutional culture that naturally brings in real-world industrial applications. Since participating in the NSF-funded SUCCEED coalition in the 1990's, faculty at Virginia Tech have increasingly focused on incorporating design across the curriculum and on providing instruction in the "soft skills" needed by engineers, including communications; people skills, such as teamwork and cultural sensitivity; and organizational skills, such as project management. The faculty later added curricular coverage of ethical and safety issues, as well as the constraints of real economic pressures on engineering solutions. Recently, the faculty has sought ways to incorporate both sustainability and international experiences into their degree programs in authentic ways.

While Virginia Tech's engineering undergraduate program is typically ranked among the nation's top accredited programs, there is a definite sense that Virginia Tech considers itself different from peer institutions. One dean's office staff member shared a motto in the College that reveals the particular strength they see in their brand of engineering education: "Well, we have this motto of 'Hands on; Minds on.' MIT, they're thinkers. Virginia Tech, we're doers!" Throughout the College of Engineering, the focus on hands-on design was evident. Woven into this focus on design is the purposeful inclusion of discussions and experiences that reinforce the importance of context to all aspects of engineering design. While we found multiple examples of how contextual competence was incorporated into the engineering education experience at Virginia Tech, certain specific examples deserve particular attention.

Design experiences at Virginia Tech, for example, are frequently situated within real-world industrial contexts. Faculty members are frequently involved in industrial partnerships and applied research projects, and they bring these experiences into the curriculum. A professor in the Department of Mining and Minerals Engineering describes the influence of faculty partnerships with industry in the mining engineering program:

All of our faculty are very active in applied research. Most of us are more of the type that do work with companies out in the field, typically. So, because of that, we tend to bring in those kinds of problems into the classroom. So when we're looking at engineering in context, design, problem solving, these are typically design problems that we've encountered out in the field.

The facilities available at Virginia Tech also help to promote students' development of their contextual competence within the design experience. The College's leadership is particularly proud of the construction in 1998 of the Ware Lab, a dedicated facility for student design teams to get first-class support and to interact with each other. At any one time, over 400 students have the opportunity to be involved in design projects and competitions that have access to the Ware Lab facilities. Closely associated with these facilities is the strong tradition of competitive

design teams among Virginia Tech students. Faculty estimate that between one-quarter and one-third of all Virginia Tech undergraduates participate in a design team at some point in their undergraduate career. Of particular note, for many students, the design team participation can serve as their senior design capstone project.

Virginia Tech has been a leader among engineering colleges in advancing (indeed, requiring) the use of technology by all students. Since 1984, the College has required students to have their own desktop computers. For the past several years, incoming first-year students have been required to own a tablet PC. Virginia Tech's technology initiatives have in many ways allowed contextual competence to be seamlessly interwoven into the curriculum. For example, in one international initiative, the required tablet PC's were means by which students at Virginia Tech collaborated with team members working on a design project in France.

Virginia Tech's long tradition of a first-year engineering core has also incorporated contextual competence elements into the students' earliest introduction to engineering. The current iteration of the required first-year sequence purposefully introduces students to elements of contextual competence, albeit, perhaps, at somewhat superficial levels initially. One faculty member described the course as follows:

We tell the students on the first day, we talk about engineering of 2020 and why we are doing it. We let them in on the secrets. This is why this doesn't look like your father's engineering class. This is the new engineering class. It is looking at international issues. It is looking at sustainability. It is looking at things in a broader context.

These early discussions of the importance of context to engineering design continue at increasingly higher levels of sophistication throughout the sophomore and junior years, culminating in the senior design sequence. The capstone requirement has a very strong applied focus and, depending upon the department, often incorporates elements of ethics, economics, sustainability, international issues, or industrial applications, as well as contextual competence.

