A Classification System for Integrative Engineering Education

Prof. Jenn Stroud Rossmann, Lafayette College

Jenn Stroud Rossmann is Associate Professor and Department Head of Mechanical Engineering at Lafayette College. She earned her BS in mechanical engineering and the PhD in applied physics from the University of California, Berkeley. Prior to joining Lafayette, she was a faculty member at Harvey Mudd College. Her scholarly interests include the fluid dynamics of blood in vessels affected by atherosclerosis and aneurysm, the cultural history of engineering, and the aerodynamics of sports projectiles. She is the co-author (with Clive Dym and Lori Bassman) of the integrative mechanics textbook Engineering Mechanics: A Continuum Approach (CRC Press, Second Edition 2015), and the author of the Public Books essay series "An engineer reads a novel."

Dr. Mary Roth, Lafayette College

Mary Roth is the Simon Cameron Long Professor of Civil and Environmental Engineering at Lafayette College in Easton, Pennsylvania. She received her degrees in civil engineering from Lafayette College (B.S.), Cornell University (M.S.), and University of Maine (Ph.D.). She joined the faculty at Lafayette in 1991 and her research interests include risk assessment for earth retaining structures, site investigation methods in karst, and engineering pedagogy. She has authored or co-authored over 50 publications and has served as principal or co-principal investigator on eight grants from the National Science Foundation. At Lafayette College Dr. Roth is currently the Department Head of Civil and Environmental Engineering and has in the past served as Director of Engineering and Associate Provost for Academic Operations in addition to multiple faculty committee assignments. She has led campus-wide accreditation and assessment initiatives, implemented new faculty orientation programs, collaborated on the development of multiple proposals to private foundations, and coordinated interdisciplinary academic programs. She has received a number of awards in recognition of her scholarship and teaching including a Fulbright Scholarship in Norway, an American Council of Education Fellowship, and multiple teaching awards. Dr. Roth is a member of ASCE, ASFE, and ASEE. She is a member of Phi Beta Kappa and Tau Beta Pi and is a licensed engineer in the states of Maine and Pennsylvania.

A Classification System for Integrative Engineering Education

Abstract

A range of initiatives at our own and other institutions have been designed to achieve "interdisciplinary" engineering education and/or to "integrate" engineering with humanities, arts, and social sciences education. The motivations cited for these initiatives range from utilitarian goals supporting career development and professionalism to more holistic goals of citizenship and broad liberal education. Appropriate definitions and measures of "success" for such efforts vary, and faculty members involved in these efforts have concerns that narrow understanding of these efforts can marginalize these interdisciplinary and integrative experiences. The goal of this work is to support ongoing conversations in higher education about integrative and interdisciplinary education efforts by providing a shared language and classification system for understanding these efforts. This paper presents a classification system for integrative engineering education efforts and applies it to examples from our own institutions. This system builds on work by others in education generally and in the area of interdisciplinary education. Classifying ongoing initiatives makes it possible to better understand the range of current integrative efforts and potentially identify gaps in institutional repertoires that may create barriers to effectively scaffolded student learning. The classification system also enables an examination of the alignment between types of integrative efforts and more traditional disciplinary education efforts, and supports improved leadership in these integrative efforts and the articulation of more meaningful methods for measuring their success.

Introduction

"Interdisciplinarity" has reliably been a trending topic in higher education for many years; recently, it has been joined by the term "integrative." In discussions, these two concepts are defined vaguely, conflated, and their associated teaching practices blurred with their learning outcomes. The wide array of practices using these labels, and the diversity of descriptors, is an obstacle for the promotion and assessment of these efforts.

We are interested in those "interdisciplinary" and, particularly, "integrative" efforts that bridge engineering education with the traditional liberal arts. A range of activities at our own and other institutions have been designed to achieve "interdisciplinary" engineering education and/or to "integrate" engineering with humanities, arts, and social sciences education. Motivations cited for these initiatives range from utilitarian goals supporting career development and professionalism to more holistic goals of citizenship and broad liberal education. The goal of this work is to support ongoing conversations in higher education about integrative and interdisciplinary education efforts by providing a shared language and classification system for understanding these efforts.

