AC 2012-3116: DEVELOPING A MEASURE OF INTERDISCIPLINARY COMPETENCE FOR ENGINEERS

Dr. Lisa R. Lattuca, University of Michigan

Lisa R. Lattuca is professor of higher education in the Center for the Study of Higher and Postsecondary Education at the University of Michigan.

Mr. David B. Knight, Pennsylvania State University, University Park

David Knight is a doctoral candidate at Pennsylvania State University in the Higher Education program. He currently works as a visiting doctoral student at the University of Michigan's Center for the Study of Higher and Postsecondary Education. Knight's research interests include STEM education, interdisciplinary teaching and learning, and organizational issues in higher education. For his dissertation research, he is developing an outcomes-based typology of undergraduate engineering students and is working toward understanding the conditions and experiences associated with developing the engineers of 2020.

Ms. Inger M. Bergom, University of Michigan

Inger Bergom is a doctoral student at the Center for the Study of Higher and Postsecondary Education (CSHPE) at the University of Michigan. She has an M.A. from CSHPE and a B.A. from Grinnell College. Her research interests include learning and teaching in college, faculty careers and roles, and program evaluation.

Developing a Measure of Interdisciplinary Competence for Engineers

Abstract

The National Academy of Engineering's *Engineer of 2020* strongly encourages colleges and universities to prepare engineers who understand that engineering problems – as well as their solutions – are embedded in complex social, cultural, political, environmental, and economic contexts. Developing solutions that account for this enlarged problem space require engineers to access, understand, evaluate, synthesize, and apply information and knowledge from engineering as well as other fields of study. Researchers are just beginning to examine how engineering students learn to synthesize and use knowledge from different fields, and few tools have been developed to date to assess such interdisciplinary learning.

In this paper we describe the development and testing of a measure of interdisciplinary competence. We identify eight dimensions of interdisciplinary competence that emerged from an extensive literature review: 1) awareness of disciplinarity; 2) appreciation of disciplinary perspectives; 3) appreciation of non-disciplinary perspectives; 4) recognition of disciplinary limitations; 5) interdisciplinary evaluation; 6) ability to find common ground; 7) reflexivity; and 8) integrative skill. We next describe how these dimensions were operationalized as a set of survey items, refined through focus groups with engineering faculty, and pilot tested. Following this development process, the items were administered to undergraduates in 30 U.S. engineering schools as part of an NSF-funded study entitled, *Prototype to Production: Processes and Conditions for Preparing the Engineer of 2020.*

The paper next presents information on the formation of (using factor analysis) and descriptive characteristics (e.g., reliabilities) of the three interdisciplinary competence scales that emerged from this process. Additional analyses demonstrate the ability of the scales to distinguish among students in different class years and engineering disciplines.

Introduction

Since the mid-1990s the engineering community has been promoting the development of knowledge and skills that are related to interdisciplinarity as it has been defined by scholars, researchers, and policy makers in a variety of fields. Perhaps most notably, since the shift to an outcomes-based accreditation criteria, ABET promoted the development of related skills and habits of mind. Criterion 3.d requires that all undergraduate engineers have the ability to work on multidisciplinary teams, and Criterion 3.h indicates that those same graduates must understand the impact of engineering solutions in a global, economic, environmental, and societal context[1].

These same contexts are acknowledged in the National Academy of Engineering's *Engineer of 2020* report[2] which contends that developing solutions that account for this enlarged problem space requires engineers to access, understand, evaluate, synthesize, and apply information and knowledge from other fields as they problem solve. Given the growing emphasis on the need for multidisciplinary and interdisciplinary skills to address complex problems, we sought to develop a measure of “interdisciplinary competence” specifically for use in large-scale studies of undergraduate engineering education. There are a few tools available to assess interdisciplinary learning, most notably a scoring rubric for assessing students’ interdisciplinary writing[3] and another rubric for assessing interdisciplinary student projects[4]. These approaches are particularly useful for assessing the progress of individual students and might be incorporated into program-level assessment programs. To assess the development of interdisciplinary competence of undergraduate engineers across programs and institutions, however, we needed a measure that could be easily administered to large numbers of students.

In this paper, we describe the development and testing of a survey-based, self-report measure to assess the perceived interdisciplinary (ID) skills of undergraduate engineering students. Because our purpose is to provide information on the development of the measure, we first describe the data and methods of the overall study for which the measure was developed. Next, we describe the dimensions of the construct we sought to operationalize for our study and present scales resulting from factor analyses of the full data set and analyses conducted to assess the validity of the measure. We close with a discussion of future directions for research to improve the measure and advance the study of interdisciplinary competence of engineering undergraduates.

Defining Interdisciplinarity

The process of defining interdisciplinarity has been a long and ongoing one. A vast literature from a large variety of fields (including education, sociology of science, philosophy of science, cognitive science, research administration, and interdisciplinary studies) has yielded a large number of definitions but surprisingly little empirical study of the concept[5,6,7,8]. In this section, we offer an overview of this definition literature and direct those interested in more in-depth discussion to additional sources. Later in this paper, however, we examine the literature relevant to interdisciplinary competencies that informed the development of our measure.

ABET’s accreditation requirement that undergraduates in engineering programs develop the ability to “work in multidisciplinary teams”[1] has led to wide usage of the term, but there is considerable ambiguity about the term, and the existence of similar terms (e.g., cross-disciplinarity, interdisciplinarity, transdisciplinarity) often leads to confusion[9]. Those who distinguish multidisciplinarity from interdisciplinarity argue that true interdisciplinarity integrates disciplinary contributions so that the separate contributions of the individual disciplines are obscured. The process of achieving integration requires identifying, evaluating, and rectifying differences between disciplinary insights[10] to achieve a new understanding. Such “cognitive advancement” is not possible without the integration or synthesis of disciplinary methods, knowledge, or insights into something new[4].