***Cross-case Analysis Summary.*** An impressive range and variety of venues for developing students' contextual competence is apparent across these six case study sites. In some instances, experiences designed to promote contextual competence are embedded in programs with already developed curricular strengths, most frequently in teaching design and problem-solving skills. On other campuses, the co-curriculum and various activities not directly linked to the formal curriculum carry a good deal of load in providing learning opportunities in this area. Frequently, dimensions of both the curriculum and co-curriculum are clearly involved. Despite the rich variety, however, it is possible to identify at least five clusters of factors that appear to be instrumental in developing contextual competence. These clusters overlap to some degree, and the overlap both across and within clusters makes developing any clear taxonomy a challenging task.

1. *Institutional Characteristics.* Our analyses across the six institutions point quickly to one or more (often intertwined) traits that are prominent drivers of the approaches each takes to providing engineering education in general and a particular focus on contextual competence. An institutional history (or founding) and the institution's mission are often – and meaningfully – the

foundation on which its curriculum and academic programs rest. Interviewees at Virginia Tech noted their roots as a land-grant university with a strong military past. Members of the Howard University faculty and staff pointed to the University's origins as a historically Black college and on the focus of its engineering programs on producing local, national, and global leaders within a community historically excluded from leadership positions. Harvey Mudd College faculty, staff, and students consistently cite the College's mission statement and its founders' determination to produce scientists and engineers who have strong technical skills, but also "a clear understanding of the impact of their work on society."

For other campuses, however, other factors were involved. Arizona State shares its Land-Grant Act origins with Virginia Tech, but ASU is also situated in the midst of one of the largest and most vibrant metropolitan regions in the southwest. Its location not only provides general direction to ASU's academic purpose, but also constitutes a significant curricular asset in the range and kinds of opportunities it affords its engineering students and faculty members. At the University of Michigan, a nearly 30-year succession of farsighted deans and associate deans, supported and assisted by equally farsighted individual faculty members, have provided the leadership and impetus for the emergence of contextual competence in the undergraduate engineering curriculum.

2. *The Curriculum.* Although this term is broad, and despite the varied forms it takes across these six institutions, the engineering curricula have several dimensions or foci in common. One is a strong (or emerging) emphasis on "global design" and the implications of that orientation for promoting students' contextual competence. On a couple of campuses, this emphasis has formal, programmatic standing (e.g., Michigan's International Minor in Engineering and Harvey Mudd College's Global Clinic). On each of the other campuses in this study, however, we found evidence that "globalization" is a focus, in some cases approached more informally than in others, being "themed" or "threaded" through the courses offered by departments. The evidence suggests, however, that the extent and emphasis of this approach is variable, both across institutions and within their programs and courses. And as some faculty members and program chairs noted, some engineering disciplines lend themselves more readily than others to developing contextual competence.

Whether and to what extent liberal arts education should be part of students' engineering education remains a matter of some discussion. The curricular emphasis on contextual competence on the campuses we studied was consistently evident, but often manifested in various forms of interdisciplinary efforts to integrate relevant content into both courses and programs. Harvey Mudd's "one-third, one-third, one-third" curriculum (as well as its Integrated Experience course requirement) is perhaps the most obvious and formal approach. More often, however, the matter appears to be relegated to individual instructors in individual courses who choose to include interdisciplinary, contextual competence-linked material.

Consistent with efforts to "globalize" their curricula, many of these campuses are aggressively expanding their capabilities to provide students some form of "international experience." Such experiences take many forms that vary widely in nature, purpose, and duration. The opportunities range from conventional study abroad opportunities to campuses with specific offices tasked with promoting international experiences specifically related to engineering (e.g., Arizona

State's Office for Global Engagement and Michigan's Office of International Programs in Engineering). In some instances, these experiences afford limited exposure to another country or culture (e.g., during mid-year or mid-semester breaks; summer internships abroad; exchange programs involving a limited number of weeks at a partner university abroad). In other cases, they entail semester-long experiences abroad in which students take (locally sanctioned) engineering and related coursework and have "emersion" experiences.

An emphasis (albeit varied) on entrepreneurship is another curricular mechanism found on most of the six campuses. Like efforts to promote international experiences, however, the nature and degree of emphasis on entrepreneurship is variable across institutions. The approaches vary from the highly informal and opportunistic (where a faculty member may learn of a particular opportunity and pass it along to students) to a formal program in entrepreneurship (e.g., at Arizona State and Michigan). Still, faculty members (with varying frequency) on most campuses linked "entrepreneurial" kinds of thinking to students' development of contextually competent thinking.

