Work in Progress – Building up STEAM – Exploring a Comprehensive Strategic Partnership between STEM and the Arts

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***Abstract* – In modern academic history there has been an artificial separation established between the technical disciplines of Science, Technology, Engineering and Mathematics (STEM) and the Arts. Increasing evidence suggests that this separation has come at a cost to both groups. At a time when there is a critical need for increasing enrollment and graduation of American students in STEM disciplines, many faculty and practitioners in STEM have lost their ties to creativity and abstract reasoning; similarly, many in the Art community have failed to keep up with the rapidly evolving technical society around them. Meeting the current technological challenges of the world requires the integration of creativity, innovation, and application within the STEM disciplines. Collaboration between the Sciences, Technology, Engineering, Arts, and Mathematics (STEAM) is gaining acceptance in the literature as a new paradigm for K-12 through post-secondary education. Such collaboration offers anticipated benefits that include increased creativity, experience working in multidisciplinary collaborative teams, and appeal to a broader population of students who otherwise might not have explored engineering as a career path. This paper presents a collaborative partnership between a K-12 institution and a university STEM program and discusses how the partnership may be developed to address key challenges facing STEM education.**

INTRODUCTION

In modern academic history there has been an artificial separation established between the technical disciplines of Science, Technology, Engineering and Mathematics (STEM) and the Arts. Though there are countless historical examples that predate this chasm – da Vinci, Eiffel, and Brunelleschi to name a few– Art and Science have become academically estranged in the modern age. Increasing evidence suggests that this separation has come at a cost to both groups. Many faculty and practitioners in STEM have lost their ties to creativity and abstract reasoning; similarly, many in the Art community have failed to keep up with the rapidly evolving technical society around them. Those who are able to appreciate and function in both worlds are a prized asset whose value is increasingly recognized. Collaboration between the Sciences, Technology, Engineering, Arts, and Mathematics (STEAM) is gaining acceptance in the literature as a new paradigm for K-12 through post-secondary education. From the perspective of engineering education, anticipated benefits of this structure include increased creativity, experience working in multidisciplinary collaborative teams, and appeal to a broader population of students who otherwise might not have explored engineering as a career path. The hope is that collaboration of this nature will enhance various aspects of recruitment, retention and quality in the engineering education process. This paper discusses several collaborative curricular projects that are being undertaken in a partnership between Youngstown State University and the nearby Liberty School District. With the assistance of YSU faculty, Liberty Schools are developing a freestanding alternative curriculum that spans most of the K-12 education. In the lower grades, a STEAM program emphasizes core competencies in all of the elements of STEAM. In grades 7-12, students may apply to participate in a dedicated STEM curriculum that specifically prepares them for university study in the STEM disciplines. At YSU, energized faculty in the College of STEM and the College of Fine and Performing Arts are developing a collaborative laboratory environment (CoLab) where faculty and interdisciplinary teams of students from both colleges can work together on real-world problem solving activities. This paper discusses some trends in literature related to the integration of STEM and the ARTS. It then explains the structures of the various programs under development, outlines the anticipated outcomes of the programs, and discusses metrics that will be used to assess the effectiveness of the programs in achieving those outcomes.

NEED AND METHODOLOGY IN THE LITERATURE

Over the past 20 years, the role of the United States as the world's technical and innovative leader has been challenged. Numbers of engineers in the U.S. reached a peak in the mid 1980's, but fell off sharply and, today, are still below their peak numbers (Figure 1). Meanwhile, over that two-decade span, many changes have occurred:

- The importance of technology as a competitive factor has increased several times over.
- China and India are graduating engineers in staggering numbers [1]
- Economic dominance of critical market segments, such as manufacturing, has slipped away from the United States.