Integration has become favored as a marker of interdisciplinarity[11,12,13], and the term “integration” appears in a number of policy documents[14,15]. Although there is not complete agreement on the role of integration in interdisciplinary work[7,13,16], the distinction made between multi- and interdisciplinarity rests on the assumption that interdisciplinarity achieves an integration of disciplinary knowledge that multidisciplinarity does not. In a recent examination of the use of these terms by engineering faculty and administrators, however, Lattuca and Knight[9] found considerable variety in the definitions and understandings within and among faculty and administrators in the same engineering programs and schools. For this study, we defined interdisciplinarity as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession…and [that] draws upon disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective"[11].

Data and Methods

The interdisciplinary competence measure was developed as part of a study funded by the National Science Foundation, entitled *Prototype to Production: Conditions and Processes for Educating the Engineer of 2020* (NSF EEC-00506080) (hereafter referred to as P2P). 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 triangulates data from several different groups to provide a comprehensive perspective of undergraduate engineering education: engineering faculty, 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 collected information on school- and program-level policies and practices related to undergraduate engineering education as well as the curricular and instructional emphases in undergraduate programs and courses. Engineering undergraduates (sophomores through super-seniors, i.e., undergraduates in their fifth year of study) and engineering alumni (surveyed three years after they earned their baccalaureate degrees) provided information on the nature of students' educational experiences. The interdisciplinary competence measure was developed for use in the engineering student and alumni surveys, and similar questions were asked of faculty members to report on seniors' interdisciplinary competence. Data on the emphasis on interdisciplinarity in the curriculum were collected from engineering faculty and students as part of a nationally-representative study of 31 colleges and universities (see Table 1).

Survey Development

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 conducted an extensive literature review on key topics related to interdisciplinarity in engineering, but also in fields outside engineering. In addition to studies collected in ASEE's conference proceedings and journals, team members identified and reviewed literature from the fields of interdisciplinary studies, education, business, research management, cognitive science, philosophy, and sociology of science. Findings from this literature review generated an item bank of potential survey items as well as eight dimensions of interdisciplinarity, which are summarized in the Findings section. In addition to this literature, the team spent a year conducting interviews and focus groups with engineering administrators, faculty members, students, and alumni at the following five campuses to understand how engineering programs sought to develop students' interdisciplinary skills 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 additional focus on different sectors of the engineering education pipeline.

Table 1. P2P Institutional Sample

Research Institutions:	Master's/Special Institutions:
Arizona State University (Main & Polytechnic)[1]	California Polytechnic State University[3]
Brigham Young University	California State University, Long Beach
Case Western Reserve University	Manhattan College
Colorado School of Mines	Mercer University
Dartmouth College	Rose-Hulman Institute of Technology
Johns Hopkins University	University of South Alabama
Massachusetts Institute of Technology[1]	
Morgan State University[2]	
New Jersey Institute of Technology	**Baccalaureate Institutions:**
North Carolina A&T[2]	Harvey Mudd College[1]
Purdue University	Lafayette College
Stony Brook University	Milwaukee School of Engineering
University of Illinois at Urbana-Champaign	Ohio Northern University
University of Michigan[1]	Penn State Erie, The Behrend College
University of New Mexico[3]	West Virginia University Institute of Technology
University of Texas, El Paso[3]	
University of Toledo	
Virginia Polytechnic Institute and State University[1]	

[1] Institution participating in the companion qualitative study
[2] Historically Black College or University
[3] Hispanic-Serving Institution

Interview and focus group meetings were transcribed and distributed to the research team, which met weekly for almost a year to discuss the findings and 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). 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 with faculty and students at Penn State-University Park and Penn State-Altoona (n=482) (survey items with established reliability and validity from other studies were not pilot tested).

The team used factor analysis techniques to explore these pilot results and further revised the survey instruments based on these findings. In addition, the research team again met with focus groups of engineering faculty members and administrators from Penn State-University Park to review the full student survey one final time to assess its construct validity (i.e., whether the items represent their intended purpose) before administering the surveys to the full P2P sample.

P2P Sample and Data Treatment

We used the American Society for Engineering Education's database for guidance in drawing the P2P sampling framework, using institution- and program-level information for the 2007–2008 academic year for enrolled students and faculty. The sampling is disproportionate, mixed random/purposeful, 6 x 3 x 2 stratified with the following strata: 6 engineering disciplines (biomedical/bioengineering, chemical, civil, electrical, industrial, and mechanical); 3 levels of highest degree offered (bachelor's, master's, and doctorate); two levels of institutional control (public and private). As such, institutions in the final sample are representative of the population with respect to type, mission, and highest degree offered.

The P2P sample is “pre-seeded” with five case study institutions that were participants in a companion qualitative study. One of the case study institutions only offers a general engineering degree, so three institutions that offer general engineering degrees were included in the sample to serve as comparison institutions for a total of seven disciplines (biomedical/bioengineering, chemical, civil, electrical, general, industrial, and mechanical). Together, these seven disciplines accounted for 70% of all baccalaureate engineering degrees awarded in 2008. A University Survey Research Center selected 23 additional institutions at random from the population within the sampling framework, including two Historically Black Colleges and Universities and three Hispanic-serving Institutions. The Survey Research Center was also responsible for data collection through a web-based questionnaire. Of the 32,737 student surveys sent, 5,249 were returned for a response rate of 16%. Though a higher rate was desired, response rates around the country have been declining[17,18], perhaps because of increased use of surveys in general through web-based forms[19,20]. We accounted for differences between the sample of responses and the overall undergraduate engineering population for the sample of 31 institutions, weighting cases based on response rates by gender, discipline, and race/ethnicity within an institution. We also weighted cases to account for varying response rates across institutions.

Missing data were imputed based on procedures recommended by Dempster et al.[21] and Graham[22] using the Expectation-Maximization (EM) algorithm of the Statistical Package for the Social Sciences (SPSS) software (v.18). We employed a principal axis analysis (Oblimin with Kaiser Normalization rotation) to reduce multiple survey questions into fewer scales. Each item was assigned to a factor based on the magnitude of the loading, the effect of keeping or discarding the item on the scale’s internal consistency reliability, and professional judgment. Factor scales were formed by taking the sum of respondents’ scores on the component items on a factor and dividing by the number of items in the scale, as prescribed by Armor[23]. The Findings section shows how this process unfolded for items related to interdisciplinary competence.