Higher education wrestles with the balance of what Kwame Appiah has called its "utopian" and the "utilitarian" instincts: the "utopian" motivation to educate citizens broadly, regardless of their future plans; and the "utilitarian" goal of burnishing their credentials for the job market. Stewart-Gambino and Rossmann (2015), surveying evidence of the effectiveness of integration efforts both historically and across many institutions, noted that this distinction echoes the division between the "liberal" and the "useful" arts, or between the humanities, arts, and social sciences – and STEM. Integration may be viewed as one way to bring the utopian and utilitarian together, uniting and unifying both subject matter and educational outcomes from "both sides."

Boix Mansilla (2005) has investigated the characteristics of interdisciplinary work; through her studies, and those of Latucca (e.g. 2006), terminology has become more precise, and efforts have been classified in ways that enable their meaningful comparison, evaluation, and assessment. Latucca's work has particularly helped to distinguish between "inter-" and "multidisciplinary" activities, and Boix Mansilla's to categorize interdisciplinary student work by its: Purpose; Disciplinary Grounding; Integration; and Thoughtfulness.

AAC&U and Carnegie Foundation's (2004) Statement on Integrative Learning identified integration of learning as a primary outcome of a college education: ''Fostering students' abilities to integrate learning—over time, across courses, and between academic, personal, and community life—is one of the most important goals and challenges of higher education" (p. 1). While interdisciplinary or integrative teaching practices (e.g. Kuh, 2008; Nelson Laird, Shoup, Kuh, & Schwarz, 2008) facilitate integrative learning processes, they do not guarantee them.

A recent study by Barber (2012) analyzed the effectiveness of "integrative" education efforts, "to investigate empirically the ways in which college students bring knowledge and experiences together so that educators can better understand undergraduate student learning and more intentionally promote the integration of learning." Barber identified three distinct types of integration of learning: (a) connection, the discovery of a similarity between ideas that themselves remain distinctive; (b) application, the use of knowledge from one context in another; and (c) synthesis, the creation of new knowledge by combining insights.

What have been the driving forces behind these interdisciplinary and integrative initiatives? At the beginning of the 20th century, a traditional liberal arts education typically included courses in sciences, social sciences, and humanities and the 20th century saw the development of new disciplines and areas of research between and at the boundaries of traditional areas of focus, e.g., neuroscience. Julie Klein, in her book *Creating Interdisciplinary Campus Cultures* (2010), describes the history of the word interdisciplinarity:

The word appears in countless reports from professional associations, educational organizations, funding agencies, and science policy bodies. It is a keyword in strategic plans, accompanied by a companion rhetoric of *innovation*, *collaboration*, *competitiveness*, and the *cutting edge*. It also echoes in the way that we describe knowledge and education today. Images of knowledge as a *foundation* or a *linear structure* have been replaced by a network and a web. Images of the curriculum follow suit, supplanting *fragmentation* and *segmentation* with *integrating*, *connecting*, *linking*, and *clustering*. The concept is not new or, as some suggest, merely a passing fad. The earliest documented use of the word dates to the 1920s, in social science research and the general education movement." (p. 1)

In the forward to Klein's book, Carol Schneider, former President of the Association of American College's and Universities (AAC&U), notes the following:

> Spanning every kind of college and university… AAC&U members overwhelmingly are incorporating more integrative and engaged forms of learning in both general education and major programs (AAC&U, 2009). Whether the actual course of study is described as disciplinary or interdisciplinary, American higher education is now engaging students with big questions and real problems. Almost invariably, those problems span conventional disciplinary boundaries. (p. xvi)

Klein makes the argument that interdisciplinarity is gaining importance based on increased requests for information and help from individuals, programs, and institutions and a 2016 AAC&U report, *Recent Trends in General Education Design, Learning Outcomes, and Teaching Approaches* states, "[n]early all AAC&U institutions offer significant integrative or applied learning projects." (p. 6) The same 2016 report summarizes a 2014 survey of employers and noted that 73 percent of employers believed that having a "significant applied learning project in college would improve both the quality of learning… and the quality of graduates' preparations for careers." (p. 7)

However, Klein notes that there is a gap between the rhetoric of support for these integrative initiatives and the reality that exists at most institutions of higher education and the 2016 AAC&U report notes that "[l]ess than one in four (23%) institutions requires all students to participate in this type of project-based learning." (p. 6). We seem to understand that these interdisciplinary or integrative experiences are beneficial for students, but we have not clearly articulated or reached consensus on what these experiences are or should be, and we don't know how to require them of all students.

