AC 2012-4880: MEASURING ENGINEERING STUDENTS' CONTEXTUAL COMPETENCE

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Measuring Engineering Students' Contextual Competence

Abstract

The belief that engineers cannot solve any problem without understanding its relevant contexts has been widely emphasized by both engineering academia and professions. Based on definitions-in-use and the literature, we defined 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. Data for this study come from an NSF-funded, nationally representative, multi-institution, cross-sectional study of engineering education in the U.S. Using responses from more than 5,000 engineering students in 31 four-year institutions during the 2009 spring and summer terms, we followed a standard psychometric scale development process to construct a measure of contextual competence. We report a set of evaluations (based on statistical procedures and professional judgment) of the content, construct, discriminant, and concurrent validity of the scale. Findings indicate that the four-item scale is conceptually clean, psychometrically sound, and internally consistent (Cronbach's alpha = .91). In short, the scale appears to be an appropriate, acceptably reliable, and parsimonious measure of the contextual competence of undergraduate engineering students.

Introduction

The practice of engineering requires more than solving for x. Engineers must be able to solve real-world engineering problems while also understanding the range of their relevant contexts. Projects such as the One Laptop per Child program, China's Three Gorges Dam, and new ultra skyscrapers illustrate the social, economic, environmental, political, and cultural challenges of today's engineering problems. The ABET program accreditation Criteria 3.c, 3.f, 3.h, and 3.j promote contextualization of engineering practice [1]. The ABET criteria mandate outcomes to ensure that engineering graduates cultivate the non-technical skills and understanding of context necessary to be responsible practicing professionals. More recently, the National Academy of Engineering (NAE) envisions the workplace of the near future as one of dynamic technological change requiring engineers to understand complex societal, cultural, global, and professional contexts [2, 3]. NAE reports that the "Engineers of 2020" must not only be technically capable, but also able to understand the contextual constraints and consequences of their work.

Despite the increased national attention on contextual competence, however, previous studies have found that engineering students generally lack key aspects of this skill [4]. The *Engineering Change* study asked a nationally representative sample of engineering students in six engineering fields to rate their abilities in nine key learning outcomes [5]. The study found that engineering seniors were least confident about their ability to understand the broader societal contexts that influenced engineering practice. Appreciation of the critical role of context in engineering design does not seem to increase over time. Atman et al.[6] found that junior and senior students had not gained a greater appreciation of the importance of the broad context of design problems compared to freshmen and sophomores. Examining more than students' simple appreciation of the importance of context, Morozov et al. [7] found that seniors reported the lowest levels of preparedness in understanding contemporary issues, business knowledge, and global and societal context. Employers corroborate these findings. The survey of 1,622

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employers conducted as part of the Engineering Change study found that 48% of responding employers judged new hires they had supervised as inadequately prepared to understand how a variety of contexts shape (and might be shaped by) engineering solutions [5].

Given that ABET, employers, and the National Academy have urged engineering education to place greater emphasis on developing students' understanding of the organizational, cultural, and environmental contexts and constraints of engineering practice, design, and research, we sought to develop a measure of "contextual competence" specifically for use in both local self-assessments and larger-scale studies of undergraduate engineering education. Tools developed by Atman and Nair [8] and Kilgore et al.[9] are now available to assess how much and how well students consider various aspects of *design-problem* contexts. These tools are particularly useful for assessing the progress of individual students who take a certain design task, and might be incorporated into capstone or design course. To examine the development of contextual competence of undergraduate engineers across programs and institutions, however, we sought to develop a measure that could be easily adopted in any engineering course or college and also be used with large numbers of students.

This paper describes the development of a measure of undergraduate engineering students' contextual competence. We summarize the findings of an extensive review of the literature, discuss the operationalization of the concept as a set of survey items, and present the final measure. We also provide evidence of the validity of the scale when used to measure students' contextual competence. Specifically, we focus on the scale's content, structural, discriminant, and concurrent validity by reporting results of the scale development process including a pilot test and factor analyses. We also evaluate the scale's ability to measure how contextual competence varies based on several student demographic backgrounds, such as gender, citizenship, class year, and academic discipline. We close with a discussion of future directions for research to improve the measure and advance the study of contextual competence of engineering undergraduates.

