Work in Progress: Transformation through Liberal Arts-Focused Grand Challenges Scholars Programs

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Dr. Alison Wood is an assistant professor of Environmental Engineering at Olin College of Engineering. She is a researcher in the fields of both water and sanitation, as well as a researcher and practitioner in using interdisciplinary thinking and approaches to solving environmental and sustainability problems. Dr. Wood is also pursuing her interests in the areas of equity and justice through education and engagement with context and values.

In addition to her teaching and advising duties at Olin, Dr. Wood serves as the Director of the Babson-Olin-Wellesley Three College Sustainability Certificate Program, the Director of Olin's Grand Challenges Scholars Program, on the Catalyst Board of the open source journal Murmurations, and as a member of Olin's Context and Ethics in Engineering Education Working Group.

After graduating from Harvard University with a B.A. in Dramatic Literature, Dr. Wood worked professionally in theater and wrote and recorded two musical albums. She then returned to school to study engineering, earning a B.S. in Civil Engineering from Rutgers University. Dr. Wood then went on to earn a Master of Science in Engineering in Environmental and Water Resources Engineering and a Ph.D. in Civil Engineering from The University of Texas at Austin, while working with the Austin chapter of Engineers Without Borders as a volunteer and project lead for a project in Peru.

She has published and presented on incentivizing decentralized sanitation and wastewater treatment, on sustainability of coastal community water and sanitation service options, as well as on integrating liberal arts and STEM education, currently through the vehicle of the Grand Challenges Scholars Program. She has co-designed workshops oriented toward educational change for Olin's Summer Institute and the joint Olin College-Emerson College event: Remaking Education.

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Karen Kashmanian Oates A nationally recognized consultant, scientist, science educator, and higher education leader, Dr. Oates joined WPI from the National Science Foundation, where she had been serving as deputy director of the Division of Undergraduate Education. At the NSF, Karen managed a budget of over $380 million and a staff of more than 35 charged with supporting innovative programs to strengthen undergraduate and graduate education and helped revitalize American entrepreneurship and competitiveness. As the inaugural Dean of Arts and Sciences, Karen brings a variety of perspectives on faculty

development, career and executive counseling, leading change and setting a collaborative culture as well as service learning and business-higher education partnerships. Among the honors she has received are the Bruce Albert's Award, presented by the American Society to Cell Biology for excellence in science education reform, and the Distinguished Public Service Award, the highest civilian honor presented by the City of Harrisburg Pennsylvania. In 2012, she was inducted as a fellow into the prestigious American Association for the Advancement as Science Education fellow, and in 2016 a Sigma Xi distinguished lecturer. She now leads the University efforts for National Academy of Engineers – Global Grand Challenge Scholar program. After receiving her Ph.D. at George Washington University Medical Center in Biochemistry, she worked as a visiting scientist at the National Institutes of Health, National Cancer Institute Oncology and Hematology Division. She began her academic career at George Mason University, where, as associate dean for the newly established College of Integrated and Interdisciplinary Studies, she helped create George Mason's New American College environment. She later served as inaugural provost for the Harrisburg University of Science and Technology, where she established the National Center for Science and Civic Engagement and helped secure NSF funds for Science Education for New Civic Engagement and Responsibilities, SENCER which works to improve undergraduate STEM/STEAM education by connecting learning to critical civic questions. After 7 years as dean, Karen has returned to the faculty at WPI.

David Spanagel, Worcester Polytechnic Institute

David Spanagel is an Associate Professor of History in the Department of Humanities and Arts at the Worcester Polytechnic Institute, Worcester, Mass. He has been active as an innovator in curriculum and instructional approaches. He co-developed the Power the World course (one of the first Great Problems Seminar themes offered as part of WPI's First Year Experience) back in 2007, and he co-developed a similar course on Extinctions in 2017 which he currently teaches with a colleague in wildlife biology. He has pioneered collaborative learning approaches in the history capstone projects that he advises for students completing the Humanities and Arts requirement. He worked with colleagues to overhaul and update WPI's history of science and technology course offerings in 2009, and again in 2017. Prior to acquiring a Ph.D. in the history of science at Harvard (1996), David's first graduate degree (an M.S. Ed.) involved academic research into mathematical problem solving techniques and pedagogy. Thus, his very first publication was an article on "Solving Extreme Value Problems Without Calculus," published in The Mathematics Teacher (1988).

Dr. James J. Winebrake, Rochester Institute of Technology

Dr. James Winebrake currently serves as the dean of the College of Liberal Arts at RIT. He works with the college's faculty, staff and students to advance education and scholarship in the social sciences, humanities, and performing arts, while also promoting interdisciplinary initiatives across RIT's nine colleges. One of his key initiatives is the integration of liberal arts and technology/engineering curricula at both the undergraduate and graduate levels.

Dr. Winebrake previously served as chair of RIT's Department of Science, Technology and Society/Public Policy and has earned international recognition for his research on issues related to the environmental impacts of transportation, including health risk assessments, life-cycle analysis of alternative fuels, and analysis of policies aimed at reducing emissions in the transportation sector. He serves or has served on several National Academies of Science committees, the New York State Energy Planning Board, and other professional boards related to energy and environmental technology and policy.