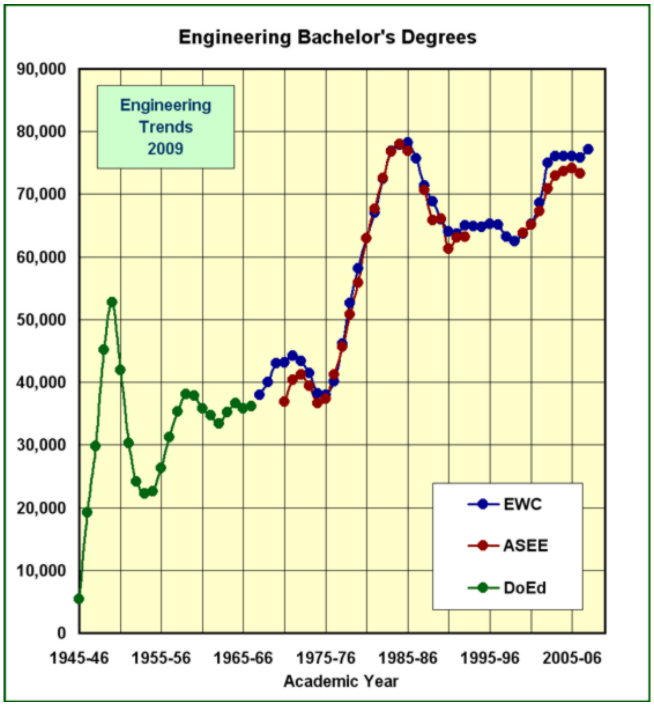

FIGURE 1
ENGINEERING BACHELOR'S DEGREES CONFERRED, 1945-2006 (AFTER [2])

The loss of technological competitiveness in a variety of U.S. competitive market segments has been considered by several studies [3,4]. The predicted consequences of national technological deficiency are grim and widespread. Central to the findings of most analyses has been the recognition that technical competence and the ability to innovate are necessary, if not sufficient, to ensure continued American competitiveness and the sustainability of the American standard of living. Unfortunately, even as these concerns continue to be raised, the competitive skills required, particularly creative skills, are not being taught to our engineering graduates.

Static Face of Education

Changes in the industrial landscape have brought about major changes to the paradigms used by successful, competitive companies. In business, profitability culls the herd of unsuccessful models. The education system, without direct economic consequences, substantially lags industry in response to major paradigm shifts. Though academic research is seen as a major source of technological innovation, the structure of the academic machine itself is glacially slow to change.

With regard to engineering education, the alarms have been sounding since the late 1950's. Journal articles dating back as early as 1959 identify creativity as being essential to the competitiveness and national security of the United States [5]. The founding mission of the National Science Foundation in 1950 illustrates that this importance was understood: "To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense" Yet, despite the awareness of the problem, the pedagogical model for engineering has changed little over the past 60 years [6].

The technologies that engineers rely on have changed somewhat. At the level of practical technology, universities often lag industry. At the teaching level, universities adopt technologies based on industry standards. When standards evolve in relatively short time spans (as is the case with software), academic institutions lag substantially.

Even slower to evolve is the methodology by which engineers are taught. Engineering programs are based on rigorous understanding of technical principles applied for analysis – not synthesis. Additionally, engineering students work in environments that are populated almost entirely with other students who share similar backgrounds, aptitudes, and attitudes. Such an environment fosters cohesive thinking, not innovation. Such an environment is also not representative of the workplace that most engineers will find upon graduation – at least not in successful companies.

Major American manufacturers have slowly developed a growing appreciation of the benefits of cross-functional design teams. Previously, design teams were homogenous and compartmentalized. The benefits of team diversity had yet to be realized. Engineering departments worked in isolation and autonomy. Today it is relatively well understood that an effective design team must rely on continuous input from individuals with widely varying skill sets. The integration of ideas and perspectives from diverse backgrounds is essential to optimal design of complex systems [7].

Applying the principals of one of the leading thinkers on structured creativity, Genrich Altshuller, we must consider that the innovative solution to the engineering education problem may depend on methods that lie outside engineering. A truly creative and effective solution may require contributions from disciplines unfamiliar to engineering [8].

Methodologies to Enhance Engineering Creativity and Recruitment

Though the practice of engineering often involves creative activity – synthesis – the teaching of engineering predominantly emphasizes analysis. In effect, we teach students how to examine "what has been done?" rather than to contemplate "what is possible?" A variety of methodologies have been developed to assist engineers in creative thought. Studies of these methodologies have shown them to be effective tools to enhance and organize creative thought. In the engineering classroom, these tools have been shown to effectively enhance the creative thinking of students [9].

Methodologies that help identify and clarify user requirements, such as Quality Function Deployment (QFD), have been used to help designers better link technical considerations to meeting customer requirements[10]. Methodologies that facilitate creative idea formation have been explored as effective tools in both practical [11, 12, 13] and educational settings [9, 6]. Such tools include brainstorming, mind mapping, lateral thinking and axiomatic design. Similarly, tools such as TRIZ (Russian acronym for Theory of Inventive Problem Solving), have been shown to be effective in organizing the creative process to converge to an optimal solution [8].

