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Often Asserted, Rarely Measured: The Value of Integrating Humanities, STEM, and Arts in Undergraduate Learning

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INTRODUCTION

We want one class of persons to have a liberal education, and we want another class of persons, a very much larger class of necessity in every society, to forgo the privilege of a liberal education and fit themselves to perform specific difficult manual tasks. Woodrow Wilson, 1909 Address to the NYC High School Teachers' Association

At the turn of the 20th century Woodrow Wilson famously cast higher education in the United States as a privilege reserved for an elite cadre of the nation's future leaders. Today, however, the public views higher education as the path to broad social and economic mobility. STEM education – science, technology, engineering, and math – is widely assumed to be the key to this role in American higher education, particularly in the most dynamic sectors of the economy and, thus, in American innovation and global competitiveness. Higher education is still considered vital for preparing future leaders; however, at the beginning of the 21st century, the prevailing view is that education must be extended to prepare a broadly informed citizenry in order for the US to meet the technical challenges of modernity and to maintain its democratic leadership in the world. Yet, the perception of a conflict between these two aims persists in the American imagination. At least since the mid- 20th century, C. P. Snow's classic delineation of academia's "two cultures"[1] has helped define the view of higher education as perennially caught in the tension of a dual mission – providing society with a technically and scientifically literate workforce and a citizenry with the analytical perspectives gained from the traditional liberal arts, particularly humanities and the arts.

Kwame Anthony Appiah (2015) recently characterized the tension between the two contemporary strains in higher education as the choice between "utility" or "utopia". This language echoes the classical notion of disciplines as belonging to either the "liberal arts" or the "useful" ones. In fact, however, U.S. higher education claims *both* to train the modern workforce that fuels economic growth *and* to educate the citizenry in the perspectives necessary for a free, democratic marketplace of ideas and values. Even in the pre-professional fields, college and university curricula historically combined both economic and social purposes. Although the particular mix varies widely across the U.S higher education landscape, students can follow career-oriented and job training tracks at the same time that they complete general education requirements which typically include courses in humanities and the arts (e.g., American Association of Community and Junior Colleges, 1988).

[1] Snow himself was joining an ongoing discussion that may have begun with Descartes' distinction between materialist and idealist thinking, and these philosophical premises, colored by capitalist economic objectives, continue to foment debate, as texts such as *The One Culture?* (Labinger and Collins, 2001) illustrate.

Still, the questions of whether higher education is an elite privilege or an accessible public good, and what its purpose(s) may be, are contentious. And they are not rhetorical questions. In large part due to stagnated wages and steadily increasing costs of higher education, today's public fears that the educational pathway to socioeconomic security now lies beyond the reach of more and more Americans. The result is a perceived crisis not only for individual's access to career-enhancing education but also for creating a workforce for the challenges of heightened international economic competition. The uneasy marriage between "utility" and "utopia" seems to some – like the author of the commentary in the Harvard Crimson entitled "Let Them Eat Code" – like a quaint legacy of a bygone era that the country can no longer afford. Heightened competition for resources, perhaps particularly in public institutions, has led to concerns "that humanities instruction may recede into the small number of elite institutions that can afford the luxury of quasi-market-inefficient activities" (Taylor et al., 2010, p. 699). This sentiment is not unique to the US. For example, Japan's education minister, Hakuban Shimomura, recently called on all of Japan's 86 national universities to take "active steps to abolish (social science and humanities) organizations or to convert them to serve areas that better meet society's needs" (Grove, 2015). These developments appear to fundamentally change the meaning and content of what an educated citizenry knows or ought to know, and the result is an embattled liberal arts, humanities, and arts community fighting to defend their relevance and value to an increasingly skeptical public.

Measuring the "worth" of higher education generally and particular majors specifically has been the focus of policy makers, employers, and accrediting bodies for some time. However, little attention has been paid to the notion – widely held among most college and university administrators and faculty – that STEM and humanities and the arts not only contribute to the strength of the nation, but they contribute to the strength of *each other*. An effective counterpoint to Wilson's remarks is Noah Feldman's invocation to 2014 college graduates: "The whole point of the liberal arts education – that fragile, extraordinary, valuable thing, which is being put in your hands – is to teach you to participate as full partners in the making of the world around you" (Feldman, 2014). To be "full partners" would seem to require a full complement of methods, content, and values, achieved by a wide-ranging education. Higher education leaders – particularly at liberal arts institutions and flagship research institutions – paint optimistic pictures of the financial and personal rewards of becoming both a scientifically literate and broadly educated citizen. While many claims are made about these mutual benefits, robust evidence is harder to find, despite the educational assessment revolution and the public's fascination with rankings, scorecards, and measures of the return on investment in higher education. This study reviews both the claims and the existing research on ways educational endeavors toward "utility" or "utopia" might enrich one another in US undergraduate education.

STEM, HUMANISTIC INQUIRY, AND ARTISTIC EXPRESSION: WHAT SHOULD WE EXPECT?

The problem is that making rigid binary (or even tertiary) divides between intellectual pursuits seems misguided and limiting: there may be more similarities and convergences between the arts and the sciences than this binary divide acknowledges: the humanities have more rigour and method than they are often given credit for, and a scientist needs the kind of imagination and flair more often associated with the arts…So, researchers working on the human genome, the poems of John Keats, dark matter, the Tractatus of Wittgenstein, the Bible and the movement of refugees are all engaged in the same ultra-human tasks – how do we interpret ourselves, our bodies, our minds, our environment, our history and our morality? Marilyn Deegan, 2014, p. 26.

The terms “STEM,” “humanities,” and “arts” all serve as umbrella terms under which a variety of intellectual endeavors fit, sometimes neatly and often not, which complicates any examination of whether learning in STEM and the humanities and arts is synergistic or complementary. A brief review of the aims and nature of inquiry under these broad umbrella terms can help define what we might expect or not expect to find.

The National Science Foundation (NSF) first coined the acronym “STEM” in the early 2000s to bring greater focus to the need for the US to train more and better prepared students in basic science, mathematics, and engineering/technology. “STEM” as a construct easily conveys to the public the national importance of continued US leadership in basic science and applied technology across a host of issues that are too complex to easily explain – for example, technology and economic growth in a globalized world, security in a highly armed and unstable world, well-being in conditions of climate change, or the bio-medical advances that promise to solve life’s most feared diseases and conditions. Yet, for colleges and universities attempting to build programs and responsibly advise students about the benefits of learning different modes of inquiry, the acronym can obscure as much as illuminate.

Academic natural scientists (in biology, chemistry, physics, and geology, for example) view their research agendas as contributing to the expansion of the frontiers of knowledge about the natural world, albeit with some expectation that their discoveries may inform widespread applications that can contribute to society and human life. Mathematicians expand our understanding of human and natural complexity by discovering underlying patterns and offering a precise language for expressing them. Engineers, on the other hand, primarily work in applied settings, resolving the vast technical challenges of achieving individuals’ and society’s aims. “STEM” not only collapses significant differences in the aims and modes of inquiry across these fields, but also obscures other fields – notably the social sciences – whose scholars employ both the scientific method and mathematical and computational tools to study individual behavior and social institutions. Perhaps not surprisingly, therefore, students of different STEM fields may gain distinctly different competencies as a result of their disciplinary mastery.