In 2010 Dr. Winebrake was awarded the RIT Trustees Scholar Award in recognition of his scholarly contributions in the energy and environmental fields. He has also received numerous other research and teaching awards during his career, including the Madison Scholar Award and the Outstanding Teacher Award while serving as a faculty member at James Madison University in Virginia.

Dr. Winebrake received his PhD in Energy Management and Policy from the University of Pennsylvania (Philadelphia, PA). He also holds a B.S. in Physics from Lafayette College (Easton, PA) and a M.S. in Technology and Policy from the Massachusetts Institute of Technology (Cambridge, MA).

Dr. Yevgeniya V. Zastavker, Franklin W. Olin College of Engineering

Yevgeniya V. Zastavker, Ph.D., is an Associate Professor of Physics at Franklin W. Olin College of Engineering and a recent Director of the Research Institute for Experiential Learning Science at Northeastern University. She earned her B.S. degree in Physics from Yale University in 1995 and her Ph. D. degree in Biological Physics from MIT in 2001. Dr. Zastavker's research interests lie in the field of STEM education with specific emphasis on innovative pedagogical and curricular practices at the intersection with the issues of gender and diversity. With the goal of improving learning opportunities for all students and equipping faculty with the knowledge and skills necessary to create such opportunities, Dr. Zastavker's recent work involves questions pertaining to students' motivational attitudes and their learning journeys in a variety of educational environments. One of the founding faculty at Olin College, Dr. Zastavker has been engaged in development and implementation of project-based experiences in fields ranging from science to engineering and design to social sciences (e.g., Critical Reflective Writing; Teaching and Learning in Undergraduate Science and Engineering, etc.) All of these activities share a common goal of creating curricular and pedagogical structures as well as academic cultures that facilitate students' interests, motivation, and desire to persist in engineering. Through this work, outreach, and involvement in the community, Dr. Zastavker continues to focus on the issues of women and minorities in science/engineering.

Work in Progress: Transformation through Liberal Arts-Focused Grand Challenges Scholars Programs

Abstract

The National Academy of Engineering's Grand Challenges Scholars Program (GCSP) was created to better prepare students to tackle the immense and immensely complex challenges of the twenty-first century. The program does this by providing education and experiences in five competency areas: talent, multidisciplinary, viable business/entrepreneurship, multicultural, and social consciousness. These competencies align well with education and experiences often acquired under the umbrella of the liberal arts. This alignment, along with the rising tide of evidence that integration of liberal arts with STEM is beneficial for students' education, led representatives from four colleges - Olin College of Engineering, Lawrence Technological University, Rochester Institute of Technology, and Worcester Polytechnic Institute - to undertake a collaborative project, supported with funding from the Teagle Foundation, to explore GCSP as a vehicle for integrating liberal arts with STEM education (primarily engineering) and addressing the NAE's five competencies.

GCSP inherently engages students beyond narrow disciplinary boundaries and encourages students to see the limits of single-method approaches to technological problem solving. The program creates opportunities for engineering (and non-engineering) students from diverse fields to engage with the social and humanistic dimensions of the Grand Challenges. When additional emphasis is placed on deep integration of liberal arts with engineering disciplines, GCSP even more effectively roots students in paradigms, epistemologies, and methodologies that they would otherwise not encounter during an engineering undergraduate degree. As discussed in a 2018 National Academies' report, developing conceptual frameworks "may enable [non-experts] to learn content more readily because they can then better understand the relevance of that information and its connections with otherwise seemingly disparate facts;" that is, the development of new conceptual frameworks, derived from a variety of disciplines, can help students better understand and synthesize a broader range of information. Gaining experience in these new ways of thinking and doing qualitatively changes the way in which students approach both learning and practice. New modes of thought and increased integration of learning and ideas also help students connect their interior, personal development with the "grand challenges" they study in GCSP, leading them to identify roles for themselves in tackling these complex problems; this identification lends itself to agency development and increased motivation. Thus we suggest that participation in a "liberal arts-infused GCSP" transforms a student's learning experience through not only acquisition of new information but also new ways of thinking, knowing, doing, and being.

As this approach to GCSP provides transformational experiences for students, the creation of these programs has also led to transformations at the levels of the participating institutions. With implementation of GCSP now in different stages at our four schools, all are finding evidence of transformations occurring at the student, institute, and community level. We illustrate these transformations in this paper and suggest that they were driven by development of liberal arts-infused GCSPs.

1. Introduction

The National Academy of Engineering's Grand Challenges Scholars Program (GCSP) was created to better prepare students to tackle the immense and immensely complex challenges of the twenty-first century. The program does this by providing education and experiences in five competency areas: talent, multidisciplinary, viable business/entrepreneurship, multicultural, and social consciousness [1]. These competencies align well with education and experiences often acquired under the umbrella of the liberal arts [2], [3]. This alignment, along with the rising tide of evidence that integration of liberal arts with STEM is beneficial for students' education [4], [5], led representatives from four colleges - Olin College of Engineering (Olin), Lawrence Technological University (LTU), Rochester Institute of Technology (RIT), and Worcester Polytechnic Institute (WPI) - to undertake a collaborative project, supported with funding from the Teagle Foundation, to explore GCSP as a vehicle for integrating liberal arts with STEM education (primarily engineering) and addressing the NAE's five competencies.