Approaches to the Integration of Engineering and Liberal Arts

Teaching Other Ways of Knowing: Fostering Familiarity

According to historian of technology Bruce Seely (1999), "[p]erhaps the most constant feature of American engineering education has been the demand for change." This demand often grows from introspective reports such as that by Grinter (1955), or the National Academy of Engineering's *Engineer of 2020* (NAE, 2004). Each call for reform "has sought to enlarge the core identity of the engineer from a technician skilled at calculation and fabrication to a professional member of the wider culture" (Cohen, Rossmann, and Sanford Bernhardt, 2014). Indeed, engineering is fundamentally sociotechnical (e.g. Cohen, Rossmann, and Sanford Bernhardt, 2014); as Grasso and Martinelli argued, "in order to serve humanity, engineers must at least attempt to understand the human condition" (Grasso and Martinelli, 2010, p 13). As a result, there are a wealth of efforts to "integrate" liberal arts knowledge, skills, and values into engineering education (e.g. those surveyed by Stewart-Gambino and Rossmann, 2015). At Lafayette College, a liberal arts college serving approximately 2500 undergraduates, of whom about a quarter pursue engineering majors, these efforts include:

- Technical courses that incorporate historical context; case studies help students tolerate ambiguity, appreciate relevance of concepts in many contexts, and identify geopolitical and economical concerns. For example, the Mechanical Engineering department's thermodynamics course has for 10 years required both a "technical" textbook and the nonfiction history of the quixotic developers of thermodynamic theory, *Warmth Disperses and Time Passes*; faculty encourage students to juxtapose the stories told by both texts.
- Three required courses and one elective in civil engineering affiliated with the College's Center for Community Engagement and engaging students in project work with a community partner.
- One mechanical engineering course that received a College "STEAM" grant to support the development of a music-related instrumentation lab experiment (Rhudy and Rossmann, 2015).
- Our first year introduction to engineering course featuring a cornerstone design experience as well as the introduction of engineering as a sociotechnical enterprise. We teach engineering design thinking as founded on empathy & interchange with all stakeholders; we encourage students to become *problem definers*, not simply problem solvers (Cohen, Rossmann, and Sanford Bernhardt, 2014).
- Engineering ethics infused throughout the engineering curricula in several majors; faculty members develop and include modules on ethics related to the course's technical content. This work in one engineering department has been recognized nationally with an award for excellence in promoting professionalism, ethics, and licensure in the curriculum;
- Our program leading to the Bachelor of Arts in Engineering Studies has, since 1970, prepared its graduates to be "technological integrators;" many work as engineers, and many others work in public policy, business, education, medicine, and law. Required coursework includes some fundamental engineering courses, some translational courses in engineering economics and engineering policy, and a sequence of courses in engineering studies – typically seminar-style, discussion-

and writing-intensive courses that ask students to consider the history of technology, interrogate the engineering profession, and through this coursework, to learn frameworks for analysis: a policy or an economic framework, for example. These courses are also open to (and popular with) nonmajors, leading to interdisciplinary discussions and project teams. The curriculum builds to a unique capstone experience (e.g. Rossmann and Sanford Bernhardt, 2015).

Engineering students at Lafayette College also take approximately one-third of their courses outside STEM subjects, in the humanities, arts, and social sciences. These distribution requirements introduce engineering students to alternate "ways of knowing," comprising a liberal education. However, these requirements are not necessarily integrative; they may provide opportunities for students to think, learn, or act integratively, but they are not designed to guarantee this. Thus, we are including in our proposed classification system only intentional acts of "integration" in which other disciplines' "ways of knowing" (methods, findings, and/or values) are included in the context of either other disciplinary or interdisciplinary experiences.