The role of creative thought in design and engineering represents an interesting topic for psychological and pedagogical research. A critique of those studies finds that they often conduct research using students as subjects but draw conclusions from the perspective of engineering design practice. Methods that have been proposed are done so with an absence of rigorous evaluation. Despite the lack of adequate research data, a plurality of studies of design education concludes that the process of design is best learned through practice. Furthermore, the design experience should be as real as possible, compelling students to draw from a wide range of skills. Through experiential learning and appropriate pedagogy, meta-cognitive processes can be elucidated and students can move from novice toward expert design skills [14].

Research suggests that the increasingly challenging problems facing engineers must be met with innovative designs that employ systems approaches. Following the traditional engineering paradigms may lead to incremental improvements, but transformational results require that problems be approached from a much broader-minded perspective. Many authors have concluded that such perspectives are best facilitated in design environments where technical and non-technical contributors must work and communicate together [15,16]. Such an environment can be created when students from art and engineering work together.

An obstacle to collaboration between the arts and engineering is the perception that the two fields are incompatible. Emerging viewpoints suggest that the apparent rift between the arts and engineering is a modern construct that has served to hamper innovation. Surely, none would question either the artistic or scientific credentials of da Vinci. Likewise, renaissance artist Albrecht Durer was a published scholar whose work explored the science of geometry in the context of art. Today there is a movement to restore the relationship between art and science, arguably for the betterment of both [17, 18]

Social, cultural, and situational pressures can cause us to favor either creativity or rational thought to the exclusion of the other. Pressures to embrace rigid, rational thinking pose a threat to the creative processes that lead to great innovation [19]. The breaking down of artificial barriers to interaction between scientific and artistic minds fosters dialogue and collaboration that support creativity. Modern examples of successful collaborations between art and science [20, 21]serve as motivation for more ambitious collaborations that extend into the formal classroom.

There are several indicators that also suggest that the heavy emphasis of theory and rigor over practice and creativity within the engineering curriculum has negatively impacted recruitment. The effectiveness of alternative paradigms for engineering education suggests that there may be a large pool of potentially very innovative engineering students who are not served by the current instructional paradigms. Anecdotal evidence regarding the success of undergraduate institutions that emphasize hands-on application, such as Rose-Hulman, Harvey Mudd, and the recently formed Olin College, have shown that some students flourish in an environment that embraces application at a level appropriate for undergraduate study [22].

Additionally, there is a growing acknowledgement that business acumen, entrepreneurship, creativity, and communications skills – historically undervalued within the engineering curricula – are essential to developing highly innovative and successful engineering graduates. Curriculum reformers such as Karl Smith at the University of Minnesota [23] and James Jones at Purdue [24] have called for revisions to engineering programs that support these crucial skills, put engineering education in a broader multidisciplinary context, and appeal to students whose proclivities are not limited to mathematics and the physical sciences.

An Innovative Solution for Recruitment and Creativity

As universities struggle to increase the number and quality of STEM graduates, particularly engineers, there must be a willingness to reevaluate the existing educational paradigms. Barriers that limit the appeal of engineering programs to otherwise well-qualified creative and practice-oriented thinkers must be removed. Methodologies that assist with structured creativity must be more thoroughly integrated into engineering programs.

The classroom application of multidisciplinary creative course content is largely limited by the traditional structure within the engineering programs. If engineers work only with other engineers, especially those from their own discipline, the seeds of creativity fall on barren soil. Creativity flourishes when conventional problems are met with unconventional solutions. To become adept at applying engineering science to open-ended problems, engineering students must be provided with an environment in which they may do so and be challenged by real engineering problems. Such problems must be representative of the innovation challenges faced in engineering practice, not just those interesting at the level of academic engineering research.

TOWARD A COMPREHENSIVE PARTNERSHIP

Reacting to a sense of both need and opportunity, two programs were independently initiated to support the need for enhanced creativity and recruitment into STEM disciplines. Both programs arrived at the same conclusion: creativity and recruitment efforts within STEM are aided by collaboration with art. These programs, now part of a broader, integrated effort between the K-12 Liberty School District and faculty at Youngstown State University, are discussed below.

Liberty Schools STEM and STEAM

The need to support STEM education at the K-12 levels is now almost universally recognized. As part of a recent initiative put forth by Ohio Governor Ted Strickland and key legislators in the Ohio General Assembly, investments have been made to establish STEP curricula in K-8 programs. The Liberty Schools' W.S. Guy Middle School recently applied for and was awarded nearly $120,000 to support STEM programs within the school. At grade levels 8-12, the school is in the process of developing a grant-funded program that integrates STEM and the arts (STEAM). That program is currently funded with a $50,000 initial grant with an expectation that an additional $450,000 will become available for program implementation.