GCSP inherently engages students beyond narrow disciplinary boundaries and encourages students to see the limits of single-method approaches to technological problem solving. The program creates opportunities for engineering (and non-engineering) students from diverse fields to engage with the social and humanistic dimensions of the Grand Challenges. When additional emphasis is placed on deep integration of liberal arts with engineering disciplines, GCSP even more effectively roots students in paradigms, epistemologies, and methodologies that they would otherwise not encounter during an engineering undergraduate degree. As discussed in a 2018 National Academies' report [4], developing conceptual frameworks "may enable [non-experts] to learn content more readily because they can then better understand the relevance of that information and its connections with otherwise seemingly disparate facts;" that is, the development of new conceptual frameworks, derived from a variety of disciplines, can help students better understand and synthesize a broader range of information. Gaining experience in these new ways of thinking and doing qualitatively changes the way in which students approach both learning and practice [6]. New modes of thought and increased integration of learning and ideas also help students connect their interior, personal development with the "grand challenges" they study in GCSP, leading them to identify roles for themselves in tackling these complex problems; this identification lends itself to agency development and increased motivation [7],

[8]. Thus we suggest that participation in a "liberal arts-infused GCSP" transforms a student's learning experience through not only acquisition of new information but also through new ways of thinking, knowing, doing, and being.

As this approach to GCSP provides transformational experiences for students, the creation of these programs has also led to transformations at the levels of the participating institutions. With implementation of GCSP now in different stages at our four schools [9], all are finding evidence of transformations occurring at the student, institute, and community level. We illustrate these transformations in this paper and suggest that they were driven by development of liberal arts-infused GCSPs.

This paper provides an overview of the work conducted at our respective institutions regarding implementing GCSPs with a strong emphasis on liberal arts education. Section 2 provides background and literature review on the importance of integrating liberal arts and STEM disciplines (particularly engineering) and on the GCSP generally. Section 3 discusses the activities within each of our academic institutions, provides readers with a sense of the flexibility and variability that allows each GCSP to function at each university, and illustrates the transformations that are underway. Lastly, Section 4 offers preliminary findings and discussion of ongoing work.

2. Background

2.1 The Liberal Arts and Engineering Education

Including the liberal arts in an engineering education is not a new idea. In 1940, the Committee on Aims and Scope of Engineering Curricula [10] recommended that the "roots [of engineering education] should extend more deeply into the social sciences and humanities as well as the physical sciences," with additionals details - such as understanding how engineering influences society and being able to communicate clearly in writing - that could just as easily have been written today. Evidence continues to accrue that engineering students benefit from studying humanities, social sciences, and arts [4], [5]; although sometimes demonized by pundits and politicians, the liberal arts are still regarded by many as critically important for both career success and the advancement of a civil, democratic society [11]–[19]. The claim that some amount of non-technical education is beneficial for engineering students is not controversial, regardless of our societal push for ever more technical content at all levels of education [20]–[25].

Education beyond the technical is, indeed, encoded in ABET's accreditation criteria: the criteria for engineering programs include "a broad education component that complements the technical

content of the curriculum" [26]. However, this criterion does not specify how this broad component is to be operationalized; many colleges and universities simply include a "general education" requirement for undergraduate engineering students (e.g., [27]–[31]). This approach typically requires students majoring in technical fields to take additional courses housed in liberal arts departments. Students learn content from the liberal arts but it remains divorced from their technical studies.

In spite of the general education requirements within technical programs of study, graduates with newly minted engineering bachelor's degrees are falling short of the expectations of their employers, who struggle to find new hires with the full complement of skills required to succeed at all aspects of the job [33]–[36]. Indeed, many students who acquire technical degrees go on to take jobs outside of their fields [37], a scenario in which the need for broader skills and mindsets is inarguable. As explained in the opening of the grant proposal leading to our current work:

> After decades of increased demand for specialized, highly technical skillsets, employers – and society – are facing a problem. They've found many of today's challenges cannot be solved by technology alone, and many professionals lack the broad skills to play a role in driving change. For this reason, it is imperative that students educated in technical disciplines receive a transformative, integrative liberal arts education to complement their technical abilities.

Thus, in spite of the longstanding recognition that social sciences and humanities are critical "roots" of engineering education, further efforts are required to create curricula that provide engineering students the education they need to truly succeed in the 21st century.

Many educators also believe that the inclusion of liberal arts education within an engineering degree is critical to help our students become better people and better community members, not just better engineers (e.g., [38], [39]). Our work on integrated education has the potential to equally address this goal and the goal of educating more competent professionals. Both ends can be served by the means of the work reported here.

2.2 The NAE Grand Challenges Scholars Program

As technical programs strive to better prepare their students for the realities of the twenty-first century, an increasing number of them are adopting the National Academy of Engineering's (NAE) Grand Challenges Scholars Program (GCSP). The NAE's GCSP grew out of the Academy's 2008 report, *Grand Challenges for Engineering* [40], which lists fourteen "grand challenges" facing society in the twenty-first century that the report's authors believe engineers have a significant role in solving. This report inspired the creation of a national program intended to prepare the next generation of engineers to face these grand challenges: the Grand Challenges Scholars Program.