We are also interested in efforts to introduce engineering knowledge, skills, and values to non-engineering students. These efforts include those labeled "technological literacy" (e.g. Krupczak, 2009) as well as experiential design projects and other courses. They aim to provide engineering "ways of knowing" to other students. At Lafayette College, examples include:

- A History of Technology course that emphasizes the historical context for and impact of various technologies;
- An American Studies course that studies the social impacts of technology through contemporary art and literature;
- Courses taught by engineering faculty for non-engineering students and designated as "Science and Technology in Social Context," including seminars on energy, global warming, media portrayals of science, and sustainability; and
- The inclusion and recruitment of non engineers in engineering capstone design teams.

It is possible to make comparisons among the "ways of knowing" classes offered in liberal arts subjects with those created to foster technological literacy. Table 1 shows the analogies made between introductory engineering courses and courses offered in other subjects to be accessible to non-majors. This comparison makes clear a taxonomy of disciplinary courses: some [known as "Survey or Focus" in Table 1] introduce concepts and methods; others ["Create, Apply, Critique, Connect"] involve more sophistication and may be better suited for more advanced students.

Table 1: Comparison of Technology Literacy Courses to Other Disciplines, from Krupczak et al, 2007, Technological Literacy of Undergraduates: Developing Standard Models

Activity	Engineering for Everyone (Technology Literacy)	English	Psychology	Music
Survey	Technology Survey Courses	English 101: *Intro to Literature*	Psychology 101: *Intro to Psych*	Music 101: *Intro to Music*
Focus	Technology Focus Courses *Fuel Cell Systems* *Materials: Foundation of Soc.*	Focus or Topics Courses *British Literature* *American Literature*	Focus or Topics Courses *Developmental Psych* *Organizational Psych*	Focus or Topics Courses *Jazz Styles and Analysis* *Music of 18th Century*
Create ***Apply***	Technology Creation Courses (Engineering Design) *Intro. to Engineering Design* *Designing People*	Writing Courses *Creative Writing: Nonfiction* *Creative Writing: Poetry*	Creation or Application Courses *Research Methods in Psych* *Clinical Assessment*	Music Performance Music Composition
Critique ***Assess*** ***Reflect*** ***Connect***	Technology Critique Courses *Converging Technologies* *Engineering in Context*	Critique Course Examples: *Literature and Cultural Difference* *Literary Forms and Reformulations*	Critique, Assess, History Ex: *History of Modern Psychology* *The Psychology of Everyday Things*	Critique, Assess, History Ex: *History of Music Theory* *Aesthetic Theory and Modernism*

Integrating Disciplines: Developing Facility and Fluency

A third category of integrative experiences originate outside disciplinary departments, or are designed not as "outreach" by any one department but as intentional integration. Examples of these at Lafayette College include:

- Selection of first year reading books that demonstrate integrative work, e.g., *The Ghost Map* by Steven Johnson and *The Immortal Life of Henrietta Lacks* by Rebecca Skloot;
- An interdisciplinary project course for nonpaying "clients" in the community, known as Technology Clinic;
- A First Year Seminar introducing design principles and design review to students from all majors;
- First Year Seminars and project-based courses tied to the Grand Challenges;
- Campus groups such as Engineers Without Borders recruit students from all majors;
- A sustainable campus food loop that includes a College-supported farm managed by faculty, staff, and students; and
- A faculty-organized annual Forum for Technology & the Liberal Arts, with guest speakers, panels, and other events designed to facilitate interdisciplinary dialogue and collaboration. Past topics have included fracking and globalization.

Classifying these Efforts

The framework of Bloom's taxonomy (1956) has proven to be a useful way to consider and categorize student learning. Many disciplinary curricula can be understood to follow this general trajectory from the acquisition of knowledge to the creation of it: from content mastery to the development of methods and higher-order skills and expertise. While some integrative classes and experiences, especially those categorized as teaching "ways of knowing," fit into this framework, the most effective, higher-order *integrative* learning is not fully captured by the standard Bloom language. In Krupczak's comparison shown in Table 1, the term "Connect" is used for this goal of interdisciplinary efforts, for example the ability to contextualize disciplines relative to each other; it is positioned at the highest level of the proposed taxonomy for technological literacy courses. "Connect" is the first, lowest-level category of interdisciplinary learning named by Barber (2012);

Bloom's system, focused on traditional disciplinary learning, does not include "Connect." Neither Bloom nor Barber include terms such as "Compare" or "Collaborate," which like "Connect" are identifiable goals of interdisciplinary and integrative efforts.