Definition of Contextual Competence

Competent professionals, Stark and Lowther [10] contend, "are characterized by their ability to link technical knowledge with appropriate values and attitudes when making complex judgments" (p. 1). Working with educators in eight undergraduate professional fields (including engineering), Stark and Lowther [10] found that all considered "contextual competence" to be an important educational outcome. Based on discussions with this network of faculty, they defined contextual competence as the graduate's "understanding of the societal context (environment) in which the profession is practiced" (p. 23). This competence includes the ability to "adopt multiple perspectives…to comprehend the complex interdependence between the profession and society" (p. 23). The consideration of the larger societal context prepares a professional "to make judgments in light of historical, social, economic, scientific, and political realities" (p. 23). This conceptualization of contextual competence is consistent with ABET's requirement in EC2000 Criteria 3.j that engineering graduates have the ability to understand the impact of engineering solutions in global and social contexts.

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Previous studies have examined particular aspects of contextual competence, for example, focusing on students' understandings of context in design tasks (e.g., Kilgore et al.[9]) or on understanding context at the global level [11]. In this section, we offer an overview of definitions of contextual competence and examine studies contextual competencies that informed the development of our measure.

Assuming that high-quality engineering design requires an understanding of how the resulting engineered artifact interacts with society, the natural environment, and other aspects of problem context, some research focuses on engineering students' context-oriented approaches to a design task. Kilgore et al.[12] refer to the consideration of global and societal implications of engineering design as "breadth of problem-scoping," and the "context" of engineering (p. 321). Their conceptualization of contextual competence focuses on broad thinking and problem-scoping activity, a critical part of the design process, in a specific engineering design task. While working through design tasks is one avenue to enhancing one's contextual competence, research suggests that other activities also influence the development of student's contextual competence. Through analyzing six institutions with exemplary engineering programs in a case study format, Lattuca et al. found that these campuses offer a variety of curricular experiences (first-year and capstone design courses) as well as co-curricular opportunities (e.g., internships, student clubs, international experiences, entrepreneurial opportunities, and faculty-linked research opportunities) intended to develop undergraduate engineering students' contextual competence [13]. In a companion study utilizing a large dataset of more than 5,000 engineering undergraduate students, Palmer et al.[14] also found that engineering students who reported being active in clubs and activities, participating in service work, and having access to an entrepreneurship minor or certificate also reported higher levels of contextual competence. Of the positive influences on contextual competence, however, curricular emphases had the largest influence. Although contextual competence may be defined in the context of design-specific tasks, we have conceptualized it more broadly.

As the engineering workplace continues to diversify and design solutions are more frequently applicable to global problems, engineers might also consider the scope of influence of their solution (e.g., local or global). Some researchers define understanding context on the global level based on geographic boundaries, distinguishing, for example, between local and global teamwork and networks[15, 16]. The global network is thus defined as a connection with geographically dispersed design teams. Others define global competency as working effectively with people who define problems differently due to cultural differences rather than regional distinctions[17]. These studies emphasize students' competence at the global level, however, Sinha [18] argued that the engineers of today must also be able to adapt to the culture of the location where their project resides and must be concerned with local problems. To solve both global and local problems, engineers consider constraints and consequences that may not only overlap in terms of scope, but also may take precedence over others (e.g., are the local economic needs of the community more urgent than sustainability on the global level?).

Our definition of contextual competence is intentionally broad. We acknowledge that many of the judgments practicing engineers must make related to design tasks, but the scope of professional decision making extends beyond the design task. There are many potential points of interaction between the profession and the society in which the profession is practiced.

Contextual competence thus includes the ability to consider thoroughly the potential constraints and consequences of alternative solutions to many kinds of engineering and engineering-related problems (for example, the problem of how to manage a work team, to work effectively with a client, or to mentor a new colleague). This enlarged conceptualization suggests that students must have a breadth of perspective that enables them to consider relevant historical, social, economic, environmental, political, cultural, and ethical facets of professional practice.

Conceptualization of Contextual Competence

Solutions to engineering problems always must be technically sound, which is why undergraduate engineering programs are heavily loaded with technical courses (e.g., thermodynamics, physics). A technically correct solution, however, is not necessarily one that will be feasible or desirable in a specific context. For example, engineers who seek to increase the processing speed of a chip must also understand how certain design solutions affect the life-cycle of the chip, as well as consider the potential environmental impact of its replacement. Unfortunately, students rarely develop non-technical knowledge, such as learning about contemporary societal issues or ethics, from technical engineering courses [19, 20]. Our study focuses, in part, on the development of this ability which is widely acknowledged as critical but, arguably, underemphasized in undergraduate engineering programs. We use the term contextual competence to refer to an individual's awareness of both the technical dimensions of an engineering problem, as well as the non-engineering factors that mediate the development of optimal engineering design solutions. It is the ability to evaluate alternative solutions that require balancing competing needs and judging the competing technical and societal assets and liabilities of alternative solutions.