GCSP is intended to be a flexible program that individual institutions can implement in ways best suited to their own curriculum, students, and resources. The primary unifying characteristic of the program as defined at the national level is a set of five competencies [1]:

1. Talent Competency: mentored research/creative experience on a Grand Challenge-like topic
2. Multidisciplinary Competency: understanding multidisciplinarity of engineering systems solutions developed through personal engagement
3. Viable Business/Entrepreneurship Competency: understanding, preferably developed through experience, of the necessity of a viable business model for solution implementation
4. Multicultural Competency: understanding different cultures, preferably through multicultural experiences, to ensure cultural acceptance of proposed engineering solutions
5. Social Consciousness Competency: understanding that the engineering solutions should primarily serve people and society reflecting social consciousness.

Each institution creates its own program to help students achieve these competencies; often these programs consist of a checklist of courses, co-curricular experiences, and/or deliverables, such that completing the checklist earns the student "Scholar" status, sometimes in conjunction with honors (e.g., [41]–[46]). This common approach led the authors to write in our grant proposal:

> In a review of the existing programs, we found that only a few emphasize liberal arts curricula as a key part of their GCSP curriculum. And in many cases, this 'nod to the liberal arts' amounts to a set of liberal arts course electives that students take in a 'checklist' type of approach, as opposed to an *intentionally integrative experience* for the students…We believe there is a great need of the more intentional *integration* of liberal arts disciplines into STEM curricula [47], [48]. Nowhere is this need more relevant or important than at institutions of higher education designed as 'institutes of technology' which graduate a larger proportion of students from STEM disciplines.

Although most undergraduate engineering curricula include liberal arts courses via general education requirements, we strongly believe that we ought to move beyond simple inclusion and reach instead for *integration* of engineering and liberal arts education. When designing this multi-institutional collaboration, we recognized that the GCSP - especially if "infused" with significant liberal arts content in a meaningful way - provided an opportunity to address this gap in engineering curricula. We also recognized that working together as a community of practice, as opposed to independently, would allow for more effective institutional learning and have a greater impact on curricular transformations at our respective schools as well as contribute new knowledge to the internationally growing GCSP effort.

2.3 Liberal Arts-Infused GCSP as a Vehicle for Transformation

In coming together as a community of practice centered on integrating liberal arts and engineering education through GCSP, our four institutions have embarked on a process of transformation at many levels. Institutions undergo change as programs evolve and students experience transformative learning as a result of participation in the programs (for student narratives see [49] and for discussion of future data collection see section 4). Institutional transformations and student transformations create productive feedback loops within each school in the community and the schools support, encourage, and respond to further transformation in each other. Figure 1 offers an illustration of these synergies by demonstrating the feedback pathways not only between student and institutional transformation, but also between this group and the adjacent communities of GCSP at the national level and all higher education programs integrating engineering and liberal arts.

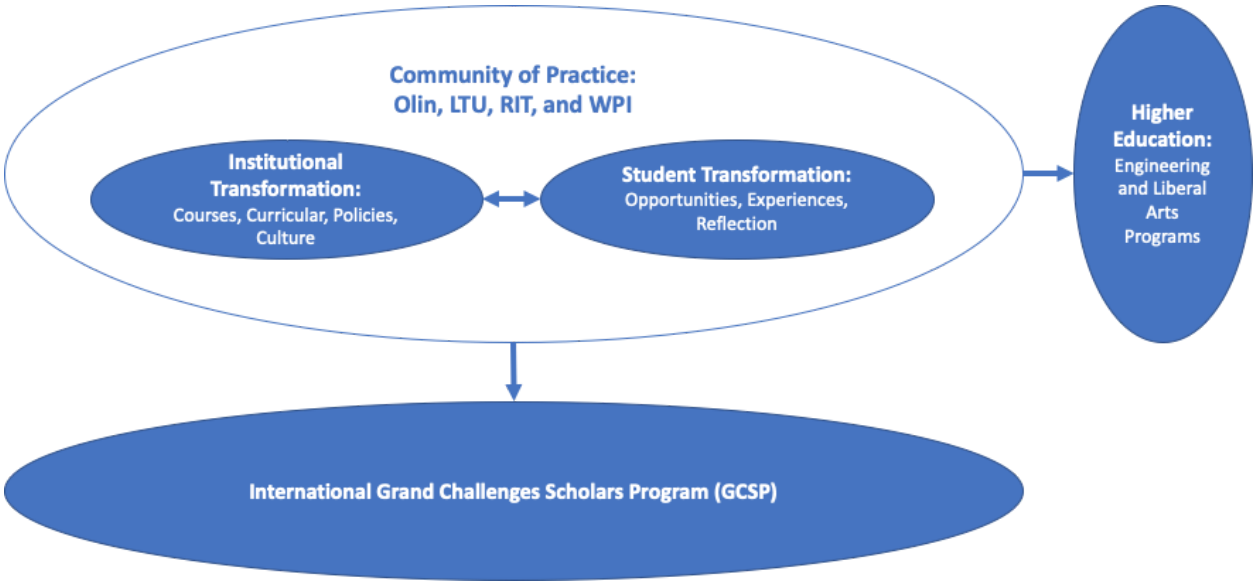

Figure 1. Diagram depicting feedback between institutional and student transformation within a community of practice that is made up of our four institutions aimed at rethinking the relationship between engineering and liberal arts practice in higher education as well as informing best practices for the international Grand Challenges Scholars Program.