We propose new language for the learning outcomes of integrative interdisciplinary efforts that includes the ability to synthesize, translate between, and collaborate among multiple disciplinary perspectives. We identify four main "levels" of student learning in intentionally integrative experiences:

- *Familiarity*: the acquisition of basic content from two or more disciplines in a context that demonstrates the need for a multi-discipline or interdisciplinary approach;
- *Facility*: the application of the language and methods of two or more disciplines, allowing students to develop and demonstrate increased comfort with disciplines outside their major
- *Fluency*: the ability to analyze and critique one discipline from a different disciplinary perspective; to appreciate multiple disciplines' unique expertise and compare them; and to collaborate meaningfully;
- *Fluidity*: the ability to combine multiple disciplines' methods and perspectives; to translate between them; and to produce new knowledge that links them.

Table 2 below maps this proposed language for intentionally integrative education to both Bloom's taxonomy and the language used in Table 1 for disciplinary education. Though the language of Barber (2012) is not included in Table 2, his "connection," "application," and "synthesis" correspond roughly to "Familiarity," "Facility," and "Fluency."

Table 2: Aligning proposed classification structure with Bloom and Krupczak

Bloom's Taxonomy	**Krupczak**	**Proposed**
Remembering	Survey	Familiarity (knowing content and context, understanding methods used)
Understanding	Focus	
Applying	Create/Apply	Facility (applying, becoming comfortable)
Analyzing	Critique/Assess	Fluency (critiquing, appreciating, comparing, collaborating)
Evaluating	Reflect	
Creating	Connect	Fluidity (connecting, moving between)

We next apply this proposed language for a taxonomy of integrative learning to the many approaches to integration at our own institution already described, showing the distribution of our integrative efforts in Table 3. The proposed classification structure distinguishes between the first category of "outreach" efforts, which are attempts to introduce disciplinary ways of knowing across disciplinary boundaries, and efforts designed to actively integrate the application of disciplinary knowledge and methods. We distinguish opportunities for engineering students from those for non-engineering students; while many of the integrative experiences appear in both columns, we intend this distinction to reveal any disparity in the available opportunities for integrative learning. The proposed structure applies both to practices that exist within a curricular structure and to experiences outside the curriculum; we label them accordingly in Table 3.

Table 3: Examples of campus approaches to the integration of engineering and the liberal arts at Lafayette College sorted by classification structure: delineating Familiarity, Facility, Fluency, and Familiarity.

Proposed Classification	For Engineering Students	For Non-Engineering Students
Familiarity	**<u>Curricular</u>** • Integrative First Year Seminar Courses, e.g., "Feed the World: The Grand Challenge of Global Hunger" • Modules included in required engineering courses that address history, ethics, or other disciplinary perspectives to engineering topics • D-School Design Thinking exercises in introduction to engineering courses • BA in Engineering Studies – introductory courses (methods and applications)	**<u>Curricular</u>** • Integrative First Year Seminar Courses, e.g., "Feed the World: The Grand Challenge of Global Hunger" • Science and Technology in a Social Context courses offered through engineering programs (an elective choice that meets CCS requirements) • Courses intentionally designed for non-engineering students to provide familiarity with integration, e.g., "Engineering America"
	<u>Extracurricular</u> • Forum on Technology and the Liberal Arts	**<u>Extra Curricular</u>** • Forum on Technology and the Liberal Arts
Facility	**<u>Curricular</u>** • BA in Engineering Studies – pre-capstone courses (methods and applications) • Opportunities to apply engineering concepts in humanities elective courses, e.g., courses in theater, studio arts, music performance, and creative writing	**<u>Curricular</u>** • Opportunities to apply concepts from humanities, sciences, or social sciences in engineering elective courses, e.g., "Environmental Site Assessment," "Green Engineering," "Biomechanics"
	<u>Extracurricular</u> • Opportunities to apply engineering concepts in competitions and performances in the creative arts, e.g., theater, studio art, music performance, creative writing • Opportunities to apply engineering concepts in competitions sponsored by IDEAL	**<u>Extracurricular</u>** • Opportunities to apply concepts from humanities, sciences, or social sciences in engineering-related projects and competitions, e.g., Society of Environmental Engineers and Scientists • Opportunities to apply concepts from humanities, sciences, or social sciences in competitions sponsored by IDEAL
Fluency	**<u>Curricular</u>** • BA in Engineering Studies – capstone courses (applications) • Art & Science team taught courses • IDEAL courses • Tech Clinic • Grand Challenges Courses	**<u>Curricular</u>** • Art & Science team taught courses • IDEAL courses • Tech Clinic • Grand Challenges Courses