Similarly, a range of disciplines are grouped under the “humanities and arts,” an umbrella that is more meaningful to academics who understand the historical origins of today’s educational administrative divisions than to the public at large. While STEM is associated with practical science and math skills necessary for the complex modern world, the humanities – the study of the human condition - suffers from association with the “softer” pursuits such as ethical, historical, theoretical and cultural understanding. Housed together in humanities divisions is a wide range of disciplines, such as literature, languages, religious studies, philosophy, art history, musicology and music history, classics, linguistics, film and media studies, and cultural and area studies. The arts, in turn, range from visual and performing arts to the creation of art in new media and in non-traditional spaces.

Are STEM and humanities and arts disciplines so different? On the one hand, yes – the scientific method and textual analysis, for example, are distinct methodologies, with one more concerned with determining facts about the natural world and the other more concerned with deepening our understanding of the complexities of the human condition. On the other hand, no – one can think of examples such as the similarities between the frontiers of philosophy and higher level mathematics or physics. Engineering design may share more in common with theater than with basic science research. In many ways, when we say “integration” we are really talking about “re-integration” of fields that were once not as distinct or as divided. Science was born of natural philosophy, and “STEM” fields are modes of inquiry carried out by humans in a social context. Their objectivity, as Lorraine Datson and Peter Galison have made clear, is an illusion (Datson and Galison, 2008). “We have to remember that what we observe is not nature in itself but nature exposed to our method of questioning,” wrote Werner Heisenberg in 1948: science is subjective, value-laden, and thus “humanist” (Heisenberg, 1948). And Thomas Kuhn made the case that scientific “truth” is a social and cultural construct, a consensus of a very specific scientific community (Kuhn, 1962).

Given the great breadth of aims and the differences in the nature of inquiry and expression within and between STEM and the humanities and arts, we might expect to find either an enormous array of educational synergy (at some level, learning itself deepens individuals’ capacity to learn) or very little (the degree of specialization in modern education makes “renaissance” learning more an ideal than a reality).

HUMANITIES AND ARTS CONTRIBUTIONS TO STEM EDUCATION

The prevailing tendency in the public discourse regarding STEM and liberal arts education is to frame the value of the humanities and arts as a way of “topping up” or “rounding out” the perspectives of STEM graduates. The argument is that taking humanities and arts courses teaches STEM students the historical, philosophical, social considerations that complement their technical and science skills so that they can understand the societal, economic, and political implications of scientific discovery and technological development (Campbell, 1985). A corollary argument is that the humanities and arts encourage the cultivation of creativity for STEM problem-solving (Adkins, 2010; Adams et al., 2003).

The confluence of claims and motivations from both the “utility” *and* the “utopia” sides of the scale, coupled with the emphasis on assessment and accreditation, may be the reason that of all the integration efforts surveyed for this report, those involving engineering education were the most numerous as well as the most thoroughly assessed. The ASEE Liberal Education and Engineering Science Division, and Union College’s annual Symposium on Engineering and Liberal Education, establish networks for those interested in pursuing integration and provide dissemination platforms for ideas and assessment. Among those who have implemented these programs, integration is valued for its contributions to both currencies.

It is often asserted that engineering, distinct from science and math, is fundamentally sociotechnical (e.g. Cohen, Rossmann, and Sanford Bernhardt, 2014), and thus that the more broadly or liberally educated the engineer, the more effectively that engineer will serve society. Echoing this sentiment, Grasso and Martinelli argue that “in order to serve humanity, engineers must at least attempt to understand the human condition” (Grasso and Martinelli, 2010, p 13). John Horgan (2013) writes, “The humanities are subversive. They undermine the claims of all authorities, whether political, religious or scientific... Science has told us a lot about ourselves, and we’re learning more every day. But the humanities remind us that we have an enormous capacity for deluding ourselves.” Such arguments resonate with those who consider education to be the development of humans, not only of “human capital” (e.g. Cassidy, 2015).

Given such arguments, one might expect to see greater evidence of a holistic approach to the liberal arts and STEM in engineering education. In fact, engineering education, created by engineering faculty, is periodically considered a candidate for redesign. As in any iterative design process, educators ask whether their curricula have achieved the initial objectives, whether those objectives are in fact the appropriate ones, and whether it may be necessary to tweak the prototype or construct a new one. The historian of technology Bruce Seely (1999) writes that "[p]erhaps the most constant feature of American engineering education has been the demand for change." This demand often takes the form of soul-searching 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 et al., 2014).

Program-level integration has been a hallmark of Lafayette College's Engineering Studies program since 1970 (Rossmann and Sanford Bernhardt, 2015), though the disciplinary boundaries its idealistic creators sought to dissolve proved stronger than anticipated. Today, the program's enrollments rival those in the College's four BS engineering disciplines. The 1970's WPI Plan (Grogan and Vaz, 2003) was a re-framing of Worcester Polytechnic Institute's technical curriculum in societal context, emphasizing cooperative, project-based integrative and interdisciplinary learning. Although a proposed AB program in engineering was neither successful nor sustained, this institutional sensibility is still reflected in WPI practices at the course level (e.g. Rudolph, 2015) as well as larger-scale initiatives. Both of these initiatives reflect the mid-to-late 1960s interest in educating "socio-technologists" to bridge the gap between competing (admiring on one hand, critical on the other) visions of technology and permit holistic progress; this period is thoroughly discussed by Matthew Wisnioski (Wisnioski, 2012).[2]

Since the late-1960s moment at which boundary-transgressing programs like the WPI Plan and Lafayette College's AB in Engineering Studies curriculum were launched, there have been many years in which disciplinary boundaries remained strong, sometimes even being fortified on campuses. Integrative activities flourished only on the margins of traditional disciplines, rarely offered much institutional nourishment or light (e.g. Wisnioski, 2012). In the 1980s, a Brown University newsletter known as "The Weaver of Information and Perspectives on Technological Literacy" features reports of many pedagogically innovative activities (e.g. Morgan and Williams, 1986) that struggled to sustain themselves. In the last decade, resurgent "interdisciplinarity" has given rise to several new programs designed to appeal to (and educate) consilient thinkers. The program in Liberal Arts and Engineering at California Polytechnic San Luis Obispo faced challenges in establishing a new hybrid course of study, but has proved popular with students who find themselves both fulfilled and employable (Gillette, Lowham, and Haungs, 2015). The University of Utah's program in Entertainment arts and Engineering, and Arizona State's School of Arts, Media + Engineering, are each described as "gaining traction" (Daniel, 2015). Another intriguing new program is the integrated CS + X joint major at Stanford University, "an experiment in learning" starting in Fall 2014, with the stated goal "to give Stanford students the chance to become a new type of engineer and a new type of humanist" (Roberts, 2014).

In January, 2015, MIT's Louis Bucciarelli convened a workshop hosted by the National Academy of Engineering and National Science Foundation, to share and discuss current practices as well as potential curricular redesign concepts to integrate liberal arts and engineering content (Bucciarelli and Drew, 2015; Bucciarelli, Drew & Tobias, 2015). A primary value of this workshop was to bring people together who normally work alone at their own institutions, in the trenches and often on the margins,

[2] Although engineering education itself was not wholly transformed by these considerations, the integrative discipline of STS – discussed later in this section – grew out of these competing visions.

and shine light on a wide range of activities and perspectives. Many existing and well-tested prototypes for the proposed redesign challenge could be discussed and evaluated. Workshop discussions addressed student prospects following integrative degree programs; the diverse range of institutional obstacles to integration; and the need for engineers both to become broadly educated *and* to recognize the limits of their expertise, and when to reach out to other experts (e.g. Klein, 2015). Gary Downey has published both the provocation for this particular workshop, as well as many participants' contributions and responses, in a special issue of the journal *Engineering Studies* (Vol. 7(2)).