Analyses of Interdisciplinary Competence Scales

To demonstrate the reliability and usefulness of our interdisciplinary competence measures, we conduct factor analyses to empirically identify the dimensions of interdisciplinary competence as well as analyses to examine how well the interdisciplinary competence scales discriminate between students’ levels of class standing and their discipline of enrollment within engineering. An analysis of covariance, controlling for SAT score, gender, and race, was conducted to test for statistically significant differences between groups.

Findings

We present our findings in three sections. In our first section, we present a summary of the literature that leads to our conceptualization of interdisciplinary competence as a multidimensional construct. We follow with two additional sections in which we report the final factor solution based on analysis of the full student data set for the study (Part 2) and discuss of the validity of the measure (Part 3).

Part 1: Conceptualization of Interdisciplinary Competence

A review of the literature yielded eight different dimensions of interdisciplinarity. The following sections summarize these dimensions and provide key citations for each.

Awareness of Disciplinarity. Many observers of interdisciplinarity argue that disciplines are fundamental to the creation of knowledge and thus to interdisciplinarity[11,13,15,24,25]. Building on the work of a wide variety of scholars[26,27,28,29,30], Lattuca[7] argued that disciplines should be understood as cognitive apparatuses that structure scholarly inquiry (comprised of assumptions about the nature of a domain of knowledge, how to study the elements of that domain, and how to validate knowledge), and as scholarly communities with particular and largely communal values and norms related to scholarship. Understanding the socially constructed nature of the disciplines may contribute to one's willingness to cross boundaries and accept the forays of others into one's own discipline.

Appreciation of Disciplinary Perspectives. Awareness is not equivalent to appreciation. Nikitina[31] emphasizes the importance of identifying strengths and weaknesses in disciplinary perspectives in the process of developing interdisciplinary competence. She writes that it is necessary to develop "an appreciative attitude towards other 'stories' and disciplinary frames of reference" (p. 413[31]). The process of gaining disciplinary knowledge and an appreciation of disciplinary perspectives involves movement from having a general knowledge of a discipline to "more specific knowledge of how each of its elements informs its insights into the problem" (p. 126[32]). Appreciation of the potential contributions of a discipline other than one's own may be necessary for learning what can be 'borrowed' from another discipline as one addresses complex issues and questions.

Appreciation of Non-disciplinary Perspectives. Under the broad umbrella of interdisciplinary approaches to knowledge, the need to appreciate non-disciplinary knowledge, experiences, and perspectives has been most fully engaged by those writing about what is increasingly called "transdisciplinarity." The term transdisciplinarity often refers to scholarship that transgresses the boundaries between academia and communities outside academia. Burger and Kamber[33] define transdisciplinarity as being comprised of "1) cognitive and social cooperation across disciplinary boundaries, 2) an intention towards the direct application of scientific knowledge in both political decision-making and societal problem-solving, and 3) the participation of non-scientific stakeholders within research processes" (p. 44). Collaboration with stakeholders provides a "reality check"[34] because in spheres of practice and experience, disciplinary and informal (or indigenous) knowledge intersect and are valued and integrated in the research process. In engineering, cross-sector work of this kind is common and can be captured under the umbrella term of interdisciplinarity.

Recognition of Disciplinary Limitations. Openness to a variety of disciplinary and nondisciplinary sources of knowledge may result in a greater awareness of the limitations of one's own field of study. Nikitina[31] writes that thinking in an interdisciplinary way requires the "defining and defying of limits imposed by one discipline, and making decisions to reject or accept different disciplinary theories based on their relevance and credibility" (p. 17). In a review of the academic major, the Association of American Colleges (AAC, now the Association of

American Colleges and Universities) argued that in addition to understanding the organization of their major fields and learning to think like practitioners in those fields, undergraduates should also learn from a properly constructed major program of study "the necessarily partial vision" of the field and critically reflect on "the successes and limitations of any particular approach to knowledge" (p. 5[35]).

Interdisciplinary Evaluation. Despite the increase in the number of interdisciplinary programs on college and university campuses[36], some have argued that methods and criteria to evaluate the effectiveness of these programs are lacking or weak[4,37]. In order to "perform" interdisciplinarity successfully, students and faculty need to be able to evaluate the effectiveness of interdisciplinary work. The seeds of interdisciplinary evaluation require that students develop awareness and appreciation of knowledge, methods, and perspectives of their own and other disciplines as well as critical understandings of the limitations of each of these.

Ability to Find Common Ground. Some argue that finding common ground is fundamental to the notion of interdisciplinarity because it makes possible integration of knowledge rooted in different disciplines[38]. Klein[10] argued that disciplinary insights must not only be evaluated (as suggested earlier), but eventually rectified if the integration necessary to interdisciplinary was to be achieved. Similarly, Newell[39] argued that creating common ground might involve "modification or reinterpretation of components or relationships from different disciplines to bring out their commonalties so that linkages can be identified between sub-systems" (p. 20[39]).

Reflexivity. Repko[32] writes that the interdisciplinary research process is necessarily a reflexive one. Reflection occurs when evaluating information sources or evaluating complex problems or controversial issues, for example. Interdisciplinary competence involves the ability to reflect on one's biases and the choices one makes when defining problems or interests, building understanding, and problem solving – and how these biases will influence directions, understandings, and solutions.

Integrative Skill. Boix Mansilla and Duraising[4] define interdisciplinary understanding as "the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement—such as explaining a phenomenon, solving a problem, or creating a product—in ways that would have been impossible or unlikely through single disciplinary means" (p. 219). Newell[39] writes, "By definition, interdisciplinary study draws insights from relevant disciplines and integrates those insights into a more comprehensive understanding" (p. 2). Thus, interdisciplinary study necessitates the ability to integrate knowledge across disciplines in the context of solving a complex problem. In the end, the goal of integration is to comprehensively explain a phenomenon that is "greater than the sum of its disciplinary parts" (p. 131[39]).