Contextual competence as it is typically discussed in engineering incorporates many different types of contexts, such as societal, cultural, historical, political, or economic. Some studies focus on only one of these dimensions. Because engineers always work to have a positive impact on our society [21], programs try to embed attention to societal and cultural aspects of contexts in engineering curricula. Mikic and Grasso [22] found that using socially relevant design projects throughout the curriculum achieved course objectives of learning the importance of working in teams and greater consideration of the societal impact of engineering practice. Bielefeldt [11] found that when students function on multidisciplinary teams and are comfortable interacting with clients from diverse backgrounds, they are better able to recognize the importance of cultural differences in the definitions of and solutions to engineering problems.

When engineers consider the contexts of problems, economic factors cannot be ignored either. Kilgore et al. [9] assessed engineering students' consideration of contextual factors such as the natural environment, specific groups of users or stakeholders, and economic impacts. In that project, the contextual influences on design problems (e.g., the Midwest experienced massive flooding of the Mississippi River) contain two dimensions: 1) narrowly defined context factors, such as costs, budget, and technical specifications, and 2) broad context factors, such as natural/environmental or social context issues relevant to the design problem. Contextual factors can also be the source of ethical questions, but the consideration of context does not guarantee that engineers make ethical choices. For example, engineers may consider the economic consequences of their solutions, but may also still make an unethical decision. Using site visits

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in undergraduate mechanical and electrical engineering programs at seven institutions, Colby and Sullivan [23] found that professional codes of ethics in engineering are a useful framework for student learning in the area of ethics and professional responsibility [23, 24].

While some research focuses on examining students' knowledge of engineering contexts relevant to problems, other research pays more attention to exploring students' values, attitudes, and beliefs as engineers who care about contexts. Focusing on environmental problems, Hyde and Karney noted the tension between the two different environmental education goals of knowing and caring for the environment [25]. Over time, environmental learning in higher education has moved from "knowing" to "caring, but Hyde and Karney argued that engineering has remained focused on "knowing" because that aspect has been perceived as the niche of technological education [25]. Faced with a demand for engineers who are environmentally sensitive, the "caring" aspect of environmental learning is increasing in importance [25]. To change engineering students' mindsets from technologically-oriented to contextually approaches, Kastenberg et al. suggest that engineering students need to possess the goals of embodying the values of a new integrated culture of engineering, as well as enhancing self-awareness of contemporary issues [20]. Manion also suggested that engineering faculty members need not only to increase students' contextual awareness but also to complement this awareness by assisting them to transform their attitudes, values, and philosophies to match the engineer of the 21st century [26]. Developing the students' attitude of having an open mind to understanding broad contexts may be an important key to seeking to understand the customs, values, beliefs, and behavioral standards of different groups, societies, and countries [27].

Relationships between Contextual Competence and Demographic Characteristics

Regardless of how it is defined or measured, engineering students' contextual competence appears to be related to their demographic characteristics, such as class year, gender, and citizenship. Kilgore et al. found that there was a small gain between first-year and senior students in terms of understanding context in their design task (although the gain was the smallest of all of the student learning outcomes in the study) [12]. In a study of German secondary physics students, Haüssler and Hoffmann found that women were more interested in topics that related to their lives and society than were men [28]. Brotman and Moore showed evidence throughout the literature that women place a larger importance on conceptual relationships and connections than men, focusing on larger, broader pictures rather than individual details [29]. .Kilgore et al. also found that women engineering students appreciate the importance of context in design processes [12]. Their self-confidence considering contexts may be lower than men, however, because women in STEM fields tend to lose that confidence upon matriculation, despite entering college with achievement and confidence levels similar to men, potentially because of isolationism feelings when they are underrepresented in certain disciplines [30] [31] . Since contextual competence is related to working with people from different cultures and countries [32], students' international status, use of English as a second language or foreign language proficiency may be related to their contextual competence. Mayhew et al. found that participants who behaved in tolerant ways toward people from other cultures learned more about their own culture by trying to see it as it is seen by people from different cultures [32]. International students who can speak a language other than English and who have multiple

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cultural backgrounds, may have higher contextual competence than U.S. students who have not had many (if any) experience with other national cultures, societies, or political systems.