Strong examples of course-level innovation include Olin College's integrated course blocks, in which two disciplines were taught in complementary ways, linked to a semester-long hands-on project that asked students to draw on both subjects. Although this ambitious curricular model was later revised, some interdisciplinary courses remain on the books, notably a team-taught class that combines materials science and history (Stolk and Martello, 2007). In the view of the Olin College faculty members, "Successful integration depended on the presence of two faculty members who had some appreciation for each other's disciplinary approach, and this appreciation soon transformed into familiarity." Team development and instruction is an aspect of other successful courses, including courses that blend art and flow visualization (e.g. Hertzberg et al., 2014; Rossmann and Skvirsky, 2010), in which students develop mutual literacies. In these courses, some outcomes are shared by both disciplines, and student achievement is highest in the common outcomes. Students generally report increased interest in both subjects as well as in interdisciplinary work as a result of completing these courses (e.g. Rossmann and Skvirsky, 2010).

David Billington of Princeton pioneered an integrative approach to the history of technology in his courses and texts (Billington and Billington, 2006). Billington's flagship course was designed to fulfill general education requirements. For example, a writing-intensive version counts as a history course for engineering students, and the same lectures with a hands-on lab course fulfill a science/engineering literacy requirement for non-engineering students. While this ingeniously ensures high enrollments of students from all backgrounds, it limits the active interaction of those students to only their shared meetings in a large lecture hall. Billington received NSF support to host an annual workshop on his teaching methods, and many institutions now offer at least one "Billington-inspired" course.

Social justice and engineering concepts have been integrated effectively by Donna Riley (Riley, 2008) and Juan Lucena (Lucena, 2013). In addition to rigorously evaluating the effects of integration in her own courses, Riley has developed modules for other instructors to include within "traditional" thermodynamics courses (Riley, 2012), and has studied and reported on the effectiveness of these modules in a wide range of educational settings (e.g. 2014 Symposium on Engineering and Liberal Education, Union College). As one example, students studying a technical subject might juxtapose a standard textbook with a history of the field, as is done at Smith (Riley, 2012) and Lafayette (Rossmann and Sanford Bernhardt, 2015) Colleges to highlight the social construction of technology and engineering theory. Natalie Jeremijenko's teaching, as well as her professional projects and installations, often critique technology and technocentric politics through an artistic lens (e.g. Jeremijenko, 2015; Schwendener, 2010).

Yet engineering education, while attentive to accreditation's insistence on "continuous improvement," and inclined to create many innovative integration sites as just described, has proven resistant to holistic overhaul and reform. Such dramatic revisions are often avoided because of the sense among engineering educators that (a) the requirements of accreditation would not permit such changes; and/or (b) the "rigor" and math-reliance of engineering education must be maintained.

Both of these assumptions demand scrutiny. The accreditation criteria are often cited as motivations for (rather than obstacles to) the development of integrative instructional methods, courses and projects. The EC 2000 criteria issued by ABET are seen by many as offering "freedom" (Ollis, Neeley, & Luegenbiehl, 2004), and many of the eleven criteria relate directly to liberal education. They require that students achieve effective communication skills; an appreciation of ethical and professional responsibility; the ability to collaborate on "multidisciplinary teams;" "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;" a knowledge of contemporary issues; an appreciation of the importance of "lifelong learning;" and other outcomes. While some likely view these outcomes as those most readily outsourced to other departments on campus, the same outcomes have led many to create thoughtfully integrated courses and programs. Furthermore, alumni and employers frequently report that so-called "soft skills" are as important as, if not more important than, "technical" ones to the success of graduates in the workplace (e.g. Wolfe, 2010). This challenges the second assumption of educators resistant to change. Indeed, the importance of these skills to the effectiveness of graduates often provides additional motivation, and potential institutional leverage, for those educators wishing to innovate and integrate.

Science and mathematics education also have created some fruitful integration sites with humanities and arts. The practice of origami provides a nexus for artistic and mathematical energies, as evidenced by interdisciplinary symposia on many campuses (including our own, in 2013), and by the popularity of computer programmer-turned-origami artist Robert Lang as a guest speaker, and further by the Guggenheim Award recently awarded to MIT's Erik and Martin Demaine (Hull, 2006; Lang, 2012; Lovelace, 2014). Similarly, the synthesis of mathematics and music has given rise to countless courses, often using one of the topics to recruit students who may be fearful of the others. Researchers have demonstrated that the inclusion of music helps students learn the mathematical concepts more effectively (e.g. Courey et al., 2012). Science, mathematics and social justice courses can help both STEM students and those from other disciplines both appreciate the societal relevance of scientific and mathematical concepts and develop a critical eye for the (mis)use of evidence in public discourse. (Chamany, 2006; Watts and Guessous, 2006; Skubikowski et al., eds, 2010, Suzuki, 2015).

Mary Flanagan of Dartmouth promotes the humanist analysis of computer games in the development of socially-conscious game design, reading games as you might a text. "The class, instead of pushing interdisciplinarity in an obvious way, relies on it in a fundamental way. One can't make games about the world without actually understanding a little bit about that world" (Barber, 2010). In the games we make and play, Flanagan argues, we reveal our cultural biases and values (Flanagan, 2014). Flanagan's game design courses intersect with digital studies courses in Film and Media Studies, Computer Science, English, Philosophy, and Studio Art.

MIT's Terrascope program integrates the production of topical radio programs into a first-year STEM experience which has helped STEM students develop communication skills and ability to contextualize their work (Epstein et al., 2010). Topical courses of current interest are often used to unite disparate fields: forensic science, climate change, sustainability and the environment, genetics, energy, stem cells, AIDS, and the like. In each, a blend of literature, history, science, technology, and cultural anthropology – in combinations specific to the particular topics and courses – addresses the central issue. Many of these courses have been evaluated and disseminated by the SENCER organization (Burns, 2012).

Since Rachel Carson's *Silent Spring*, or perhaps since Thoreau, there has been a strong link between environmental science and the humanities. Carson's descendants now populate a field that might best be called "environmental justice" (Ottinger and Cohen, Eds, 2011). At many institutions, courses are offered that integrate scientific and humanist texts, methods, and values; this integration is critical to most degree programs in environmental studies and science (e.g. Whitman, 2015; Hope, 2015). Carolyn Merchant braided together gender and environmental studies (Merchant, 1980). At Harvey Mudd College, humanities, art, and media studies courses address environmental and life sciences questions (Mayeri, 2014).

Many universities with both strong STEM and liberal arts programs have a long history of offering programs in Science, Technology, and Society (STS, sometimes called or viewed as part of "science studies"). Generally, these programs apply the methods and values of humanities and social science inquiry to the natural sciences and engineering. They teach students to understand and critique science and technology in their historical, political, and cultural contexts, and to appreciate the social construction of scientific knowledge and engineering artifacts (Ackay and Ackay, 2015; Han and Jeong, 2014). These programs can achieve true integration in that students must understand the nature of scientific and technical inquiry and innovation as well as develop the critical thinking skills associated with political science, history, sociology/anthropology, and ethics. Each of these programs has its own particular niche, both in the broader field of STS and at its own institution. For example, the programs at Virginia Tech and the University of Virginia are housed within engineering schools and offer courses including engineering ethics to engineering undergraduates. Others, for example Lehigh University's program, are housed in arts and sciences and were founded with the vision of attracting both engineering and liberal arts students. Trevor Pinch's work integrating sociology with science and engineering education demonstrates that STEM students appreciate the "relevance" of sociology to their intended professions (Pinch, 2008). He also notes that similar courses are rarely taught within sociology departments, but were more likely to be found in STS programs.