Part 2: Final Factor Solution for Interdisciplinary Competence

We administered the undergraduate student surveys in 31 of the 32 P2P institutions (one institution did not provide student contact information needed to administer the surveys) from April through November of 2009. Once these data were collected and cleaned, we again factor analyzed all 51 items related to different learning outcomes, including interdisciplinary competence, fundamentals, design skills, contextual awareness, leadership, communication, and teamwork skills (a different factor analysis procedure than the one for the pilot survey, as only items related to interdisciplinary competence were analyzed in the preliminary analysis). Nine separate learning outcome scales emerged, three of which are related to interdisciplinary competence. Despite being administered to a different student population than the pilot study, the same three factors of items emerged from this factor analysis (Table 2). The only item that did not load as it did in the pilot study was "I usually know when my own biases are getting in the way of my understanding of a problem or finding a solution." This item had a factor loading below .40 on all 9 student outcome factors and was removed from the analysis. Students may have interpreted "biases" in a variety of ways, and in hindsight a more explicit emphasis on disciplinary biases might have improved the specificity and thus the interpretability of this survey item. We reviewed the names of the factors developed during the pilot testing phase and revised these to reflect more accurately the contents of each factor. The revised factor names are Interdisciplinary Skills, Reflective Behavior, and Recognizing Disciplinary Perspectives.

The Interdisciplinary Skills scale assesses students' perceptions of their abilities to think about and use different disciplinary perspectives in solving interdisciplinary problems or to make connections across academic fields. The Reflective Behavior scale includes items that operationalize the "reflexivity" dimension of interdisciplinarity identified through the literature review. This scale includes items that tap students' perceived ability to recognize the need to reconsider the direction of their thinking and problem-solving approaches. The final scale, Recognizing Disciplinary Perspectives, taps students' perceived understandings of disciplinary knowledge, methods, expectations, and boundaries and how disciplinary knowledge might be applied in different situations.

Each of these three factors exhibits high internal consistency, with Cronbach's alpha values ranging from .684 to .790. Even when we removed individual items, the factors maintained alpha values of at least .50. Because Recognizing Disciplinary Perspectives had fewer items comprising the scale, the effect of removing a single item was greater on the remaining alpha value than it was for the Interdisciplinary Skills factor. Taking into account all of this evidence, we computed scales for these three factors as well as the six other learning outcome scales by taking the average of the items comprising each.

For scales to provide meaningful and different information, they should not exhibit excessively high correlation coefficients with other scales. Correlation coefficients between each interdisciplinary competence scale and pairwise comparisons for the other outcome scales ranged from .170 and .437 (Table 3). These low values indicate that the nine scales are indeed providing different information, as they tended not to co-vary with one another. Focusing on the three interdisciplinary competence scales, we note that the highest correlation coefficient is .419 between Interdisciplinary Skills and Recognizing Disciplinary Perspectives, indicating the distinctiveness of the three different dimensions of interdisciplinary competence from one another. The emergence of the same three factors from two separate populations of students (the Penn State pilot test and the 31-institution full sample) lends further support for the claim that the scales are measuring distinctive skills that are relevant to undergraduate engineering students. Because the three scales did not correlate strongly to each other or to other scales, there is evidence of discriminant validity, a form of criterion-related validity that indicates the measure does not correlate strongly to other constructs that are theoretically different[40].

Table 2. Factor analysis results of the P2P survey related to interdisciplinary competence. Values in the right column denote the mean and standard deviations in parentheses for each item.

Factor	**Item** STEM: To what extent do you agree or disagree with each of the statements below.[1]	**Alpha if Item Deleted**	**Item Means (Std Dev.)**
Interdisciplinary Skills (Alpha = .790)	I value reading about topics outside of engineering	0.784	4.21 (.87)
	I enjoy thinking about how different fields approach the same problem in different ways.	0.762	4.04 (.79)
	Not all engineering problems have purely technical solutions.	0.776	4.26 (.73)
	In solving engineering problems I often seek information from experts in other academic fields.	0.782	3.50 (.94)
	Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.	0.763	3.99 (.67)
	I see connections between ideas in engineering and ideas in the humanities and social sciences.	0.758	3.89 (.91)
	I can take ideas from outside engineering and synthesize them in ways that help me better understand	0.749	4.02 (.76)
	I can use what I have learned in one field in another setting.	0.757	4.23 (.67)
Reflective Behavior (Alpha = .730)	I often step back and reflect on what I am thinking to determine whether I might be missing something.	NA	4.03 (.76)
	I frequently stop to think about where I might be going wrong or right with a problem solution.	NA	3.85 (.77)
Recognizing Disciplinary Perspectives (Alpha = .684)	If asked, I could identify the kinds of knowledge and ideas that are distinctive to different fields of study	0.575	3.69 (.88)
	I recognize the kinds of evidence that different fields of study rely on.	0.508	3.81 (.75)
	I'm good at figuring out what experts in different fields have missed in explaining a problem/solution	0.693	3.38 (.92)

[1] Scale: 1= Strongly disagree, 2=Disagree, 3= Neither agree nor disagree, 4=Agree, 5=Strongly agree

For scales to provide meaningful and different information, they should not exhibit excessively high correlation coefficients with other scales. Correlation coefficients between each interdisciplinary competence scale and pairwise comparisons for the other outcome scales ranged from .170 and .437 (Table 3). These low values indicate that the nine scales are indeed providing different information, as they tended not to co-vary with one another. Focusing on the three interdisciplinary competence scales, we note that the highest correlation coefficient is .419 between Interdisciplinary Skills and Recognizing Disciplinary Perspectives, indicating the distinctiveness of the three different dimensions of interdisciplinary competence from one another. The emergence of the same three factors from two separate populations of students (the Penn State pilot test and the 31-institution full sample) lends further support for the claim that the scales are measuring distinctive skills that are relevant to undergraduate engineering students. Because the three scales did not correlate strongly to each other or to other scales, there is evidence of discriminant validity, a form of criterion-related validity that indicates the measure does not correlate strongly to other constructs that are theoretically different[40].