	• Sustainable Solutions Course • Engineering capstone courses that include students from humanities, sciences, and/or social sciences	• Sustainable Solutions Course • Opportunities to be involved in engineering capstone courses to integrate content and methods from humanities, sciences, or social sciences to capstone projects
	<u>Extracurricular</u> • Engineers Without Borders • Society of Environmental Engineers and Scientists • College Farm projects	**<u>Extracurricular</u>** • Engineers Without Borders • Society of Environmental Engineers and Scientists • College Farm projects
Fluidity	While participating in a thoughtful combination of these opportunities may present the chance for an undergraduate to achieve integrative "fluidity," none of these experiences at Lafayette would guarantee such mastery.	

We can make some observations from this table of the integrated education efforts for Lafayette. As one might expect, we offer the most experiences at the level of introductory "familiarity" with a way of knowing. This is balanced by a similarly full menu of integrative "fluency" opportunities. However, fewer of our efforts fall in the middle, developmental "facility" level. We note, further, that many efforts at all levels are optional, or listed as "opportunities" to be involved. Making some of these experiences required, or integrating extracurricular experiences into the curriculum, would increase the number of students affected *and* send an institutional message about the importance of interdisciplinary integration.

We note that the "fluidity" category is the least populated at our undergraduate college. This may well be because truly integrative work can only occur at a more advanced level, in graduate study or beyond – once a single discipline has truly been mastered. "Fluidity" as we have defined it may also require multiple experiences in "familiarity" and "fluency" rather than being achievable in a single experience. Still, the relative dearth of opportunities in this category may also direct us to identify promising ideas elsewhere that can help our institution fill its "gaps." We should also consider whether a higher-level outcome like interdisciplinary *fluidity* requires reflection and analysis on the part of the student beyond the mere accumulation of a set of experiences; composing a portfolio of work and some introspective analysis about the effect of those experiences might reveal the degree of "fluidity" a student had achieved. While "fluidity" may be uncommonly attained by undergraduate students, it is a more likely result for <u>faculty</u> who participate in interdisciplinary integrative work. Institutions such as ours could encourage and facilitate this through faculty development supporting these initiatives.

Discussion: Applicability of the Proposed Classification System.

The development of a shared language to talk about and categorize opportunities for integrative learning can also improve campus communication, facilitate curriculum development, support the development of effective approaches to the assessment of these learning experiences, and strengthen campus leadership efforts.

The history of the assessment movement within higher education provides an example of the benefits of developing shared language and understandings regarding cross disciplinary campus initiatives. An early challenge in the assessment movement was developing language and understanding of terms such as goals, outcomes, evaluation, and the word assessment itself. There is no universally agreed upon set of terms, but most campuses have developed their own glossary of terms with meanings that align with campus culture (e.g., www.swarthmore.edu/assessment/assessment-basics, www.cmu.edu/teaching/assessment/basics/glossary.html, gradschool.wsu.edu/assessment-terminology.). Shared language benefits the discussion and advancement of any initiative.