Because each institution is evolving individually, each school's process of transformation has its own shape and pace. For example, RIT began offering GCSP-specific courses in fall 2016 and thus has amassed a body of evidence of student transformation arising directly from the institutional changes taking place, whereas Olin, though it has had a GCSP for a number of

years, is only now instituting programmatic changes as a result of work with this community of practice and thus has been largely focused on changes at the institutional level. Each of the institutions in this community has reflected on its own transformational process associated with implementing a GCSP focused on integrating liberal arts and engineering. The following section demonstrates how liberal arts-focused GCSP has been a vehicle for transformation at both the institutional and student levels.

3. Integrating Liberal Arts and Engineering through the GCSP: One Community of Practice, Four Approaches, Four Transformations

3.1 Olin College of Engineering

Olin College of Engineering is a small, private engineering college that embeds experiential learning throughout its curriculum. It occupies a unique position within this community as one of the earliest schools to create a GCSP. The original program, designed primarily by students and guided by a faculty advisor, relied heavily on existing programming and student intrinsic motivation. The premise of the program was that, by virtue of participation in the school's curriculum, students gained learning and experience in all five of the competencies defined by the NAE. Thus every student at the school could potentially be considered a Grand Challenges Scholar.

However, the creators of the program chose two additional requirements for students to graduate with Scholar designation: students were asked to work together in self-organized groups around the GCSP challenge areas and to engage with a process of critical reflection during their senior year. This reflection was captured in an essay, which provided an opportunity for explicit integration of liberal arts approaches into the education of engineering students through the process of critical reflective practice, writing, and revision. Integration of the liberal arts was otherwise less emphasized in the original program: the "multidisciplinary" competency does not specify integration of disciplines outside of STEM and it was historically accomplished at Olin through a variety of interdisciplinary courses within the curriculum.

Although the program has been relatively successful, several factors led Olin to revise it and launch "GCSP 2.0." In the years since faculty and students collaboratively created the school's original program, the student body had shifted - and the program had shifted from being primarily student led to being primarily directed by faculty. While intrinsic motivation is still generally very high among the students, they tend to seek more structure and scaffolding than the students in the early days of the school's program. The students enrolled during the years of this grant were no less motivated and engaged, but they needed a different type of program to capture

their attention amidst the din of demands on their time and to provide more structured support through a challenging process of self-discovery. The stage was thus set for transformation.

The realization that the students might benefit from a new program structure was energized by collaboration with the community formed by this work. It also was catalyzed by the coincidental occurrence of a change in program director, when the previous program director shifted to a new opportunity and an incoming junior faculty took over the role: this shift in leadership was a natural point for new ideas to be introduced and the opportunity presented by the Teagle-funded project opened the door for those ideas to be big ones. Rather than feeling constrained to small adjustments to the program, the new director found herself in the perfect moment to address the shifting student needs with a larger program overhaul. At the same time, Olin was undergoing a school-wide resurgence in its focus on contributing positively to the world through engineering, which fueled broader interest in supporting GCSP revisions through additional faculty time and other resources. The coincidence of these factors and the support of the grant community led to the creation of "GCSP 2.0" at Olin: the transformation was underway.

The new program is articulated in a Venn diagram, with GCSP placed at the intersection of three circles: developing self (I), developing Olin (we), and developing the world (all of us). The mission of the program is currently stated as: *GCSP helps students leverage their educational experiences and participation in the school's community to galvanize lifelong learning and community participation*. In addition to the GCSP-aligned experiences already existing throughout the curriculum, new courses are being created to provide bookends to the student experience, particularly through the introduction of new ways of thinking and knowing, drawn from liberal arts disciplines.

For example, a new experimental offering in spring 2019 included content that will eventually be divided into a two-course sequence: an introductory seminar to be taken (ideally) in the first or second year, and a practicum to be taken alongside a major project experience in the third or fourth year. The current experimental course includes introducing students to several ethical frameworks and notions of systems and paradigms, as well as discussing and critiquing several different "grand challenges" frameworks (the NAE's and the United Nations' Sustainable Development Goals, among others), and challenging students to articulate their own personal values and how those values both derive from educational experiences and lead to future commitments to doing good in the world. Feedback from students on the (potentially) transformative learning provided by this course will be used to guide revision to increase the transformative impact of future offerings, fueling a cycle of transformation at many levels as depicted in Figure 1.

This transformation of Olin's GCSP would not have happened without the community created by this collaborative project. This opportunity has provided impetus, resources, inspiration, and support for the work: the very premise of the funded work emboldened the new program director to embrace her own perception of GCSP as an opportunity to provide engineering students with some of the benefits of a liberal arts education. Participation in this project helped to motivate more significant changes than would otherwise have arisen at this time and then helped provide resources to pursue these changes. Ideas drawn from the group contributed to the many conversations and design sessions leading to GCSP 2.0: examples include WPI's declaration that each student at their institution will graduate with both "a major and a mission," which informed thinking about a personal "mission" as an integral outcome of the educational experience, and several institutions' creation of new courses integrating liberal arts and engineering in ways that look different from the common "add some X to an engineering course and call it integrated" approach, where X is commonly writing or ethics. Working with this community of practice has also led to new opportunities for students at Olin, such as participating as panelists and co-authors for ASEE in presenting their own narratives of transformative learning [49]. Design of an assessment plan is underway to collect, among other data, evidence of students' transformational experiences.