The profound ethical questions resulting from rapid scientific and technological advances, particularly in medicine and technology, create natural sites for potential humanistic and STEM integration. Both pre-med and engineering curricula, perhaps because they also are more obviously oriented toward professional tracks, bring together philosophical, sociological, and humanistic modes of inquiry and content in integrated ethics instruction. Bioethics, in particular, is a formerly novel and now well-established integrative discipline. In bioethics courses, students develop the tools and context for moral discernment in life sciences, medicine, and biotechnology, infusing their analyses with content and perspectives from law, policy, and philosophy (Vaughn, 2012; Lewin et al., 2004; Leppa and Terry, 2004). In physics and other natural sciences, ethics is a standard (and often required) component of sponsored research programs (Hicks, 2013).

Many integrative practices are organized under the heading of "STEAM," which includes arts in STEM. John Maeda (e.g. 2013) argues that STEAM makes STEM into something more powerful, capable of generating transformative innovation. There is undeniable elegance to such arguments, including the notion that both science and art pursue (and prize) truth and beauty. STEAM initiatives have significant momentum in both K-12 and higher education (Miller, 2014; Maldonado and Pearson, 2013; Cooper and

Heaverlo, 2013). STEAM efforts have gained legislative support through House Resolution 319, introduced in 2012 and still under Committee consideration, which "expresses the sense of the House of Representatives that adding art and design into federal programs that target Science, Technology, Engineering and Math (STEM) fields, encourages innovation and economic growth in the United States." Notable STEAM efforts include instruction in hand drawing (Leake, at Illinois), and narrative and role playing (at the University of Delaware), both celebrated by Maeda (2013). One study of two university programs that integrate arts with STEM education finds that such programs can boost STEM students' retention of material, learning enjoyment, and career choices. Yet, the author questions whether "there is a disproportionate emphasis on solely improving STEM learning" and notes that the evidence is not clear about whether "there are similar sentiments about STEAM programs as a vehicle to exposure to STEM fields" among non-STEM students (Ghanbari, 2015).

Within medical education, there has been a push toward medical humanities and the use of "narrative medicine" – viewing patient histories as stories, and analyzing them as one might unpack a novel's themes and plot strands. While this movement is beyond the scope of the current study's focus on primarily undergraduate education, it is a useful example of the methods and values of the humanities being integrated for enhanced STEM outcomes. The development of this methodology from a "good idea" (Charon, 2001) to a widespread practice provides a useful model for other integration efforts.

STEM CONTRIBUTIONS TO HUMANITIES AND ARTS EDUCATION

The times demand that we use all of the tools we have to improve our students' scientific literacy. To successfully open a dialog with those who are doubtful about science, we must speak clearly about the benefits and risks in scientific advances. We must listen carefully to those outside the science enterprise and recognize that there is no monolithic viewpoint. If people and institutions have the will, then we can turn the tide for scientific literacy. Time is not our ally, and action is needed now. Wayne Clough, Secretary, Smithsonian Institution (2011)

Similar to the view that humanities and arts can "round out" STEM students' perspectives in ways that may sharpen their creativity, design, and diagnostic skills, we might expect to find a corresponding suggestion that STEM "tops up" the skills students gain in the traditional liberal arts. There are few claims that infusing STEM education into humanities and arts majors helps students become better scholars of humanities or arts, per se. Rather, STEM education is broadly viewed as necessary for non-STEM students in their capacities as future voters, potential policy-makers, or managers. Polls demonstrate that disturbing percentages of Americans have (at best) superficial understanding of such issues such as climate change, medical research, gene mapping, or other complex issues in the modern world. The perceived crisis of "scientific illiteracy" among those who will fill the ranks of the citizenry – for example, teachers, parents, employees, non-profit leaders, and politicians – receives attention among STEM educators who fear that the US political structure will not be able to cope with the scientific and technological choices that are necessary in the 21st century. In short, humanities and arts graduates must be armed with an understanding of technical and scientific knowledge that informs the study of the human condition.

Sometimes claims about the potential for greater exposure to STEM education to complement and support the liberal arts curricula are most passionately made by STEM scholars themselves (e.g. Frankenfeld, 1992; Schachterle, 2008; Rossmann, 2014). When Americans read about wind farms, fracking, ethanol subsidies, or have to decide whether to buy an electric car for their families, they would be well served by some knowledge of thermodynamics. Discussions of climate change are strengthened by an understanding of the relevant earth science *and* of scientific methods. Frankenfeld (1992) coined the term "technological citizenship" to describe exactly this. Being a good technological citizen means asking questions and not thinking of your phone or your car or an airplane as a "black box," whose workings are abstract and mysterious. Agile intellectual curiosity fed and fueled by a liberal education should, by this reasoning, *include* technology: how it works, how it is made, how it was developed, how it is distributed. Noted philosopher Martha Nussbaum agrees that democracies need "complete citizens who can think for themselves, criticize tradition, and understand the significance of another person's sufferings and achievements" (Nussbaum, 2010, p. 2). A liberal education that includes STEM methods and values prepares this citizen more fully.

Advocates for technological literacy have created a variety of courses and experiences, and a wide range of these have been surveyed and evaluated (e.g. Krupczak, 2004; Krupczak and Ollis, 2005 and 2006; Ebert-May et al., 2010). In a 2007 workshop co-hosted by the National Science Foundation and the National Academy of Engineering, John Krupczak and colleagues defined four main categories of such efforts to foster technological citizenship: survey courses; courses focused on a particular topic; design courses that involved students in technology creation; and "technology in context" courses in which technology is critically connected to other disciplines. (It is worth observing here that a curriculum in "science and technology studies," or STS, would likely contain all of these.) While these reports emphasize the benefits these courses have for non-engineers, historian and ethicist of technology Sarah Pfatteicher has pointed out that many engineers' educations would also be strengthened by such experiences (quoted in Krupczak, 2007). These longitudinal studies of technological literacy efforts have yielded a relatively robust set of technological literacy outcomes and methods for their assessment, all of which build on two NAE/NRC reports (*Technically Speaking*, 2002 and *Tech Tally*, 2006).

Some humanists make the broader claim that STEM pedagogies can strengthen humanities learning outcomes. For example, Cavanaugh (2010) argues that humanists should borrow from cognitive science that shows that techniques like problem-based learning, wikis, service learning, and other software tools boost the outcomes associated with the humanities. "Among the features of brain-based learning are active uncertainty or the tolerance for ambiguity; problem solving; questioning; and patterning by drawing relationships through the use of metaphor, similes, and demonstrations" (p. 140). Other examples of course-level integration of STEM concepts and context into humanities learning include, for example, a literature course in which "useless design" objects are constructed by students as they read Heidegger, Charles Keller, Matthew Crawford, and others (Crawford et al., 2014). Ogilvie and Scagnetti (2015) involved communication design students and methods in Ogilvie's research on endangered languages, using digital tools "to support efforts to preserve and revitalized endangered languages."

Others make a more instrumental argument for the utility of STEM education for the liberal arts. For humanities and arts students who face a difficult job market without a clearly pre-professional degree, additional proficiency in technical and computational tools that are valued by employers can add to individual's job competitiveness. Although humanities and art scholars always have used technical tools in their research and pedagogy, more and more scholars and their students will engage with the sophisticated technical tools grouped under the umbrella terms like "digital humanities" and "big data." These include Geographic Information Systems (GIS) mapping (Bodenhamer, et al., 2010), the use of databases for research, rapid prototyping or "3D printers," and other technologies. It is important to note, however, that the instrumental value of adding proficiency with technical tools to enhance one's resume, without additional instruction or discussion, does not "integrate" STEM education into the humanities or arts curriculum – just as incorporating writing or artistic assignments into STEM courses is not automatically an act of meaningful integration.