3. *The Co-Curriculum.* Each campus (probably like most engineering colleges/schools) provides co-curricular or other "out-of-class" opportunities for students to develop contextual competence. These typically include engineering design competitions, student chapters of the professional engineering societies, and other campus organizations and associations, frequently linked to national groups (e.g., WISE, NSBE, SHPE, and SWE). The extent to which the formal curriculum and co-curriculum are linked, however, varies across campuses. We found the clearest and most extensive links (often associated with specific facilities) at Virginia Tech (e.g., via the Ware Lab), Michigan (the BLUElab and the campus's extensive network of engineering clubs and international opportunities), and Arizona State's international and entrepreneurial initiatives.

4. *Linking Preparation to Professional Practice.* The attention given to developing contextual competence is many times related (based on our site visit interviews and observations) to the extent to which the process a campus uses prepares students for professional practice or for graduate school and research. As implied above, the professional practice orientation is most apparent at Arizona State (particularly on its Polytechnic Campus), Harvey Mudd, Howard, and Virginia Tech, but both MIT and the University of Michigan recognizes the importance of contextual competence and actively promote it, whether for research or practice.

5. *Links with Industry.* Perhaps the single-most common theme across all six institutions was the presence of industry links. In all instances, these links provided ideas for design projects that had clear implications and opportunities for the development of students' contextual competence. In the case of Arizona State, industry links also entailed industry or corporate expectations that the programs they support will promote contextual competence and that the graduates they hire will have contextual competence skills. In virtually all cases, these links also provide financial support (of varying amounts) for design projects (of varying duration). It seems clear to us that design projects provide the most obvious and ubiquitous formal curricular venues for promoting contextual competence skills.

## Discussion and Conclusions

The results of these two complementary studies provide some insight into how engineering programs can enhance their students' contextual competence.

Administrators and faculty may look to some of the following suggestions to guide their efforts at program and curricular reform:

- Review the “roots” of one’s institution as a roadmap for promoting one or another curricular thrust. The successful institutions described here capitalized on the past in moving into the future, by using the strengths inherent in their particular mission or institutional history. This may serve as a rallying point for faculty, as well as for attracting alumni and industrial support.
- Invite industry participation within the curriculum, particularly in creating authentic design experiences. Close working relationships with industry may also help faculty to recognize the “expectations” for contextual competence that industry employers are coming to expect from their new hires. Industry partnership may also directly motivate students to understand the contexts of their design solutions as they come to understand real-world constraints on engineering practice.
- The influence of the curriculum is paramount. In addition to emphasizing core engineering skills, promote interdisciplinary and general education components of the curriculum that can enhance students’ ability to wrestle with the global and local, social, ethical, political, economic and environmental impacts of engineering practices. Consider creating curricular and/or extracurricular programs that promote entrepreneurial skills and thinking.
- Examine institutional facilities and their role in supporting both curricular and co-curricular activities. Designated laboratory facilities where individual students or student groups can practice hands-on engineering design promote both not only design and problem-solving skills but also students’ abilities to recognize important contextual constraints of their projects.
- Support engineering student organizations, in particular those that focus on women and underrepresented groups and those which provide opportunities for humanitarian service projects. The co-curricular activities of students are a fertile area for providing experiences that underscore the complexities of today’s engineering practice.

Contextual competence can no longer be the goal of a few elite programs. It is, quite simply, a necessity in today’s increasingly interconnected society. The engineer of 2020 will view the implementation of problem solutions as the tossing of a small pebble into an otherwise calm lake and will see the ever expanding ripples caused by that one action as they proceed toward the opposite shore. This project explored the educational components that influence contextual competence as a learning outcome, bringing both large-scale empirical evidence and in-depth qualitative analysis to bear on the question in order to provide engineering educators with an expanded toolbox for developing this skill in students.



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