In addition to engineering students' personal demographics, their contextual competence appears to vary based on their academic major. The literature suggests that academic programs' curricular emphases and faculty members' engagement in teaching -- which influence students' experiences and learning [33] -- vary across engineering disciplines. Lattuca, Terenzini, Harper, and Yin found that engineering faculty members varied in their perceptions of changing curricular and pedagogical requirements, and these differences were consistent with the patterns suggest by Holland's typology-based disciplinary environments [34]. In terms of changing curricular requirements for contextual learning, Enterprising (industrial engineering) and Investigative (chemical and civil engineering) programs reported greater increases than Realistic (electrical and mechanical engineering) programs, in their emphasis on professional and ethical responsibilities, and the societal and global implications of engineering solutions, in their courses. Drake et al. also suggest that engineering ethics must be incorporated into specific disciplinary context, to improve a student's moral reasoning and sensitivity to ethical issues [35]. Since faculty members' reports of curricular emphases on contextual competence vary by discipline, we would expect to see those disciplinary differences in students' contextual competence outcomes. Palmer et al. [14] found that the contextual competence of students in general engineering was higher than that of students with undeclared majors, even after controlling for curricular emphases on certain topics. Finding the same relationships in the current study would provide evidence that the scale has validity for measuring contextual competence.

Data and Methods

The contextual competence measure was developed as part of a study, entitled *Prototype to Production: Conditions and Processes for Educating the Engineer of 2020* (hereafter referred to as "P2P"), funded by the National Science Foundation (NSF Grant EEC-00506080). The overall goal of the P2P study was to examine the curricular, instructional, cultural, and organizational features that support high-quality learning in engineering programs. The study design consolidates data from several constituent groups to provide a comprehensive perspective of undergraduate engineering education: engineering faculty members, program chairs and associate deans for undergraduate education, as well as engineering undergraduates and alumni, from the same engineering programs and schools. Surveys developed for engineering faculty, administrators, and associate deans focused on school- and program-level policies and practices related to undergraduate engineering education, as well as on the curricular and instructional emphases in undergraduate programs and courses. Engineering undergraduates (sophomores through super-seniors) and engineering alumni (surveyed three years after they earned their baccalaureate degrees) provided information on the nature of students' educational experiences. The contextual competence measure was developed for use in the engineering student and alumni surveys.

Survey design process.

A team of education and engineering researchers collaborated on the development of the survey-based instruments for engineering students, faculty, and administrators during a rigorous, two-year process. The team first conducted an extensive literature review on key topics related to contextual competence in engineering, but also in fields outside engineering. In addition to reviewing this literature and developing a bank of relevant items from existing studies, the team spent a year conducting interviews and focus groups with engineering administrators, faculty members, students, and alumni at five campuses to understand how engineering programs sought to develop students' contextual competence through the curriculum and co-curriculum: Penn State - University Park, Penn State - Altoona, City College of New York, Borough of Manhattan Community College, and Hostos Community College.   Faculty, administrators and students at the two-year campuses were included in the study because of its interest in different sectors of the engineering education pipeline.

Interview and focus group transcripts were fully transcribed and distributed to the research team, which then meet weekly for almost a year to discuss the findings. The goal of these weekly meetings was to draft potential survey items for the instruments for the five populations (faculty, administrators, associate deans, undergraduates and alumni of four-year institutions, and pre-engineering students in community colleges). As part of this item-development process, the team developed sets of items for use in examining the focal outcomes of the study (one of which was contextual competence). The research group included faculty members who had extensive experience with quantitative social science studies of college student experiences and outcomes, an engineering faculty member, and doctoral students who had worked in colleges of engineering, had previous engineering experience in both college and industry, or were graduate engineering students.

Once drafted, the survey instruments were reviewed by engineering faculty and administrators at Penn State who met in focus groups with the members of the team to revise and refine the individual items.   The faculty, four-year student, and two-year college student instruments were then pilot tested as described in a subsequent section. After the pilot test, the research team again met with focus groups of engineering faculty members and administrators from Penn State - University Park to review the final student survey before administering the surveys to the full P2P sample.

The initial five questions included in the contextual competence scale are listed below. Respondents were asked to "indicate your knowledge/ability in each area using the scale where 1=Little or none; 2=Some; 3=Adequate; 4=High; 5=Very high." The final scale items and their psychometric properties are in Table 2 in the "Results" section.

1. Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem
2. Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit
3. Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions
4. Ability to recognize how different contexts can change a solution

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5. *Ability to maintain an open mind while seeking to understand the customs, values, beliefs, and behavioral standards of different groups, societies, or countries* (Note, this item was removed from the scale based on the pilot test analysis.)

P2P sample and data treatment

The P2P study utilized a cross-sectional survey design to assess engineering education at 31 four-year U.S. institutions. A disproportional, stratified random sampling plan was used to produce 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). Because the P2P study was also designed to inform analyses of a closely related set of six case studies (one of which offered only a baccalaureate-level general engineering program), the sample was also refined to include three institutions that offered a general engineering program in addition to their discipline-based programs. All faculty members, program chairs, and sophomore, junior, and senior students at the 31 institutions were invited to participate in web-based surveys. The student survey included questions regarding respondents' background and demographic characteristics, future career plans, perceptions of classroom practices, out-of-class interactions with faculty, and extracurricular experiences. The survey also queried students' self-assessments of selected learning outcomes, including contextual competency. [Copies of these instruments are available at: http://www.ed.psu.edu/educ/e2020/surveys-1/E20204yrStudentSurvey.pdf.]

The survey instrument was first pilot tested on a sample of 478 engineering students from two four-year public institutions in the Mid-Atlantic region of the United States. The final version of the survey was administered to 32,737 engineering students, 5,249 (16%) of who responded (Table 1 summarizes the demographic characteristics of pilot test and full-sample respondents). Such a relatively low response rate (by current standards), however, is not uncommon. Survey response rates have been in decline for several decades [36-39], and web-based surveys often have relatively low response rates [40, 41]. Weights were created to adjust for response bias (at the campus level) with respect to sex, race/ethnicity, class year, and engineering discipline, as well as for differences in institutional response rates. These procedures resulted in a nationally representative sample of students attending the 31 participating institutions. However, weights were not applied to the dataset for the factor analysis (see below) because doing so would have created scale variables that would become double weighted when used in subsequent analysis where weights were applied. Missing student data due to non-response were imputed using the Expectation-Maximization (EM) algorithm of the Statistical Package for the Social Sciences (SPSS) software (v.18).

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Table 1. Pilot and Final Dataset Key Demographics

	Pilot Data (n=478)		Full Sample Data (n=5,249)	
	Count	Percent	Count	Percent
Major				
Biomedical/Bioengineering	34	7.1	457	8.7
Chemical Engineering	57	11.9	756	14.4
Civil Engineering	86	18.0	908	17.3
Electrical Engineering	59	12.3	919	17.5
Industrial Engineering	50	10.5	226	4.3
Mechanical Engineering	144	30.1	1,527	29.1
General Engineering/Engineering Science	5	1.0	425	8.1
Other/Undeclared	43	9.0	--	--
Gender				
Women	376	78.7	1,013	19.3
Men	102	21.3	4,236	80.7
Race/Ethnicity				
African American	8	1.7	310	5.9
Asian or Pacific Islander	42	8.8	646	12.3
Caucasian	398	83.3	3,186	60.7
Hispanic/Latino/a	15	3.1	320	6.1
American Indian/Native American	3	0.6	31	0.6
Other	12	2.5	378	7.2
Foreign National	14	2.9	373	7.1

Note: Percentages may not total to 100% due to item non-response.

Data analyses

The research team applied principle components analysis to the pilot study sample and factor analysis techniques to the full national sample to evaluate the psychometric characteristics of the survey instruments and the conceptual structure of each outcome scale, including contextual competence. Each scale included in the pilot study survey (initially developed *a priori*) was separately examined using principal components analysis to determine how strongly each of the items related to each other and to reduce the number of items necessary to adequately measure the construct [42, 43]. All of the outcome scales in the full sample were analyzed at once using principle axis factoring in order to verify the existence of the theoretical constructs underlying the scales [42-44].

For both analyses factors were extracted based on the Kaiser criterion [45] and a review of the scree plots [46], a direct oblimin oblique rotation was used to more clearly distinguish the factor structure [42-44], and items were included in a factor if the item's factor loading was at least 0.4, the minimum acceptable loading according to the literature on factor analysis [43, 47]. Cronbach's alpha [48], which reflects the extent to which scale items are closely related to one another, is the most widely used measure of the internal consistency of a scale [49, 50]. 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 0.7 [42, 49, 51, 52]. Alpha was

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considered when determining if individual items with relatively weaker factor loadings should be retained to maintain high internal consistency, or dropped to make the scale more parsimonious while also remaining reliable. In cases where an item loaded above .40 on multiple factors, the item was assigned to a factor based on the magnitude of the loadings, the effect of keeping/discarding the item on reliability (alpha), and professional judgment. Finally, the factor correlation matrix was examined to determine if any factors are so highly correlated (for example, > .85 [43]) that they may actually be measuring the same construct [47].