Table 3. Correlation coefficients between the nine student learning outcome scales[1].

	Interdisciplinary Skills	Recognize Disciplinary Perspectives	Reflective Behavior	Fundamental Skills	Design Skills	Contextual Awareness	Teamwork Skills	Communication Skills	Leadership Skills
Interdisciplinary Skills	1								
Recognizing Disciplinary Perspectives	.419	1							
Reflective Behavior Practice	.374	.306	1						
Fundamental Skills	.289	.276	.300	1					
Design Skills	.422	.344	.324	.621	1				
Contextual Awareness	.437	.418	.170	.364	.664	1			
Teamwork Skills	.361	.280	.227	.362	.584	.541	1		
Communication Skills	.384	.306	.239	.450	.642	.542	.635	1	
Leadership Skills	.337	.316	.236	.442	.713	.603	.744	.707	1

[1] Interdisciplinary competence scales are shaded in gray.

Part 3: Validity of the Interdisciplinary Competence Scales

In the previous section we discussed the internal reliability of the interdisciplinary competence scales. In this section we take up the question of the validity of the measures, providing the results of analyses designed to assess the construct validity of the three scales. Before we begin, however, we suggest that the research and development process we used to develop the survey items that comprise the scales, which involved engineering faculty and administrators, also contributes to the construct validity of the measure. According to these engineers, the survey items we developed assess interdisciplinary competence for engineering undergraduates. This review by a group of experts within the field builds confidence that the survey items would be interpreted by engineering students in the intended manner.

Construct validity "involves making inferences from the sampling particulars of a study to the higher-order constructs they represent"[41]. We developed our survey items after a review of the literature on interdisciplinarity, which is largely speculative rather than empirical in nature. Furthermore, although there is a growing literature on interdisciplinarity in engineering education, much of it was not published at the time we developed our measure. Thus, the dimensions of interdisciplinarity we identified, although consistent with the literature, may not fully describe the construct of interdisciplinary competence or how it is manifested in engineering education contexts. In future studies now in the planning stages, we hope to directly assess interdisciplinary competence in engineering students; these assessments could provide the basis for a test of the construct validity of the survey-based measure we have developed to date.

The analyses we are able to conduct with our data, however, provide considerable evidence of concurrent validity, which assesses the ability of an operationalization to distinguish between groups that it should theoretically be able to distinguish[42,43]. In the analyses below, we show that the three interdisciplinary competence scales are able to discriminate, with varying levels of success, among engineers in the engineering disciplines targeted for the study. To demonstrate this, we conducted an analysis of covariance for all seniors and super-seniors for each scale. In these analyses, we controlled for students' race/ethnicity, gender, and SAT composite score, and compared each pairwise difference of the adjusted means (Table 4).

For the Interdisciplinary Skills scale, seniors from three disciplines reported significantly higher skills than the other disciplines: biomedical/bioengineering, general engineering, and industrial engineering. These three disciplines are ones that we would expect to be more interdisciplinary in outlook because they draw on multiple engineering fields (general engineering) or link engineering with other fields (bioengineering and industrial engineering) and also tend to take more of a systems perspective. It thus stands to reason that students enrolled in these disciplines would report higher interdisciplinary skills levels than students in the other disciplines we studied (chemical, civil, electrical, and mechanical engineering). It is important to note that in the P2P sample, the general engineering programs are organized purposefully rather than acting as a "catch-all" major for students who are unsure of their interest in engineering or who have weaker academic skills. Several of the general engineering programs in our study are both highly selective and very intentional in curricular and pedagogical design (i.e., Harvey Mudd College, Dartmouth, Arizona State University-Polytechnic Campus). The finding that the Interdisciplinary Skills scale effectively distinguishes between students in these engineering disciplines thus supports the measure's concurrent validity.

We observed fewer disciplinary differences by discipline for the Recognizing Disciplinary Perspectives scale and the Reflective Behavior scale. Chemical engineering students reported significantly lower ratings on this scale than biomedical/bioengineers and electrical engineers. Chemical engineers' self-ratings, which are the lowest of all seniors in the study, are consistent with the finding for the Interdisciplinary Skills scale. Potential explanations for these consistent findings include a lack of emphasis on interdisciplinarity in the chemical engineering curriculum, which might lead to less exposure to other fields and thus less familiarity with other disciplinary perspectives. Our previous analyses of curricular emphases in these fields show that chemical engineering students and faculty reported less emphasis on topics associated with interdisciplinarity than their counterparts in other fields[44] and thus may be less familiar with the content, concepts, theories and methods associated with other fields of study.

Table 4. Adjusted means for 4th- and 5th-year seniors of the scales related to interdisciplinary competence by engineering discipline. Disciplinary pairwise comparisons of the means are calculated as the “focal discipline” subtracted by the “comparison discipline.” Significant differences ($p<.05$) for the pairwise comparisons are shaded in light gray and were determined via an analysis of covariance, controlling for gender, race/ethnicity, and SAT composite score.