3.2 Lawrence Technological University

As a small, private technological university historically represented by its College of Engineering, Lawrence Technological University (LTU) discovered the transformative power of the GCSP in the integration of liberal arts perspectives and methodologies into engineering research projects through its participation in this collaborative project. The NAE's call for engineering curriculum to focus upon multiculturalism, multidisciplinarity, entrepreneurship, and social consciousness was heard at LTU as a call for the talents of the College of Arts & Sciences. The design and launch of LTU's GCSP has been one of the most intensive collaborations between its College of Engineering and College of Arts & Sciences in its history.

The distinguishing feature of LTU's GCSP is the overlapping of Engineering and Arts & Sciences GCSP curricular tracks that corral students from diverse major programs in both colleges into common GCSP courses and research collaborations. Every Engineering and every Arts & Sciences student is now introduced in their first semester to the possibilities of advanced research through the Grand Challenges paradigm. Engineering students, in their *Engineering Fundamentals* course, and Arts & Sciences students, in their *Pathways to Research Careers* course, design research posters applying a known problem in their major field to one of the NAE's fourteen Grand Challenges. LTU's Grand Challenge Research Poster night has become one of the biggest campus events culminating fall term, with hundreds of students presenting posters, faculty and VIPs serving as judges, a keynote address and substantial awards for the winning research proposals. A subset of these students elect to go on to complete the curricular

requirements for graduation as Grand Challenges Scholars. But every student is introduced to the possibilities of their senior research projects through the Grand Challenges paradigm, and as a collaborative enterprise between the colleges.

LTU's GCSP curricular requirements further emphasize the interdisciplinary nature of engineering research. Grand Challenges students take "GCSP" sections of the core curriculum literature and philosophy surveys. In these courses, liberal arts faculty have taken on the "grand challenge" of exploring cultural adaptation to technological change through the themes of the fourteen Grand Challenges. For example, Mary Shelley's *Frankenstein*, a core text of the modern literature survey, provides an open field for exploring artificial intelligence and cultural reaction to biomedical engineering. Faculty from diverse liberal arts backgrounds teach the core surveys, and each brings their own methodologies to the common challenge. GCSP sections are open to all students to satisfy their core curriculum requirements.

For Grand Challenges students, the counterpart to the experience of a semester with a liberal arts professor devoted to demonstrating how their field informs and illuminates the Grand Challenges comes in the College of Engineering's second-year Entrepreneurial Design Studio. Arts & Sciences Grand Challenges students join their Engineering peers for a term of small-team collaboration on product design and development. The Engineering faculty work with local non-profits, primarily around disability-access issues, and through this service learning Grand Challenges scholars' interdisciplinary collaborations become exercises in social consciousness.

LTU had two goals in developing the introductory and intermediate GCSP curriculum: a) to allow the GCSP paradigm to emanate as broadly outside the confines of the program members as possible, and b) progressively to winnow cohorts of Grand Challenges students focused on specific Grand Challenge senior projects. Those Grand Challenge projects are further supported programmatically with liberal arts research seminars developed in collaboration with their STEM faculty mentors. Grand Challenges students working on senior projects in the areas of climate change or alternative energy can take the GCSP Political Science seminar "The Geopolitics of Natural Resources" and find case studies directly related to their projects. These collaborations have led our Psychology faculty to lead experiments in our Biomedical Engineering Department's "Wearable Technologies" course, and our Art History faculty to lead Computer Science seminars on the color spectrums of art periods and how to map them. Grand Challenges scholars are exposed to a technological problem from multiple research methodologies.

Still in the toddler stages of its development, yet gaining significant traction across the institution, LTU's GCSP has had the greatest impact in the first- and second- year curriculum. The Grand Challenges have become a branding keynote for the humanities core curriculum. The development of Grand Challenge research projects have led to promising new collaborations

with external partners. Grand Challenges students have won research awards and patents, earned selective internships, and collaborated with peers from across the university with whom they might otherwise never have interacted: all as a result of the transformative vehicle provided by a liberal arts-infused Grand Challenges Scholars Program.

3.3 Rochester Institute of Technology

The GCSP at Rochester Institute of Technology (RIT) is the product of engineering and liberal arts faculty collaborating to design and implement the program. The tendency for faculty to work within the silo of their home college is no different at RIT than at many universities, so the development of the GCSP has fostered a sustained collaboration of faculty who have not regularly worked together on academic initiatives. This team created the program's framework and engaged with partners in the community of practice established by the Teagle-funded project to write the proposal that launched the program in 2017.

Though the program is open to any student at RIT, it is promoted primarily to first-year students from liberal arts and engineering. The program is highly flexible to leverage the wide variety of experiences students already pursue both inside and outside the classroom related to the Grand Challenges. Many of the typical activities that students use to fulfill the five GCSP competencies are embedded in the engineering curriculum (e.g., co-op work assignments and senior design projects connected to Grand Challenges), but the GCSP has provided a mechanism for shifting the paradigm with which students think about their liberal arts coursework. Students have always selected from a robust set of liberal arts course offerings as part of their general education requirements, but engineering students are not always thoughtful about how these courses fit into their overall educational goals. The GCSP has provided a platform to help students understand that liberal arts are essential to effectively address the ambitious grand challenges that excite them about becoming an engineer.