These factor analysis techniques provided evidence of structural and discriminant validity. In addition, we gathered evidence of concurrent validity by examining the capacity of the contextual competence scale to distinguish between groups of students, as would be expected based on theory or prior empirical evidence [53, 54]. In order to determine how the scale scores vary between the groups identified in the literature review we conducted a linear regression analysis of contextual competence, regressing the scale scores on gender, citizenship, class standing, and academic major. This technique allowed us to determine the relationship between levels of contextual competence and each of the selected demographic variables while simultaneously controlling for the influence of the other variables (and prior achievement via SAT score, which was used to clarify the relationship with gender since research indicates women rate their own confidence lower than men, regardless of their actual ability).

Results

"Validity refers to the degree to which evidence and theory support the interpretation of test scores entailed by proposed uses of tests" [55]. Evaluating validity requires developing sound scientific evidence for judging the interpretability of the instrument's results and subsequent decision-making based on this evidence [55, 56]. There are a variety of types of evidence that may be used to validate an instrument, depending on the proposed interpretation and use of the resulting scale scores [55, 57]. For this paper we focused on aspects of validity that were addressed through the scale development process. The results are organized based on the type of validity examined: a) content validity, b) structural or construct validity, c) discriminant validity, and d) concurrent or criterion-related validity.

Content Validity

"Content validity" refers to the extent to which a scale's items, in the aggregate, constitute a representative sample of the topic's content domain: Do the items, indeed, reflect what has been defined as "contextual competence"? [53, 54] To answer the question, content experts are consulted and their professional judgment is taken to reflect the degree of "content validity." As noted earlier, the survey development team included professionals with expertise in social science research, higher education, engineering education, and engineering practice. These team members crafted and selected survey items that, in their judgment, reflected the meaning and content of "contextual competence." After creating a draft of the survey, the team conducted several focus groups with Penn State engineering faculty members and program chairs representing multiple academic departments and a range of academic and professional experience. As a result of these meetings, and in an effort to be parsimonious, the contextual competence items were reduced from nine to the five group members concluded adequately

reflected the construct of contextual competence. Those five items were used for the pilot survey.

Structural/Construct Validity

"Structural validity" is a type of "construct validity" in that it refers to the extent to which a set of items or a measure reflects the underlying "construct," in this case, "contextual competence" [53]. Evaluation of a scale's construct validity typically entails examining the correlations among the scale items and applying statistical procedures that will reflect whether the items, in the aggregate, constitute a common, underlying factor (the construct). In order to examine the internal structure of the construct of contextual competence, the research team applied principle components and factor analysis techniques to both the pilot test data and the full four-year student dataset, as described above. The results from the pilot test show that the items in the contextual competence scale do, indeed, define a unidimensional construct, one that, given this set of items, is not divisible into separate knowledge and ability domains. The analysis also provided evidence that allowed the team to reduce the length of the scale without lowering the reliability by removing one item. The factor analysis based on the final dataset shows that all four remaining items load strongly on this factor, and that the resulting scale has high internal consistency reliability (Table 2).

Table 2. Final Contextual Competence Scale

Contextual Competence (Alpha = .91)	Factor Loading	Mean	Std. Dev.
Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem	.83	3.35	1.03
Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	.85	3.35	1.02
Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	.86	3.24	1.13
Ability to recognize how different contexts can change a solution	.78	3.54	0.99

Discriminant Validity

"Discriminant Validity" is a form of "criterion-related validity" which indicates that the measure does not strongly relate to other constructs that are theoretically different [54, 57]. The factor analysis of the full dataset included all of the student outcome items on the four-year student survey. The resulting factor structure clearly distinguished between contextual competence and other areas of student competence that may be related but distinctly different, including design skills, interdisciplinary skills, recognizing disciplinary perspectives, reflective behavior, communication skills, and teamwork skills. The use of an oblique rotation allowed for the factors to correlate with each other, but the highest correlation coefficient associated with contextual competence was .65, with all of the other correlations being below .60. There is no

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generally accepted cut-off value for strength of the correlation in this situation, though .85 has been given as an example by one source [43] The fact that neither the contextual competence factor nor its individual items correlated highly with any of the other constructs provides some evidence of discriminant validity.