	Interdisciplinary Skills			Recognizing Disciplinary Perspectives		Reflective Behavior Practice	
Focal Discipline	Mean	Comparison Discipline	Mean Difference	Mean	Mean Difference	Mean	Mean Difference
Biomedical/ Bioengineering	4.12	Chem	.218	3.70	.182	4.10	.108
		Civil	.146		.096		.077
		Elec	.174		.033		.047
		Gen	-.057		.130		-.119
		Indus	.073		.052		.067
		Mech	.133		.096		.118
Chemical Engineering	3.91	Bio	-.218	3.52	-.182	3.99	-.108
		Civil	-.072		-.086		-.030
		Elec	-.044		-.149		-.061
		Gen	-.275		-.052		-.227
		Indus	-.145		-.130		-.041
		Mech	-.085		-.086		.010
Civil Engineering	3.98	Bio	-.146	3.60	-.096	4.02	-.077
		Chem	.072		.086		.030
		Elec	.028		-.063		-.030
		Gen	-.203		.034		-.196
		Indus	-.073		-.044		-.011
		Mech	-.013		.000		.041
Electrical Engineering	3.95	Bio	-.174	3.66	-.033	4.05	-.047
		Chem	.044		.149		.061
		Civil	-.028		.063		.030
		Gen	-.231		.097		-.166
		Indus	-.101		.019		.020
		Mech	-.041		.063		.071
General Engineering	4.18	Bio	.057	3.57	-.130	4.22	.119
		Chem	.275		.052		.227
		Civil	.203		-.034		.196
		Elec	.231		-.097		.166
		Indus	.130		-.078		.186
		Mech	.189		-.034		.237
Industrial Engineering	4.05	Bio	-.073	3.65	-.052	4.03	-.067
		Chem	.145		.130		.041
		Civil	.073		.044		.011
		Elec	.101		-.019		-.020
		Gen	-.130		.078		-.186
		Mech	.060		.044		.051
Mechanical Engineering	3.99	Bio	-.133	3.60	-.096	3.98	-.118
		Chem	.085		.086		-.010
		Civil	.013		.000		-.041
		Elec	.041		-.063		-.071
		Gen	-.189		.034		-.237
		Indus	-.060		-.044		-.051

While the high levels of confidence in Recognizing Disciplinary Perspectives reported by electrical engineers (compared to chemical engineers) may seem counterintuitive, two explanations may be possible. First, as a field of study, electrical engineering is composed of distinctive subdisciplines and seniors' knowledge of these fields may have influenced their understanding of the term "discipline" and thus their ratings of their abilities. It is also possible that the strong discipline-focus in electrical engineering programs makes students very aware of how their discipline is different from others; engineering fields that are more interdisciplinary in focus may not make such distinctions as obvious to undergraduates, stressing similarities or affinities across fields rather than differences. This interpretation is supported by our previous analyses which demonstrate that the seven engineering disciplines in the P2P study are arrayed on a continuum from more to less interdisciplinary based both on data on students' learning outcomes and in reports of curricular emphasis by chairs and faculty[44].

Finally we consider the findings for the Reflective Behavior scale. General engineers reported significantly higher scores for this scale than chemical engineers and mechanical engineers. Students enrolled in the purposefully designed general engineering programs that populate our sample would be expected to report higher levels of confidence in their reflective behavior than students in other disciplines because it is stressed in these programs. In addition, the composition of the scale should be noted. Only two survey items comprise the Reflective Behavior scale, and this may contribute to its inability to discriminate between the other disciplines. Though the disciplines can be arranged on a continuum on this scale, having fewer items from which to calculate an average value for the scale may contribute to the increased difficulty in observing statistically significant differences between additional disciplines.

The items that comprise this scale seem to tap students' metacognitive skills, while the Interdisciplinary Skills scale tends to tap behaviors. Biomedical/bioengineering students and those in general engineering programs reported the highest ratings for these items, suggesting that fields that are more interdisciplinary in focus either attract students who are more metacognitive than those in other fields or help students develop these skills. Reflection and interdisciplinarity, as our discussion of the dimensions of interdisciplinarity suggests, are not mutually-exclusive. Moreover, in engineering, reflection is a key aspect of the problem solving and design process, in which all engineers engage to a certain extent. The abilities measured by the Recognizing Disciplinary Perspectives scale, therefore, might be achieved in a variety of ways and associated with a variety of activities. This may explain the more limited ability of the scale (when compared to the Interdisciplinary Skills scale) to distinguish between among students in different engineering disciplines.

We also explored whether the scales differed in their abilities to distinguish between students at different levels of class standing. Our comparisons of sophomores, juniors, and seniors did not show statistically significant differences on the Recognizing Disciplinary Perspectives and Reflective Behavior scales. Differences in curricular approaches may also be at work here. Different fields, as well as different programs within the same field may differently emphasize the dimensions of interdisciplinary thinking we have identified. Variations in program curricula would make it more difficult to show development across class standing. Another potential curricular explanation for the mixed results for the Reflective Behavior scale may be that engineering students are typically introduced to problem solving early in the curricular sequence;

if this skill is taught early, and perhaps used more often, it would be more difficult to demonstrate substantial gains as students progressed through their majors.

In contrast, seniors reported significantly higher Interdisciplinary Skills than sophomores and juniors (Table 5). Though the survey was cross-sectional in design (individual students were not followed over time, but we compared populations of students at different stages of their academic careers), one would expect students further along in their programs to report significantly higher Interdisciplinary Skills).

Table 5. Adjusted means for Interdisciplinary Skills by class standing. Pairwise comparisons calculated as the "class standing" subtracted by the "comparison year." Significant differences ($p<.05$) are shaded in gray and were determined via an analysis of covariance, controlling for gender, race/ethnicity, engineering discipline, and SAT composite score.

	Interdisciplinary Skills		
Class Standing	Mean	Comparison Year	Mean Difference
Sophomore	3.91	Junior	-0.027
		Senior	-0.056
Junior	3.94	Sophomore	0.027
		Senior	-0.029
Senior	3.97	Sophomore	0.056
		Junior	0.029

The higher skill level reported by seniors relative to their sophomore and junior colleagues is consistent with prior research. Single-institution longitudinal studies of undergraduate engineering students show limited cognitive development during the first two years of college; the first two years of the engineering curriculum are typically comprised of rote learning and application of formulae, foundational science and math courses that tend to not promote more advanced forms of thinking[45,46]. In higher level courses during the third and fourth years, however, a different educational environment may play a role in cognitive development. Similar work[47] in non-engineering environments also suggests that in general students experience limited development of critical thinking skills and complex reasoning during their first two years of college. Since interdisciplinary skills require higher order thinking skills such as synthesis and evaluation, the higher levels reported by senior engineering students in our study is consistent with expectations and provides further evidence of the validity of the scales.