Much as humanities and arts content often serve to contextualize STEM content, some humanists have turned their lenses on technology, making STEM the context for application of humanist and artistic methodologies. The interdisciplinary discussions fostered by the Society for Literature, Science, and the Arts in its journal *Configurations* served as a forum for such scholars as Katherine Hayles and Donna Haraway to discuss what it means to be human in a "post-human" (e.g. Hayles, 1999) or increasingly techno-philic (e.g. Haraway, 1994) world.

Overall, however, infusions of STEM content, context, and methods into humanities and arts experiences are much rarer than their inverse. Furthermore, like the technological literacy and STS curricula, these experiences appear motivated by the opportunity to develop "full partners" and "complete citizens" rather than to strengthen the humanities and arts as valuable endeavors in their own right.

A shift away from a search for evidence that might suggest that STEM content might help strengthen humanities and arts student learning, per se, yields other examples of successful educational outcomes. The section below examines multidisciplinary experiential learning *in addition* to disciplinary work. The advantage of framing the endeavor as a mutually-beneficial collaboration across disciplines is that it allows educators and students to sidestep the perceived "utility" versus "utopia" tension, concentrating instead on developing each team member's skills and perspectives in service of a larger goal.

THE PROMISE OF EXPERIENTIAL, MULTIDISCIPLINARY LEARNING IN CONTEXT

The United States has many advantages when it comes to creativity, including freedom of thought and speech, a diverse population, an open society, capital markets that quickly move to support new and exciting ideas, and a heritage of risk taking and pushing back frontiers. For these reasons, the changes in the global environment play to our strengths. We are well-positioned to maintain and even increase our prosperity over the coming decades, and colleges and universities will play a critical role in this national endeavor as centers for a creative, liberal education. Deborah L. Wince-Smith, President, Council on Competitiveness (2006, p. 14)

Multidisciplinary, experiential learning experiences offer students from various disciplines an opportunity to appreciate both their own and others' contributions and importance to a shared outcome. Such projects may be commercially or socially entrepreneurial, community-based, concerned with social justice, or any combination of valued goals. And, they may be framed with varying pedagogical tools such as problem-based learning, design thinking, or other collaborative processes.

A platform for collaborations between STEM and humanities/arts (in addition to other fields) often can be found in campus-based centers for innovation, creativity, and/or entrepreneurship. President Obama made the case in his 2011 State of the Union address that the vitality and strength of the US economy rests on our ability to produce a creative, innovative workforce, and he has called repeatedly for strengthening the K-12 STEM pipeline toward this goal. Wince-Smith (2006) echoes that “creativity and innovation have become essential to generating the jobs that we will need in order to sustain our standard of living over the coming decades…In today’s economy, that means focusing on the most creative aspects – generating intellectual property, emphasizing design, and taking risks on completely new ways of doing business” (p.14). But, unlike President Obama whose rhetoric and initiatives emphasize the centrality of STEM education for building an innovative economy, Wince-Smith argues “It is important to recognize that while science and technology are critical to the innovation process, innovation is not the sole preserve of scientists and engineers. A truly cross-disciplinary team must span the arts, humanities, and social sciences as well as the sciences….An innovative economy depends on creative people in the arts, literature, design, marketing, management, and a range of other areas” (p. 14).

Coining the acronym ICE (innovation, creativity, entrepreneurship), Buller (2011) argues that transcending the binary conception of STEM versus liberal arts allows higher education to consider that “what constitutes original thought might be similar across professional programs, the liberal arts, STEM disciplines, and other academic fields.” Many examples of non-profit and public sector improvements through the implementation of a new practice or existing tool show that social innovation is as relevant as innovative commercial ventures (Tidd and Bessant, 2011; Windrum and Koch, 2008 cited in Gulbrandsen and Aanstaad, 2015). Buller points to programs such as those at DePaul and Wake Forest that invite students from all disciplines into opportunities from first year seminars through graduate programs as examples of successful integration of multiple disciplines. In addition to the claims that such programs can fulfill President Obama’s call for higher education to produce graduates ready for global competition, these programs might provide the kinds of experiences that strengthen both STEM and non-STEM students’ abilities to value the merits of their own disciplinary training while learning more about the contributions of others’ (Brown and Kuratko, 2015). Whether these programs strengthen students’ learning in their own fields, or deepen their understanding of others, requires further research.

The National Academy of Engineering in 2008 issued a set of “Grand Challenges” to motivate engineering educators and practicing engineers to consider problems such as clean water, energy availability, and global health. These challenges are inherently socio-technical and are intertwined with geopolitical, economic, philosophical, and cultural factors. Institutions that develop Grand Challenges project experiences recruit student from many majors, in at least one case developing new descriptions of the Challenges that emphasize their interdisciplinarity (e.g. Rossmann and Sanford Bernhardt, 2015). In working together to define design problems and to identify possible solutions and context-specific issues, students from all backgrounds gain appreciation for the methods, values, and history of other disciplines. When designed to explicitly include non-engineering students, the aim is for students to develop a mutual literacy in one another’s disciplines and collaborate in this shared space (NAE, 2012).

Worcester Polytechnic Institute’s Great Problems Seminars (Savilonis, Spanagel, and Wobbe, 2010) address a wide range of vexing global sociotechnical problems, including the Grand Challenges. Since 2007, this team-taught problem-based learning course has engaged first-year students in “interdisciplinary, not multidisciplinary” discussions and design projects related to these global concerns. Faculty teams are multidisciplinary: for example, a chemist teamed with an economist. WPI has used both internal and external assessment results on the seminars to refine the course outcomes, structure, and delivery. The faculty members have also developed a handbook to enable additional WPI faculty to join the Great Problems teaching team, and to disseminate their effective strategies.

In addition to programs that invite STEM and non-STEM students to work on complex projects that require multiple disciplinary lenses, global education also can offer opportunities for building integrative competencies. For example, the University of Rhode Island's successful International Engineering Program in which engineering students double major in a foreign language and an engineering discipline (coupled with a study abroad experience) has grown steadily and expanded to several language tracks. Perhaps more intriguing, however, is that the IEP program has produced other, less-anticipated benefits: "Women have enrolled in engineering in increasing numbers…(while) the academic quality of Rhode Island's engineering students has improved" (Fischer, 2012). Although such programs are built to couple STEM with language ability, their appeal to students suggests that multidisciplinary projects such as the Grand Challenges in a global context may not only strengthen all students' global citizenship, but also strengthen the perceived relevance of the contributions of both the STEM and liberal arts. Blue, et al. (2013) and Nieusma (2011) and others have documented the challenges and rewards of such global projects for a wide range of students.

Within these multidisciplinary project teams, whether the focus is local or global, or on capital or social entrepreneurship, students are often brought together to define and address a design problem. The engineering design process synthesizes humanistic, social, creative, and analytical skills, and is thus one logical forum for meaningful integration of a range of disciplinary methods and values.

Frameworks for the engineering design process use varying nomenclature to describe the same essential elements: need-finding (or empathy); problem definition and framing; creative idea generation (sometimes, "ideation"); prototyping; and testing and analysis. The process is iterative and communication with multiple stakeholders is critical throughout the process. (Engineering design differs profoundly from the scientific method, and from mathematical problem solving, and the use of a monolithic "STEM" acronym elides their key distinctions.) While this is an engineering methodology, it shares with the arts an emphasis on creativity, and with the humanities and social sciences a comfort with the ambiguity of non-unique, context-specific solutions. Design experiences develop self-efficacy and creative confidence (Kelley and Kelley, 2013).