Concurrent Validity

"Concurrent validity" is another type of criterion-related validity that pertains to whether the scale score correlates to scores on other variables as would be expected based on the theory underlying the construct [53, 54].   The goal is to have a measure that is able to identify differences among individuals or groups that might be reasonably expected to differ on the trait reflected in the measure. In order to assess the relations identified in our literature review, we conducted a linear regression analysis of contextual competence, regressing scale scores on gender, citizenship, class standing, and academic major. This technique allowed us to determine the relationship between level of contextual competence and each of the selected demographic variables while simultaneously controlling for the influence of the other variables (as well as achievement measured by SAT score, which was added to clarify the relationship with gender). The full linear regression model was significant ($F_{(11, 5069)} = 17.577$, $p < .001$). Graphs of the residuals indicate that the model is appropriately specified and that residuals are not related to the other variables in the model.

As expected, we found that Juniors and Seniors scored higher on contextual competence than sophomores (Table 3).   Also, men reported higher levels of contextual competence than women. As discussed in the literature review, other research has indicated that women rate their own abilities lower than do men, regardless of their actual ability [30] [31]. In other analyses conducted by our research team, men's self-reported design skills were higher than those of women [58].

Table 3. Results of regression exploring relationships between contextual competence and gender, citizenship, SAT composite score, class year, and major (n=5,182)

Variables	β	
Men	.031	*
Foreign national students	.007	
Juniors[1]	.066	***
Seniors[1]	.169	***
SAT composite score	.093	***
Biomedical/bioengineering[2]	.007	
Chemical engineering[2]	-.022	
Civil engineering[2]	.018	
Electrical engineering[2]	-.031	*
General engineering[2]	.048	**
Industrial engineering[2]	.070	***
Adjusted R^2 = 0.035 ***		

Notes. β = Beta, the standardized regression coefficient
1. Reference group is sophomore students
2. Reference group is Mechanical Engineering; disciplines were dummy coded, where 1 = in a particular major and 0 = not in that major.
*p < .05 **p < .01 ***p < .001

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In addition, foreign nationals in this study did not score differently from U.S. citizens. This finding may be due to the fact that, in our sample, both of these populations are diverse groups with a complex set of characteristics. We may be unable to tap into the specific factors that distinguish high contextual competence foreign nationals from U.S. students [32]. Finally, no differences in contextual competence were seen among most of the engineering programs. Students in General Engineering and Industrial Engineering (IE), however, did report higher levels of contextual competence than did their peers in our reference group of Mechanical Engineering (ME), while students in Electrical Engineering (EE) scored lower. These findings are consistent with previous research indicating that Enterprising programs (like IE) were showing greater increases in curricular emphases on the societal and global implications of engineering solutions, more so than Realistic programs (including ME and EE) [34].

The findings related to gender, class standing, and academic majors are consistent with theory and previous research. They provide evidence of concurrent validity. However, the lack of a significant finding for foreign nationals indicates that the scale could be modified to better measure their contextual competence.

Limitations

As with any piece of research, this study is limited in several ways. First, one can define "contextual competence" in ways that include some of the sub-dimensions of the construct, and those dimensions can be measured separately. For example, one might develop a measure of contextual competence that reflects specific and discrete contexts, such as environmental, cultural, and social, as well as, say, the cultural diversity of a project team's members. Because of the complexity of the larger study of which the contextual competence scale was but a part, however, the need for instrument parsimony in order to optimize response rates imposed strict limitations on the number of items that could be used and, consequently, on the depth at which the complexity of any outcome (including contextual competence) could be explored. Thus, the scale described here must be understood as a global measure of what is probably a substantially more complex engineering skill. The measure is probably best used in situations that require parsimony, whether for space requirements (as in a study of multiple outcomes) or time (as in a quick assessment of a particular class unit, course, or program intended to promote contextual competence).

Second, the relatively small sample sizes in some disciplines (e.g., bio-medical/bio-engineering, general engineering, and industrial engineering) and some racial/ethnic groups limit the opportunities to examine differences across disciplines and racial/ethnic groups in both the scale's psychometric characteristics and students' performance levels. Future studies should involve larger numbers of cases in these groups to permit examination of potentially fine-grained variations among these important subsets of engineering students.