Providing engineering students with a relatable context that highlights the importance of liberal arts to their full education is proving to be transformative. In developing the new program, the GCSP steering committee has created a framework that maps liberal arts coursework at RIT to the Grand Challenges so that students may select courses to take in partial fulfillment of the required core competencies. Beyond the GCSP, this framework is a useful way to provide academic and faculty advisors a relatable context to help first-year engineering students, even those not part of the GCSP, appreciate the importance of the liberal arts to their overall education. The engineering and liberal arts faculty have also collaborated to develop a new, interdisciplinary course that provides a gateway to the GCSP. This general education course, *Grand Challenges*, is team taught by a faculty member from Engineering and one from Liberal Arts and uses one of the Grand Challenges as a topic to introduce broad concepts such as ethical decision-making, cultural contexts, communication, and teamwork. Inspiration for the course

originally came from a visit to a poster session for a course at WPI during a planning meeting for the Teagle collaboration and it was further developed through sharing of syllabi. The course has been taught three times by a pair of faculty (an engineer and a philosopher), who share interest in the challenge of *providing the world with clean water*. However, the course learning objectives are easily adaptable to any Grand Challenge, and additional offerings using other Grand Challenges and new interdisciplinary faculty partnerships are in the planning stage. The course on clean water includes case studies and essay writing on recent and current topics such as the Flint crisis, Great Lakes water levels, and the Green Revolution in Bali, as well as an extensive team project on a specific team-selected water issue. The project culminates in a poster presentation and is executed in phases as the students learn skills related to understanding a problem and proposing solutions.

Though assessment of both the Grand Challenges course and the overall program is in the early stages, students in the course complete a self-assessment to evaluate the extent to which they perceive development toward achievement of the course learning outcomes. Broadly defined, the course outcomes relate to a number of the GCSP competencies, and include: 1) evaluating information from multiple sources, 2) identifying and analyzing a problem and proposing solutions, 3) presenting to an audience, 4) writing, 5) understanding ethical issues, and 6) working collaboratively on a team. Students rate themselves on how often they work to develop specific learning outcomes (always, often, sometimes, rarely, never) and provide specific examples to support their survey responses. The self-assessment instrument was administered in 2017 and 2018 to approximately 50 students at the beginning and end of the course, and a t-test was used to compare the proportion of students who indicated "often" or "always" for each learning outcome. Table 1 lists the learning outcomes for which a statistically significant improvement ($\alpha = 0.05$) was observed.

Table 1: Competencies for which students reported statistically significant increase in percentage of "often" or "always" after having taken the Grand Challenges course.

Category	**Learning Outcome**
Teamwork	● Respond to conflicts in a helpful way ● Listen and consider different points of view and perspectives
Ethics	● Identify a potential position on an issue and consider the ethical implication(s)
Writing	● Revise a written piece to make improvements ● Integrate evidence from and cite or document sources ● Organize and synthesize information from sources to achieve a specific purpose ● Use a variety of sources directly related to a purpose or problem
Problem-Solving	● Identify similarities and differences between alternative approaches to the solution ● Seek advice from experts or review expert material/data to understand the problem

Using Sources	● Weigh the overall importance of the information ● Compare the strengths and weaknesses of different explanations or arguments

Although the survey is a self-assessment, it gives an indication that transformative learning has occured and that students gained new awareness and perspective on the competencies. Students' qualitative responses to a self-reflection assigned as a final exam give additional support to this argument. Many students reflect that they are now more able to recognize what they did not know prior to the course and where they continue to fall short. For example, one student remarked, *"[The class] helped me broaden my understanding of engineering, to realize that not all problems are a matter of math and science."* Another student clearly articulated the transformation brought about by engaging with this GCSP course: *"I personally have become more self-aware of the world around me and will never see water the same way."* Importantly, the student feedback has also informed new ideas for members of the GCSP team to transform curricula and practices within their own disciplines, thereby leading to the transformative feedback effects demonstrated earlier in Figure 1. The community of practice at RIT is growing as additional STEM and liberal arts faculty have come forward to develop their own collaborative courses. The Teagle collaboration has been and remains a way to identify successful practices and replicate them within RIT's program. For example, our evaluation techniques were inspired by WPI and, in addition to the collaborative course above, a new practicum course similar to that offered at Olin is being considered.

3.4 Worcester Polytechnic Institute

The GCSP at Worcester Polytechnic Institute (WPI) was created in accordance with the school's strategic planning initiative for undergraduate education entitled "Major and a Mission," with an aim to achieve full implementation within three years. In response to the strategic plan, the program provides integration of expertise across the campus. With support from this Teagle-funded project, the Colleges of Arts and Sciences, Engineering, and Business jointly submitted an application for the GCSP to the NAE, which was approved in June 2017. The proposal, with a strong emphasis on integrating engineering with the liberal arts as a distinctive feature, was largely formulated and significantly shaped by work done in collaboration with the community formed under this collaborative grant project. Community members shared information about challenges on each campus, as well as infrastructural, leadership, and administrative needs to support the program, providing a body of knowledge to guide the creation of the GCSP and the subsequent successful application.