Effective [engineering] design begins with, and maintains, "empathy" or "understanding" for people and for the societal, cultural, ecological, political, etc. contexts in which they live. This is sometimes called "need finding" or "need identification;" both terms emphasize that design is for people, and that designers must learn enough to appreciate how people might use and interact with designed products and processes, how people might gain access and/or what might prevent people from adopting new designs, and who else's needs or interests designers ought to be considering. Empathy has been shown to be a skill (e.g. Cameron et al., 2015) that can be further developed by paying careful attention to literature (and other artistic expressions) from a range of cultures and perspectives (e.g. Kidd and Castano, 2013). Effective design teams must draw on this empathy and also comprehend the larger societal and cultural issues affecting *all* possible stakeholders in the manufacture or implementation and distribution of their design; they must value this sociological, political, and economic expertise, and must view such experts as partners. It is hard to imagine a stronger argument for the broadest possible education, or for multidisciplinary collaboration that respects and values the contributions of all disciplines.

Establishing empathy and appreciation for the complex societal and social contexts in which one's stakeholders reside enables designers to consider the *definition* of relevant problems, rather than the mere solution of pre-defined and possibly ill-posed ones. Downey (2009) has eloquently justified the centralization of problem definition to design processes: “practices of collaborative problem definition that …had been performing in the margins did not have to be marginal.” Thoughtful process definition meaningfully involves non-engineering participants, including those engaged in a critique of science and technology, and in his own experience, “those who held stakes in the dominant image of problem solving as well as others engaged in struggle over that image and its practices could see themselves in it” (Downey, 2009, p. 71).

Another key “step” in the iterative design process is prototyping and testing a design. Whether this is a device, a process, or an experience, it is crucial for designers to build a representation a physical model, or a storyboard of users interacting with the design, or some other way of allowing prospective users to interact with and respond to the design. Engineers must consider the feasibility of their designs at this stage; manufacturing concerns may force designs to be revised. Much is learned from observing users’ interactions with and responses to prototypes, allowing designs themselves, or even the initial problem definition, to be refined to better fulfill a user’s needs (Houde and Hill, 1997). In turn, humanists can “see” how their own cultural, ethical, or philosophical lenses “play out” in these design contexts.

The overlap between prototyping and making means that makerspaces and design studios are often housed in engineering spaces, but these activities, like design itself, are not limited to engineering students. In fact, making is also a studio art, an act of creation – what is “designed” might be a story, or a textile, as easily as a 3D printed widget. In critical making, students apply analytical faculties from humanities and social sciences to this creative endeavor (Somerson, Hermano & Maeda, 2013). Matthew Crawford has persuasively contented that such handwork is also “soul craft,” enriching students’ humanity and person-hood as well as their professional development (Crawford, 2010).

The importance of effective communication with various parties, and of collaboration with fellow designers, integrates additional elements to the design process. Interpersonal dynamics and written and oral communication are critical to effective and successful design. Through such project-based collaboration, students develop both skills and confidence in the value of their own expertise to the success of a collaborative project. Again, the best examples of this kind of collaboration are ones in which all members bring distinct skills and disciplinary perspectives to bear on shared goals, rather than ones in which humanities and arts students serve as mere supports in solving an essentially technical design challenge.

Notable multidisciplinary design project-based experiences include MIT’s Terrascope, a first-year living-learning program that supplements the fundamental introductory courses with problem-based experiences and cross-disciplinary teams has had a powerful effect on student engagement and retention (Lipson et al., 2007). The iFoundry program at the University of Illinois began as an infusion of philosophical and other perspectives into engineering education and is now a multifaceted, “cross-disciplinary curriculum incubator” for project-based learning, entrepreneurship and innovation experiences, and methods for enhancing students’ intrinsic motivation (e.g. Goldberg, 2008).

We particularly admire an initiative at Smith College to involve faculty, students, and staff from all disciplines in a design thinking community to reimagine the liberal arts. This project embraces “radical collaboration to encourage the unconventional mixing of ideas, thereby creating a culture where ideas (and the technologies that help us realize these ideas) belong simultaneously to no one and everyone" (Mikic, 2014).

The potential for such multidisciplinary collaborative design projects to integrate, and value, the contributions of a variety of disciplines is enormous. Not only do these projects improve design *products*, they also underscore the intrinsic value of learning *both* STEM and humanities and arts. Such projects are "expensive" in the academic currencies of faculty time and energy, and they may require faculty development efforts as well as consumable supplies, but the rewards may be great enough to justify the investment.

ADDRESSING DIFFERENCE: RECRUITING AND RETAINING UNDERREPRESENTED GROUPS

Through our research and teaching, we educators can foster inclusion of the varied manifestations of diversity in our students and our courses, grappling with the difference and sameness not as conundrums, but as synergistic and intersecting dynamics that reveal the human experience and ways to improve it. Johnnella Butler (2014, p. 4)

Some observers of persistent inequalities in US higher education access and retention examine the question of STEM and liberal arts integration through the lens of gender, race, socio-economic status, and ethnicity. The concern in these debates is not simply whether STEM and liberal arts deepen students' understanding of disciplinary content within a broader conception of society; rather, the question focuses on who is missing at the table and whether a more integrative approach helps diversify the so-called "leaky pipeline" into all areas of higher education.

Once again, widespread public assumptions mask complex realities. For example, the characterization of "hard" STEM fields versus the "soft" humanities maps onto widely shared gender assumptions that men are attracted to modern, useful STEM inquiry and women are drawn to or excel at the softer, traditional, utopian humanities. Closer examination of the evidence shows that the reality is more nuanced; women are well represented in some STEM fields (albeit with a pay gap) (Broyles, 2009), although clear gender differences remain particularly in engineering, computing, and physics.[3] Yet gendered dualisms run deep in Western thought and are difficult to dislodge from the public imagination which, in turn, influence the institutionalization of higher education.[4]

The assumption that men are better suited than women for the "hard" STEM fields also maps onto racial stereotypes.[5] Studies "confirm the enduring presence of racism and sexism in STEM education" in spite of programs aimed at recruiting and retaining women and people of color (Charleston et al., 2014; Chakraverty, 2014) which, in turn, reinforces the notion that institutional culture is a significant consideration in the study of underrepresented and underserved populations (Museus, 2011; Museus et al., 2011).[1] Barone's (2011) study of gender differences in Europe concludes that "the influence of gender categorizations is so resistant to change because it operates not only through the internalization of sex stereotypes but also through the evaluation of opportunities and

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[3] Women comprise 77% psychology, 60% biology, 54% social science, and 50% chemistry student populations. At the same time, however, women's share of bachelor's degrees in computing, mathematics, and engineering remain disproportionately low (National Science Board, 2010). The majority of bachelor's degrees awarded in engineering, computing, and physics (81%, 81%, and 79%, respectively) were awarded to male STEM aspirants (National Science Board, 2010).

[5] The National Science Board reports that over 70% of the country's 3.5 million scientists and engineers are white.

constraints. For instance, the overrepresentation of female graduates in care-oriented fields reflects both their intrinsic occupational preferences and the increasing job opportunities created in service economies" (p. 43). Joshi and Knight's research shows that inequalities in perceived status based on demographic attributes (for example, gender, race, or ethnicity) are reinforced in patterns of deference afforded to white men in teamwork that involve STEM expertise, further explaining the persistence of stereotypes (Joshi and Knight, 2015).