In addition, the format of the survey itself may have been psychometrically problematic. The survey was administered on-line and was presented as a series of web pages. When respondents felt they were done with a page of questions they would click "Next" to move to the next page. Question items were organized by topic or learning outcome with a common question stem and response scale. Thus, the contextual competence questions appeared together in a table

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on the same page.   It is possible that the factor analysis was somewhat influenced by this visual and organizational structure. However, the results of the full factor analysis of all of the learning outcome questions from the four-year student survey show that some questions, contrary to expectations, loaded on other learning outcome factors, even on outcomes that were on other pages of the survey. Administering the survey with a different or randomized organization may isolate any formatting effects for more precise psychometric analysis, but it was impractical to do so for such a large, comprehensive study of engineering student characteristics, program curricula, extra-curricular activities, and learning outcomes.

A final limitation involves determining the reliability of the scale. The reliability evidence is provided by a single measure, Cronbach's alpha. Alpha is useful as an optimized extension of split-half reliability that takes into account all parts of the instrument instead of only correlating responses between two equal subsets [44, 48]. As such, it is more technically described as a measure of consistency that estimates a lower bound to reliability [44, 50]. However, a limitation of analyzing reliability based on a single administration of an instrument is the acknowledgement that certain types of error, such as natural variations in human response, ability, mood, concentration, or interaction with environmental circumstances, are "frozen" at the time of administration and are therefore not included in the estimate of instrument error variance [50]. There are other measurements of reliability typically employed in classical measurement theory to address this concern. Parallel forms reliability evidence can be calculated by administering separate versions of the instrument that are psychometrically equivalent in key aspects [44, 50]. We are unable to provide this type of evidence because we developed and tested a single form of the scale. Test-retest reliability is also frequently calculated to assess the extent to which the trait being measured is stable over situation and time. It requires a set of two data collections from the same sample, temporally spaced far enough apart so subjects do not remember how they answered the questions the first time, but not so delayed that what's being measured may have changed [44, 50]. A limitation to our reliability analysis is the single pilot data collection and the single national study data collection. Future research to calculate additional forms of reliability evidence would provide additional information on the psychometric properties of the scale.

Discussion

Stark, Lowther, and Hagerty were among the first to formally call attention to the importance of contextual awareness as an important learning outcome for professional education, including such fields as medicine, business, law, and nursing, as well as engineering[59]. A decade later, ABET reinforced the importance of that learning outcome by including it as Criterion 3.h in the list of 11 outcomes criteria to be reviewed for reaccreditation. Specifically, ABET formally required engineering education to promote (among other things) students' abilities to "understand the impact of engineering solutions in a global, economic, environmental, and societal context" [60]. The rapidly increasing globalization of the world's economies and engineering has underscored the importance of understanding (and working skillfully within) the contextual constraints on engineering-problem solutions that are imposed by the national, cultural, environmental, social, political, and economic factors shaping the implementation of optimally effective solutions. More recently, the urgency of the need to produce engineering graduates with "contextual competence" are clear in several national reports

to the engineering community [2, 3]. In addition, ABET has restated its original Criterion 3.c ("Design a system, to meet desired needs" component, or process" to read: "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*" [1] (italics added). With a few exceptions [8]' [61, 62], however, research on students' development of contextual competence are scarce, and sound instruments are rare.

This paper describes the efforts taken to develop a psychometrically sound, practical, and useful instrument for assessing undergraduate engineering students' contextual competence. For the study from which the data used in this paper comes, "contextual competence" was defined as "an engineer's ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions."

The instrument development process followed the guidelines and standards recommended by test and instrument development experts. The content and items were the products of a process that included a thorough literature review and an iterative review process that included faculty, administrators, and students to ensure that the content of the items reflects the construct in ways that are both psychometrically sound, as well as meaningful to students.

The analyses reported above entailed a set of evaluations (based on statistical procedures and professional judgment) of the content, construct, discriminant, and concurrent validity of the scale. Findings indicate that the four-item scale is both conceptually clean and generally psychometrically sound. In addition, the scale has strong internal consistency reliability (Cronbach's alpha = .91). In short, the scale appears to be an appropriate, acceptably reliable, and parsimonious representation of contextual competence as here defined.

The measure, moreover, appears to be practical, meeting the challenge of finding an appropriate intersection between psychometric rigor and practicality [63]. The instrument allows engineering programs to use the scale to meet ABET and other self-study requirements with relative ease and little expense. The items can be completed by students in small and large groups easily and quickly. The scale permits both sound and parsimonious assessment of students' contextual competence, leaving room in survey instruments for the assessment of other areas of interest to engineering programs without overburdening students and reducing survey response rates.

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