Discussion and Conclusions

In this study we describe the development and psychometric properties of a measure of "interdisciplinary competence" designed for use in larger-scale studies of undergraduate engineering education. Using data from our own studies, we are able to provide some evidence supporting the construct validity of the three scales that emerged during our research process. The evidence is strongest for the scale measuring Interdisciplinary Skills, which is able to distinguish among students in different engineering fields and in different years of study in ways that would be theoretically expected. Our analysis provided more limited evidence of construct validity for the two related scales, Recognizing Disciplinary Perspectives and Reflective Behavior. In this section, we suggest research to further test and potentially improve the scales.

Following this discussion, we consider the contribution of this work to conceptualizations of interdisciplinarity in engineering education.

Future Research

We were unable to test fully the construct validity of our scales due to the lack of a direct measure of interdisciplinary knowledge or skills. An important direction for future research, then, is the comparison of students' performance on an authentic interdisciplinary task that requires the application of knowledge and/or skills from multiple disciplines (inside and outside engineering) with scores on our scale, which is based on self-ratings. As noted earlier, we hope to be able to conduct this work in the near future.

Additional work to improve the Reflective Behavior and Recognizing Disciplinary Perspectives scales is warranted. The Reflective Behavior scale is composed of two survey items and this limits the sensitivity of the measure. We relied on literature on interdisciplinarity to identify this dimension of interdisciplinarity, but further investigation of the literatures on metacognition (which the scale may be tapping) as well as measures of engineering problem solving may suggest additional behaviors that are associated with reflective practice.

More qualitative studies of how engineering students interpret the concept of "discipline" might help researchers better understand how interdisciplinarity is understood by engineering students and faculty. Findings from Lattuca's[7] study of college and university faculty members' interdisciplinary research and teaching led her to speculate that understandings of the term interdisciplinarity are related to individuals' conceptions of the scope and boundaries of their own fields of study. The use of the terms multi- and interdisciplinarity by different engineering faculty may reflect such differences, and these may be passed along to students through disciplinary socialization processes. In addition, further specification of the term "discipline" in the stem of the survey items for this scale, or in the survey items themselves, should assist students – and researchers – in interpreting the items and scale scores.

Conceptual Contribution

Although many scholars suggest that multidisciplinarity and interdisciplinary are different approaches to knowledge creation, our studies of interdisciplinarity in engineering programs suggest that the two may not be entirely separate. In the context of undergraduate education, multidisciplinarity may in some cases constitute a step on the path toward interdisciplinarity. Recall that definitions of interdisciplinarity describe it as a *process* of knowledge creation rather than solely as a *product* of research teaching activities, and that many scholars argue that disciplinary grounding is a prerequisite to interdisciplinary knowledge creation. In the context of undergraduate education, this implies that students must first understand and be able to apply disciplinary knowledge before they can (potentially) integrate disciplinary concepts, theories, methods, and insights in a process of interdisciplinary knowledge production. Our review of the literature on interdisciplinarity lends support to this conceptualization: the dimensions of interdisciplinarity that we present in our Findings section could be interpreted as a developmental learning trajectory for interdisciplinary competence, suggested in our previous work[9]. The three scales we have developed might be used in longitudinal studies of engineering students' interdisciplinary skills to see if the recognition of disciplinary perspectives and reflective behaviors developmentally occur prior to the development of robust interdisciplinary skills (as measured by the Interdisciplinary Skills scale). The cross-sectional nature of our data cannot fully test this conceptualization but the scales might be used in such an investigation.

References

[1]ABET (2012). Criteria for accrediting engineering programs, 2012–2013. Accrediting Board for Engineering and Technology. http://www.abet.org/engineering-criteria-2012-2013/.

[2]National Academy of Engineering (2004). *The engineer of 2020: Visions of engineering in the new century*. Washington, D.C.: National Academies Press.

[3]Wolfe, C. R. & Haynes, C. (2003). Interdisciplinary writing assessment profiles. *Issues in Integrative Studies*, *21*, 126-169.

[4]Boix Mansilla, V., & Dawes Duraising, E. (2007). Targeted assessment of students' interdisciplinary work: An empirically grounded framework proposed. *Journal of Higher Education*, *78*(2), 215-237.

[5]Klein, J. T. (2010a). *Creating Interdisciplinary Campus Cultures: A Model for Strength and Sustainability*. San Francisco: Jossey-Bass.

[6]Klein, J. T. (2010b). A taxonomy of interdisciplinarity. In R. Frodeman & J. T. Klein (Eds.), *The Oxford handbook of interdisciplinarity* (15-30). New York: Oxford University Press.

[7]Lattuca, L. R. (2001). *Creating interdisciplinarity: Interdisciplinary research and teaching among college and university faculty*. Nashville, TN: Vanderbilt University Press.

[8]Lattuca, L.R., L.J. Voigt and K.Q. Fath (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education*, *28*, 23–48.

[9]Lattuca, L. R., & Knight, D. B. (2010, June). In the eye of the beholder: Defining and studying interdisciplinarity in engineering education. *Proceedings of the 117th Annual Conference of the American Society of Engineering Education*, Louisville, KY.

[10]Klein, J. T. (1996). *Crossing boundaries: Knowledge, disciplinarities, and interdisciplinarities*. Charlottesville: University Press of Virginia.

[11]Klein, J. T, & Newell, W. H. (1997). Advancing interdisciplinary studies. In Jerry G. Gaff, James L. Ratcliff and Associates (Eds.), *Handbook of the undergraduate curriculum: A comprehensive guide to purposes, structures, practices, and change* (pp. 393-415). San Francisco: Jossey-Bass.

[12]Newell, W. H. (1998). *Interdisciplinarity: Essays from the literature*. NY: College Entrance Examination Board.

[13]Repko, A. F. (2012). *Interdisciplinary research: Process and theory* (2nd ed.). Los Angeles, CA: Sage Publications.