Examination of inequalities and higher education is a useful lens for understanding whether the integration of community-based and social justice applications might help to recruit underrepresented and/or underserved populations to STEM and especially engineering fields (Nilsson, 2015). One study finds that female students' attitudes toward the relevance of introductory science courses to problem-solving improves when taught with a social, context-based (or STS) pedagogy (Perkins, 2011). The success story of Computer Science at Harvey Mudd College hinges on casting its introductory courses as problem-solving and creative endeavors (AAUW, 2015). California State University – Monterey Bay, recognized as a national leader in engaged or civic learning, finds that STEM programs that require students to work with community partners using a social justice frame not only boost civic engagement and critical thinking among STEM students, but they also may attract students from underrepresented groups into STEM study (Calderon and Pollack, 2015). Cleveland State University has recruited more diverse students into health professions programs through close partnerships with eight urban neighborhoods targeted for their low health indicators (Whyte, White, and Menscer, 2015). Mount Sinai Medical Center's groundbreaking program, originally called the Humanities and Medical Program, intentionally recruits students whose interests in humanities will likely improve their understanding of patients and their contexts (Whyte, White, and Menscer, 2015).

It is worth noting that women's and gender studies scholars warn against focusing on differences – in confidence, in preparation, or in motivation – in ways that make outreach transparent and ineffective: "engineering lipstick [Hollar et al., 2002], Barbie® computers (and 'cooperative' or 'nonviolent' games for girls [Cassell and Jenkins, 1998])" (Riley and Pawley, 2011). Instead of addressing the underlying issues, the authors argue that these strategies reinforce gender hierarchies: "We should not be surprised if this gender essentialism gives way to gender determinism, where certain areas of engineering that fit gender stereotypes – for example, areas with environmental or humanitarian ends, for example – are carved out as "women's sphere" [Bix, 2004] much the way home economics was in the 20th century" (Riley and Pawley, 2011, p. 3).

It is also a concern that these efforts emphasize recruitment of under-represented groups to STEM at the possible expense of retention. Retaining female and other under-represented students will be made even more challenging if the early, "attractive" experience feels distinct from the curriculum that follows in tone, content, or style. Still, efforts made to make STEM more inclusive, more richly contextualized, and more attractive to a more diverse student body yield benefits for all STEM students. It has even been observed that the broadening of the most in-demand STEM populations – women and other underrepresented groups – may have made them less likely to enter the workforce as STEM practitioners (Wang et al., 2013). This joint study by the Universities of Pittsburgh and Michigan revealed that women have more options when they have both verbal and mathematical abilities and that these options often pull them away from STEM-only fields.

The number of examples of integrative, contextualized learning that appear to be effective in recruiting women and other underrepresented populations raise the question of why STEM education ever felt it necessary to "strip out" the historical and societal contexts of its disciplinary content. Although this question lies beyond the scope of this report, the answer may lie in a combination of factors: the complex history of 20th century institutionalization of modern education, Cold War-era attitudes that prioritized technical content, the particularly-American ambivalence about the role of the state in public and private education, or in a familiar professional drive to establish disciplinary "rigor" (Riley, 2008). Amy Slaton's work (2010) that documents the many ways this insistence on rigor established and fortified an effective "color line" in STEM education and professional engineering practice provides a promising starting place for this discussion.

EMPLOYERS

With a shriveled vision of what the nation and the world needs, (some) attack the humanities with special vindictiveness, shoving to the side a long educational tradition in which these fields have served as the very glue that combined together knowledge, values, and civic agency. In its place jobs and wealth are proposed as the new gold standard. Carol McTighe Musil (2015, p. 244)

Given the almost universal assertion that the national economy needs more graduates from STEM fields, it is not surprising that observers pay attention to STEM graduates' employment rates and salaries relative to those from non-STEM fields. These data show some preference for STEM graduates in the marketplace (Miller, 2014); for example STEM graduates are more likely to secure employment within six months of graduation and receive higher starting and career salaries than their fellow graduates from non-STEM disciplines (Langdon, et al., 2011; Skorton and Altshuler, 2011). Longitudinal data, however, suggest a more nuanced picture of salary differences over a career span (Humphreys and Kelly, 2014; Hiner, 2012). Non-STEM graduates are more likely to pursue additional post-graduate education that boosts income potential. While STEM graduates on average continue to earn more than non-STEM graduates (among whom there is great variability), there is less variation between successful, high earning non-technical graduates and their STEM counterparts over career trajectories (Herschbein and Kearney, Hamilton Project, 2014; Humanities Indicators, AAAS, 2014; Xu, 2015). Many factors such as mentorship, networking, and self-confidence appear to contribute to career success, possibly explaining the narrowing of career differences between STEM and non-STEM graduates over time (Blickle, et al., 2009; Scandura, 1992).

Perhaps more important than salary data, surveys of employers underscore the promise of interdisciplinary, experiential, and integrative educational opportunities across all disciplinary tracks. Studies show that on average employers are looking for broad competencies in college graduates rather than specific, content knowledge (AAC&U, 2013). The types of competencies typically cited by CEOs can be characterized as systemic rather than disciplinary – for example, written and oral communication, information literacy, along with civic responsibility and engagement, ethical reasoning, intercultural knowledge and actions, and propensity for lifelong learning. The degree to which students gain these broad skills more successfully in traditionally disciplinary or multidisciplinary, integrative experiences cannot be easily teased out of existing data. Labor statistics allow observers to gauge the career success as measured by salaries of graduates from a wide variety of undergraduate majors. Yet, as Bradburn and Fuqua point out in their comprehensive examination of the effects of humanities course completion on post-graduation outcomes, U.S. Department of Labor statistics do not include measures that correlate to the educational aspirations of the humanities or arts, such as cultural participation or communication, analytical, and interpersonal skills (Bradburn and Fuqua, 2013).

CONCLUSION

Examples of faculty reaching across disciplines not only to better teach specific academic content but also to excite and inspire their students to think critically and creatively is more than merely encouraging on pedagogical grounds. Such examples vividly demonstrate that many faculty on both sides of C.P. Snow's "two cultures" resist the perceived primacy of STEM as the driving imperative of U.S higher education. Rather, many faculty – notably in the STEM disciplines, themselves – embrace a holistic mission of higher education that serves both individuals and the nation, technological innovation and democratic vitality. STEM literacy **and** the ability to imagine and contest what an educated citizenry knows or ought to know are equally critical for both economic and democratic ends. STEM and non-STEM fields are vital in themselves, but more importantly they inform and enliven intellectual pursuit in *each other*.

Some program-specific attempts to measure student learning on individual campuses appear to support the plentiful anecdotes about the merits of integrative approaches both in terms of student learning as well as recruitment and retention of underrepresented groups in STEM fields. But additional focused attention and study, beyond discipline-level and/or general education assessment, is warranted.

National organizations such as the American Association of Colleges and Universities (AAC&U) and Imagining America provide the clearest examples of efforts to develop measurable outcomes for integrative curricular work. To some degree, such organizations have been successful in drawing attention to the educational merit of innovative, integrative courses and programs. Equally importantly, their attempts to ground localized programs in a national conversation about appropriate assessment and reward structures elevate their visibility and transformative potential. Some national organizations, such as the National Academies, National Science Foundation, and Teagle Foundation, are also able to achieve a panoramic perspective on many such efforts, enabling broad review, categorization, and evaluation of an array of integrative activities. By shining their own light on interdisciplinary integration, in fact, these organizations communicate its importance to the larger higher education agenda.