In 2009, the AAC&U released collaboratively developed "VALUE" rubrics for various learning outcomes, including "integrative learning" (Rhodes, 2010). We see a strong endorsement of the value of shared language in AAC&U's stated goal of providing "a basic framework of expectations such that evidence of learning can by shared nationally through a common dialog and understanding of student success." (https://aacu.org/value/rubrics/integrative-learning) Although AAC&U's definition of "integrative learning" is not inherently interdisciplinary, but a more general description of "an understanding and a disposition that a student builds across the curriculum and co-curriculum," the VALUE rubrics are a useful tool for assessment of learning outcomes that are difficult to measure.

Having a shared language and categories for integrative learning facilitates curriculum development. The language proposed here with its parallels to Bloom's taxonomy may be applied to a course, a cluster of classes, or a curriculum and used to map the scaffolding supporting the integrative learning outcomes. By mapping the activities we develop for our initiative to the levels of student knowledge and ability, it is possible to identify where we may have gaps as we build our students' capacity from familiarity and facility to fluency and fluidity. The language also helps to clearly articulate our desired outcomes for integrative initiatives.

It is useful to think of the classification system, as we think of Bloom's taxonomy, as a progressive path along which students develop, furthering skills by building on foundational knowledge. To help students achieve advanced levels of interdisciplinary integration like "fluency" and "fluidity," it is necessary for them to have adequate opportunity to gain "familiarity" and "facility."

If students have not had an introduction to another discipline's "ways of knowing," it may be challenging, or even inappropriate, for educators asking them to "synthesize" them in another course or experience. It may be more effective to "scaffold" integrative experiences so that "ways of knowing" (content and methods) are available and understood prior to their application. But, since many of these experiences originate in different places on campus, that scaffolding cannot currently be constructed nor visualized by traditional methods such as departmental prerequisites. (And indeed, one goal of interdisciplinary and integrative teaching is to lower real and perceived barriers between disciplines.) By categorizing current opportunities for integrative learning in this way, institutions can visualize the areas of most need. (For example, if there are many opportunities supporting facility and fluency but insufficient experiences focused on the fundamental step of familiarity).

Common language and categories can also facilitate the development and sharing of assessment approaches. In particular, the mapping of terminology that encompasses integrative learning experiences to Bloom's taxonomy may create alignments between assessment approaches that have found to be useful in disciplinary initiatives with the assessment needs of integrative initiatives.

We find ABET's accreditation terminology both a useful example of unifying language and an illustration of a potential pitfall for those hoping to perform integrative collaboration and develop shared language to support that collaboration. First, ABET's formalization of shared language has indeed made "program objectives" and "learning outcomes" commonly understood terms among engineering educators. This is an indication of the power of shared language to standardize terminology and communicate across institutions. However, the lack of parallelism between ABET and non-engineering programs' accreditation standards means that non-engineering faculty do not necessarily have a similarly shared assessment vocabulary. Engineering faculty must be careful not to approach initiatives to "share language" related to integration efforts by simply imposing their own language on other disciplines. The language proposed here may be considered as a starting point for these cross-disciplinary conversations.

Finally, a shared language and classification system for integrative initiatives will benefit individuals in campus leadership positions, positional or otherwise. As noted above, a significant majority of employers believe that students are better prepared for employment if they engage in a "significant applied learning project." Campus leaders must be comfortable with the language of integrative learning in order to cultivate increased support for these initiatives.

Future work

We intend this proposal for shared language as an invitation to further conversation about integrated educational experiences. We believe thinking carefully about what we hope students acquire and achieve in integrated experiences will help us strategize about how such experiences may be sequenced, scaffolded, and more often curricularized into required, rather than optional, classes and projects.

The proposed classification system has highlighted areas of strength as well as areas Lafayette may wish to strengthen or consider more deeply. We next plan to consider how integrative efforts at other institutions might fit within the classification system. We will refer to review articles (e.g. Stewart-Gambino and Rossmann, 2015) to identify a range of interdisciplinary efforts; we plan to administer a survey of faculty and administrators to learn more about their efforts and how they might place them in the proposed system; we also hope to continue the conversation through an ASEE panel or hosted discussion. These applications of the system and discussions may well lead to refinements in the proposed language and system that make it more useful.