[14]National Academy of Engineering (2005). *Educating the engineer of 2020: Adapting engineering education for the new century*. Washington, D.C.: National Academies Press.

[15]National Research Council (2004). *Facilitating Interdisciplinary Research*. Washington, DC: The National Academies Press.

[16]Organisation for Economic Co-operation and Development (1972). *Interdisciplinarity: Problems of Teaching and Research in Universities*. Paris: OECD.

[17]Baruch, Y. (1999). Response rate in academic studies—A comparative analysis. *Human Relations, 52*, 421-438.

18Porter, S. R., & Umbach, P. D. (2001, June). *What works best? Collecting alumni data with multiple technologies.* Paper presented at the annual meeting of the Association for Institutional Research, Long Beach, CA.

[19]Porter, S. R., & Umbach, P. D. (2006). Student survey response rates across institutions: Why do they vary? *Research in Higher Education, 47*(2), 229-247.

[20]Van Horn, P. S., Green, K. E., & Martinussen, M. (2009). Survey response rates and survey administration in counseling and clinical psychology: A meta-analysis. *Educational and Psychological Measurement, 69*, 389-403.

[21]Dempster, A. P., Laird, N.M., & Rubin, D. B. (1977). Maximum likelihood from incomplete data via the EM algorithm. Journal of the Royal Statistical Society, Series B, 39, 1–38.

[22]Graham, J. W. (2009). Missing data: Making it work in the real world. *Annual Review of Psychology, 60*, 549-576.

[23]Armor, D. J. (1974). Theta reliability and factor scaling. In H. Costner (Ed.). *Sociological methodology: 1973-1974.* San Francisco: Jossey-Bass, pp. 17-50.

[24]Klein, J. T. (1998). Blurring, cracking, and crossing. In W. H. Newell (Ed.), *Interdisciplinarity: Essays from the literature* (pp. 273-295). New York, NY: College Entrance Examination Board.

[25]Newell, W. H. (1992). Academic disciplines and undergraduate interdisciplinary education: Lessons from the School of Interdisciplinary Studies at Miami University, Ohio. *European Journal of Education*, *27*, 211–221.

[26]Becher, T. (1989). *Academic tribes and territories: Intellectual enquiry and the cultures of disciplines*. Bristol, PA: The Society for Research into Higher Education and Open University Press.

[27]Dressel, P., & Marcus, D. (1982). *Teaching and learning in college*. San Francisco: Jossey-Bass.

[28]King, A. R., & Brownell, J. A. (1967). The curriculum and the disciplines of knowledge. *Teachers College Record, 68*(5), 346-346.

[29]Kuhn, T. S. (1970).*The structure of scientific revolutions* (2nd ed., enlarged). Chicago: Chicago University Press.

[30]Toulmin, S. (1972). *Human understanding* (Vol. 1). Princeton: Princeton University Press.

[31]Nikitina, S. (2005). Pathways of interdisciplinary cognition. *Cognition and Instruction, 23*(3), 389-425.

[32]Repko, A. F. (2008). *Interdisciplinary research: Process and theory*. Los Angeles, CA: Sage Publications.

[33]Burger, P., & Kamber, R. (2003). Cognitive integration in transdisciplinary science: Knowledge as a key notion. *Issues in Integrative Studies, 21*, 43-73.

[34]Wickson, F., Carew, A. L., & Russell, A. W. (2006). Transdisciplinary research: Characteristics, quandaries and quality. *Futures, 38*, 1046-1059.

[35]Association of American Colleges. (1991). *The challenge of connecting learning: Project on liberal learning, stud-in-depth, and the arts and sciences major* (Vol. 1). Washington, DC.

[36]Brint, S. G., Turk-Bicakci, L., Proctor, K., & Murphy, S. P. (2009). Expanding the social frame of knowledge: Interdisciplinary, degree-granting fields in American colleges and universities, 1975-2000. *The Review of Higher Education*, *32*(2), 155-183.

[37]Schilling, K. L. (2001). Interdisciplinary assessment for interdisciplinary programs. In B. L. Smith & J. McCann (Eds.), *Reinventing ourselves: Interdisciplinary education, collaborative learning and experimentation in higher education* (pp. 344–354). Bolton, MA: Anker.

[38]Repko, A. F. (2007). Integrating interdisciplinarity: How the theories of common ground and cognitive interdisciplinarity are informing the debate on interdisciplinary integration. *Issues in Integrative Studies, 25*, 1-31.

[39]Newell, W. H. (2001). A theory of interdisciplinary studies. *Issues in Integrative Studies, 19*, 1-25.

[40]Leighton, J.P. (2008). *Validity*, in *Encyclopedia of Educational Psychology*, N.J. Salkind and K. Rasmussen, Editors. SAGE Publications: Thousand Oaks, CA. p. 995-1000.

[41]Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*: Houghton, Mifflin and Company.

[42]Suen, H.K. (2008), *Measurement*, in *Encyclopedia of Educational Psychology*, N.J. Salkind and K. Rasmussen, Editors. SAGE Publications: Thousand Oaks, CA. p. 641-647.

[43]Trochim, W.M.K. (2006). *Research Methods Knowledge Base*. 2006; Available from: http://www.socialresearchmethods.net/kb.

[44]Lattuca, L. R., Trautvetter, L., Codd, S., & Knight, D. B. (2011). Working as a team: Enhancing interdisciplinarity for the Engineer of 2020. Paper forthcoming at the American Association of Engineering Educators, Vancouver, Canada.

[45]Marra, R. M., Palmer, B., & Litzinger, T. A. (2000). The effects of a first-year engineering design course on student intellectual development as measured by the Perry class scheme. *Journal of Engineering Education, 89*(1), 39-45.

[46]Wise, J. C., Lee, S., Litzinger, T. A., Marra, R. M., & Palmer, B. (2001, June). *Measuring cognitive change in engineering undergraduates: A longitudinal study*. Paper presented at the American Society for Engineering Education Conference, Albuquerque, NM.

[47]Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses.* Chicago, IL: University of Chicago Press.