Beyond these organizations, one might expect accrediting bodies (both regional and discipline-specific) to foster a greater appetite for evidence of learning in integrative STEM, humanities, and arts initiatives, especially given their expanded role demanding evidence of student learning. However, most integrative course and program learning outcomes are not easily captured by broad accreditation standards. Because these kinds of courses and programs tend to be built at the curricular grassroots, they often fall beneath the institutional accreditation radar – leaving the vision, theoretical grounding, pedagogical skills, and assessment lessons learned in the trenches.

Continued institutional (and external) support necessary for the sustainability of such efforts would seem to require more than simply the use of metrics and benchmarks to determine whether these endeavors – costly in terms of faculty time and energy, often team-taught – are achieving the existing student outcomes. The measure of success of such initiatives is not as simple as applying standard measures for "un-integrated" courses to gauge whether students' disciplinary knowledge is achieved or even enhanced by integration. The value of interdisciplinarity and integration is not merely to improve the learning of standard content by additional contextualization, but to achieve something **more** than could be attained by any single discipline alone – much as effective multidisciplinary collaboration yields a product better than any individual member could have generated. Successful student learning in integrated courses and programs includes the consideration of both standard disciplinary outcomes *and* outcomes specific to interdisciplinary learning. Borrego and Newsander's (2010) content analysis of 129 successful NSF proposals identifies five key outcome categories for interdisciplinary instruction: disciplinary grounding, integration, teamwork, communication, and critical awareness. However, the authors lament the relative paucity of benchmarks and assessment methods for interdisciplinary and integrative work. Lisa Lattuca's work (e.g. Lattuca et al., 2006) in defining interdisciplinarity, and differentiating it from multidisciplinarity and other related but distinct activities, remains a somewhat solitary standard. Through interviews and analysis of student work, Veronica Boix Mansilla (2005) composed an assessment framework highlighting four dimensions of student interdisciplinary work: Purpose, Disciplinary Grounding, Integration and Thoughtfulness. Both this framework and a timed design-based assessment tool known as a "charette" were reviewed and endorsed by a Teagle Foundation white paper on the assessment of interdisciplinary work (Rhoten et al., 2006). Diane Michelfelder et al. (2013) warn that an interdisciplinary approach may alter disciplinary "purity" and transform student outcomes into something possessing "hybridity," which may not be captured by traditional assessment metrics.

As important as the efforts to adequately measure the worth of integration are, these efforts often bog down in methodological debates about measurement itself. Given the power of our contemporary empirical and computing tools, it is not surprising that quantitative data generated from coding artifacts of student work appears to be a more trustworthy measure of educational outcomes. The promise is that quantitative measurement eliminates the "bias" that passionate instructors or eager students might use to describe their own educational experiences. Similarly, student or instructor reports on their own perceptions of learning, interest, motivation, or meaning – especially when they are gathered with qualitative methods – typically are dismissed or, at best, considered weak supplements to "real" measurement. To be sure, methodological debates are important, especially when concrete resource implications rest on perceptions of the authority of the measures. But, as Joseph (2014) suggests, the focus on accountancy or measurement rests on the assumption that "student learning" is equivalent to decontextualized or "objective" observations of the natural world (and, hence, a world best evaluated with STEM-like precision) rather than complex individual interactions with knowledge in a human context. The focus on accountancy, therefore, can eclipse the larger question of accountability. If we embrace the notion that the examples reviewed in this paper are, in fact, examples of the *re*-integration of fields, and that re-integration both enlivens the inquiry itself and broadens the range of student interest, then how do we – educators, policy-makers, and the public - hold ourselves accountable for fostering this approach? Our methods should follow our inquiry; testing the value of re-integration is best pursued with integrative methods. A methodological approach that embraces both our computational sophistication and the human drive to make meaning out of experience and knowledge – although messy – will strengthen the authority of our findings.

In spite of consistent voices from the academy, employers, and citizens calling for integrative educational efforts, some policy-makers continue to assert the primacy of STEM as though economic utility is all a contemporary individual or society needs. Such a myopic vision of human intellect has real policy implications: reducing federal funding for humanities and arts while increasing funds for STEM-related teaching and research; shifting the costs of access to cultural expression to private or foundation support; or privatizing national cultural production as simply another commodity in an entertainment market. According to this view, only decontextualized STEM knowledge is a public good; the public can no longer afford the examination of knowledge's meaning in human context. Not only is this a dangerous experiment that takes for granted the foundation of democracy in an informed and fully-literate citizenry, it is a view of the human intellect that is foreign to most educators and that, ironically, may result in scientific and technological stagnation.

Here, the conflict between "utilitarian" and "utopian" aims is clear: utility is easier to measure. Whether students are made more employable, or see an increased starting salary, or perform well in standard ways – these outcomes will not disappoint those who value integration, but neither will they be sufficient. Integration promises to deliver improved learning of disciplinary content within a broader goal of strengthening ideals of citizenship, mindfulness, and empathetic engagement with the world. Yet, it may be difficult to articulate outcomes that are measurable and meaningful. In addition, students may manifest these outcomes on a timescale far beyond a semester or other curricular milestone. The "narrative" of these efforts is also meaningful, though context is important – a narrative of success tells us what works at some institutions, for some faculty members, for some students; and what "works" varies with the goals for integration. And, we as educators should listen to these narratives because they are often spoken by our most impassioned and enthusiastic colleagues, motivated to improve and evolve their own teaching. (Put another way, the characters and setting of these narratives are as worthy of attention as the plot points.) In order to make these context-specific narratives useful to a broader discussion in higher education, and potentially transferrable, the methods of humanists and social scientists may provide a complement to the STEM-infused quantitative measurement tools to determine which questions about student learning are most important, and how they can be addressed.

Perhaps it is more instructive to ask why – given many local efforts grounded in the practical perspective that students often learn more readily and feel more confident about their knowledge in multidisciplinary, contextualized, experiential opportunities – these initiatives remain both under-examined and under-funded. Why do faculty who invest their time and energy in these kinds of efforts remain the minority of faculty across STEM, humanities, and arts disciplines? Why do endeavors such as Grand Challenges, global citizenship, or centers for innovation/creativity/entrepreneurship struggle to find campus leadership champions or national support across the whole spectrum of US higher education? The specifics of the obstacles likely vary among institution types, suggesting that the most effective incentives and resolutions to those obstacles will vary as well. The current climate of intense resource competition, both nationally as well as on individual campuses, may strengthen disincentives for faculty collaboration, multidisciplinary risk-taking, or development of measures of long-term educational value to students and society. Particularly for the humanities and arts, disciplines that have seen the sharpest rise in the proportion of contingent versus tenure-track faculty, incentives to "double down" in traditional measures of faculty excellence rather than collaborative work can be at play. STEM faculty, under pressure to deliver increasingly sophisticated graduates in an era of rapidly shifting frontiers of knowledge, may resist the call to inject their courses with additional content. As Kezar and Gehke suggest (2014), the increasing complexity of managing higher education may undermine administrators' ability to strategically create conditions conducive for integrative programs. Meanwhile, the STEM "branding" acronym reinforces a perception of practical value – as opposed to the impractical, "utopian" humanities and arts - that intensifies competition for scarce resources. Investing in research regarding the obstacles – from national funding priorities to campus (dis)incentives for faculty and staff – also is warranted.

Without sustained focus and leadership at the campus and national level, it is likely that similar essays in 2025, 2050, or beyond will bemoan the false assertion of the "two cultures," leaving the impression that faculty continue to teach in their insular and traditional ways while the economy searches for adequately prepared workers and the country yearns for the informed citizenry that 21st century democracy requires.

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