In anticipation of the program's approval, 16 faculty designed and tested collaborative engineering and liberal arts-themed modules within an array of courses in various majors and programs. These grant-supported course experiences were aimed at seeding the undergraduate population with individuals who might be interested in entering the program, as well as shifting

the broader culture of the faculty to think more readily about research and teaching collaborations across the engineering/liberal arts boundaries.

After the program was approved, WPI's GCSP co-directors launched a pilot program in the fall of 2017 by identifying approximately 20 senior undergraduates who, through their self-directed efforts, already met several of the program criteria (as outlined in WPI's GCSP design). Because of WPI's rich traditions of project-based learning, global engagement, and a well-established interdisciplinary first-year program fostering small group student projects about world problems, as well as recent investments in the development of curricula for innovation and entrepreneurship, a sizable pool of students was available for the pilot program. The pilot GCSP was intended to help identify weaknesses and potential improvements to the implementation of the program for subsequent years, as well as to showcase student achievements that might induce institutional excitement and momentum for the program going forward.

The 2018-19 academic year is being devoted to recruiting students to join the GCSP from the sophomore, junior and senior year classes (approximately 10 students apiece) to build upon the pilot program's initial experience. Working both with these students and with the feedback gathered from among the pilot group, the co-directors intend to develop, test, and refine the various advising, reflection, and documentation mechanisms envisioned in the original institutional NAE proposal as well as the co-directors' implementation document.

A fundamental element of WPI's approach to this project was to bring faculty of diverse background and disciplines together who may never have had the opportunity to learn from each other and allow them to co-create something new while utilizing their expertise. Participating in this grant-funded community has led to these productive and satisfying collaborations as well as to students at WPI engaging with the complexity of learning that integrates engineering and the liberal arts.

4. Discussion and Future Work

Each of the four schools participating in this project has undergone its own transformational experience through this collaborative project. Olin and WPI have largely focused thus far on institutional transformations, while LTU and RIT have witnessed transformative learning for students that is in turn informing larger curricular, programmatic, and institutional transformations. All four schools' experiences were driven by the creation of GCSPs integrating liberal arts and engineering education. In addition, all four institutions found that creating these programs led to increased - sometimes unprecedented - collaborations between faculty from different disciplines. These collaborations gave rise to new experiences for students and early evidence indicates that they have been transformative. (For student narratives of transformation, see [49].) While it is not possible to rule out other factors that might have contributed to the

transformations at our schools, we believe that the work we have done together centered on GCSP has been a primary driver of change at each of our institutions.

Also, the programmatic activities at each school have not occurred independently. Because of the collaborative nature of this partnership, we have learned a great deal from each other. Regular conference calls and meetings among participants from each school allowed us to share ideas, successes, frustrations, and approaches to problem-solving. Those discussions provided important input to the development of liberal arts-infused GCSPs at each individual school. Moreover, the professional relationships we developed through this project have provided support in other ways that go beyond programmatic: we have developed a group of thoughtful colleagues and collaborators across our institutions who support each other as participants in the community of practice created by this work.

Beyond even our own community, this project has also influenced a larger community within higher education. Due in no small part to this project's activities, the NAE's approach to the creation and approval of new GCSPs has broadened to include an explicit mentorship piece that allows for development of mini communities of practice between mentors - members of the NAE GCSP Steering Committee - and the leadership of new programs (just as Olin served as a mentor to other programs within this community of practice), that lead to productive long-term mentorship and professional collaborations. Our collaboration has further spotlighted the critical importance of integrating liberal and engineering education within the context of GCSP, which was acknowledged and highlighted by the NAE GCSP Steering Committee and allowed for critical changes in the language of the "Proposing GCSP at your School" document [50], which serves as an application template for new GCSPs, to include liberal arts fields. As four schools that have seen how this increased breadth can positively impact students, faculty, and institutions, we are optimistic that the transformative experiences we have witnessed will, over time, spread to a wider set of colleges and universities.

While the work described here was supported through a grant, we believe that similar transformations are possible through the commitments of faculty and institutions even without dedicated funding. Administrative support and resources to not only start but also maintain a GCSP are critical; if funding is required to provide that support, then funding will be a key ingredient; funding is not necessary in and of itself. In particular, much of the collaboration and community-building discussed herein is independent of funding. Collaborations between faculty from different disciplines were facilitated by grant dollars but institutional support for such collaborations is not contingent on funding; for example, an institution might choose to support such collaborations by reducing service loads for participating faculty or by including recognition of this work in promotion and tenure processes. Similarly, development of an institutional GCSP does not require funding though it does require an investment of time; official

recognition of the time required for the creation of a program might prove sufficient to incentivize the investment of that time. Finally, participation in a community is perhaps the simplest to achieve without dedicated funding for the effort. The GCSP community continues to grow nationwide and globally, with dedicated annual meetings bringing practitioners together in Washington, D.C. In addition, the annual meeting of the American Society for Engineering Education typically draws a number of people involved in GCSP and provides further opportunities for building community.

Our ongoing and future work will focus on collecting further data to assess transformative learning for students participating in the GCSPs created through this project. Assessment design is underway, as assessment strategies for GCSP are still being developed even at the national program level. Some narratives of transformation and qualitative evidence have been captured; additional assessments are planned to investigate the power of using GCSP as a vehicle to integrate liberal arts and engineering education to provide transformative learning experiences for students.

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