We are also interested in the student perspective on interdisciplinary and integrative work, and plan to perform a content analysis on existing student course evaluations to determine whether students' sense of course goals corresponds to faculty and administrators' notions.

References

Huber, M.T., and Hutchings, P. (2004). Integrative Learning: Mapping the Terrain. Washington, DC: Association of American Colleges and Universities.

Appiah, K.A. (September 13, 2015). What is the point of college? *New York Times*, pp. 18−20.

Association of American Colleges and Universities (2016). *Recent Trends in General Education Design, Learning Outcomes, and Teaching Approaches*, Association of American Colleges and Universities, Washington, DC.

Barber, James. Integration of Learning: A Grounded Theory Analysis of College Students' Learning, *American Educational Research Journal,* June 2012, Vol. 49, No. 3, pp. 590-617.

Bloom, B. S.; Engelhart, M. D.; Furst, E. J.; Hill, W. H.; Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals. *Handbook I: Cognitive domain*. New York: David McKay Company.

Boix-Mansilla, V. (2005). Assessing student work at disciplinary crossroads. *Change*, 37 (January/February), 14–21.

Bordogna, Joseph, Fromm, Eli, and Ernst, Edward W. (2013) Engineering Education: Innovation Through Integration Journal of Engineering Education Volume 82, Issue 1.

Bordogna, Joseph, Fromm, Eli, and Ernst, Edward W. (1995) An Integrative and Holistic Engineering Education *Journal of Science Education and Technology* Vol. 4, No. 3 (Sep., 1995), pp. 191-198

Cohen, B. R., Rossmann, J.S., and Sanford Bernhardt, K.L. (2014) Introducing Engineering as a Sociotechnical Enterprise. Proceedings of ASEE 2014: Annual Conference and Exposition. Indianapolis, Indiana: American Society for Engineering Education.

Grasso, D., & Martinelli, D. (2010). Holistic engineering education. In D. Grasso, & M. B. Burkins (Eds.), *Holistic engineering education: Beyond technology* (pp. 81-92). New York: Springer.

Klein J. T. (2005). Integrative learning and interdisciplinary studies. Peer Review, 7(4): 8–10.

Klein, Julie (2010) *Creating Interdisciplinary Campus Cultures,* Jossey-Bass.

Krupczak, J. et al. (2007) Technological Literacy of Undergraduates: Developing Standard Models, Workshop, National Academy of Engineering, Washington D.C., March 26-27, 2007

Krupczak, J. (2009). Engineering courses for non-engineers: Identifying and developing course models. Proceedings of ASEE 2009: Annual Conference & Exposition. Austin, Texas: American Society for Engineering Education.

Kuh G. D. (2008). High-impact educational practices: What they are, who has access to them, and why they matter. Washington, DC: Association of American Colleges and Universities.

Lattuca, L.R., Terenzini,P.T., & Volkwein, J.F. (2006). *Engineering change: A study of the impact of EC2000.* Baltimore, MD: ABET, Inc.

Nelson Laird, T. F., Shoup, R., Kuh, G. D., & Schwarz, M. J. (2008). The effects of discipline on deep approaches to student learning and college outcomes. Research in Higher Education, 49, 469-494.

Rhodes, T.L. (2010). Assessing Outcomes and Improving Achievement: Tips and Tools for Using Rubrics, Association of American Colleges and Universities, Washington, DC.

Rhudy, M., & Rossmann, T. (2015) Musical Analogies as a Teaching Tool for Engineering Concepts, Proceedings of ASEE 2015: Seattle, Washington: American Society for Engineering Education.10.18260/p.24517

Rossmann, J. S., & Sanford Bernhardt, K. (2015). Reaction: Sociotechnical engineering is one facet of prismatic liberal education. *Engineering Studies* 7(2-3):1-4 DOI: 10.1080/19378629.2015.1062505

Seely, B. (1999). Other Re-engineering of Engineering Education. *Journal of Engineering Education, 88*(3), 285-294.

Stewart-Gambino, H and Rossmann, J. S. (2015). "Often Asserted, Rarely Measured: The Value of Integrating Humanities, STEM, and Arts in Undergraduate Learning." National Academies of Sciences, Engineering and Medicine.