These programs are leading to the creation of a complete K-12 curriculum offered as an alternative to the traditional curriculum. Students who participate in these programs will, from the perspective of state accreditation, be attending an entirely different school than their peers in the traditional curriculum. The curricula will not overlap. In this manner, the programs under development differ substantially from extracurricular activities such as Odyssey of the Mind [25] and Destination Imagination [26].

To assist with the development of appropriate programs in STEM, faculty and administrators in the Liberty School District have sought input from faculty and administrators of the nearby Youngstown State University. Through interactions between these faculty, teachers at the K-12 level are gaining an appreciation for the nature and rigor of skills that are necessary for students to be successful in collegiate STEM programs. Additionally, faculty are being educated as to the nature of engineering and how it integrates not only the broad topics of the sciences and mathematics, but also creative aspects more traditionally associated with the arts.

The Liberty Schools STEM and STEAM initiatives are presently under active development. As the programs are implemented, they will incorporate methods of instruction that integrate the languages of science, technology, engineering, arts and mathematics. The teaching methods will emphasize experiential and inquiry-based learning to help students learn problem-solving, collaboration, critical-thinking and research skills.

Students will work together in learning-event cadres, using personal growth plans to learn and apply 21st century workplace skills. Recognizing the importance of interdisciplinary collaboration, these skills will include group communications skills as well as time and resource management skills.

A primary goal of this program is to increase the number of students attending post secondary school, particularly those who might be interested in pursuing STEM-related fields of study. By providing successful learning opportunities to students who might not otherwise feel qualified to pursue college, it is anticipated that the program will expand the pool of college-bound high school graduates. A critical element of this program is to engage students through a multi-dimensional curriculum that may inspire and engage a broader population of students than do the traditional approaches to STEM education.

Each aspect of the school is rooted in best practice and backed by research in STEM and Arts education. Each hands-on, minds-on, authentic STEAM learning experience will enable students to relate their personal and academic interests to their learning of STEAM, exploring their own schema for each event. Activities will be structured for students to engage in activities appropriate in terms of complexity and pacing for their current level of knowledge and skill, while challenging them to move forward. The teaching-learning cycle will be based on Vygotsky's recursive nature of learning and will form the foundation of the scientifically based research on instructional and application practices. To facilitate this paradigm shift, adapted enrichment centers will be implemented.

The introduction of the arts into the STEM curriculum supports and nurtures development of cognitive, social and personal competencies. Complementary to the efforts to expand the pool of STEM students, arts-based learning reaches students who may not otherwise be reached. Success in arts becomes a bridge to learning and success by tapping into different learning styles Participating in the arts connects learning experiences to the world in that students and their teachers learn the ability to generate ideas, bring those ideas to life and communicate them in a 21st century workplace

As the first cohort of 7th and 8th grade students begins in Fall 2010, assessment activities will measure the rigor and effectiveness of the program implementations. Consistent with state assessment criteria, an array of strong accountability and performance systems will serve as the methods and means for monitoring and evaluating progress in achieving goals and objectives. Periodic and ongoing formative and summative assessments, as well as formal and informal assessments will be employed, including: authentic performance evaluations, portfolio assessment with rubrics and exemplars, checklists, Likert scales, anecdotal notes, and reflective entries. Based on the assessment data, ongoing and iterative improvements will be made to the instructional program. Details of the assessment methodologies are being worked out over the summer recess in anticipation of the start of the program.

YSU CoLab Project

At the university level, a group of energized faculty has independently recognized the merits of collaboration between the arts and engineering. Envisioning the potential benefits of collaboration, faculty from Youngstown State University's College of Science, Technology, Engineering and Mathematics (STEM) and the College of Fine and Performing Arts (FPA), have begun to explore how to integrate learning experiences to the benefit of students in both programs. Over the past 18 months, a small group of faculty has proposed the development of a collaborative laboratory setting that has been dubbed CoLab. In a pilot exercise, several students from FPA and STEM have been working cooperatively.

The student design teams are formed based on complementary skill sets. Students from FPA have an artistic vision and aesthetic motivation, but they may lack the technical expertise to bring a project to fruition. The engineering students from STEM have technical expertise, but they have not likely been challenged to apply those skills to solve problems that are unusual, abstract, or loosely constrained. This collaboration between art and science has gained substantial interest, but has not yet been studied formally to measure effectiveness on meeting engineering education goals.

The CoLab concept is to pool the resources of multiple colleges within the university to give students maximum access to equipment. While engineering is well equipped in many aspects of manufacturing processes and metrology, some of the best fabrication facilities on campus are tied to the sculpture department of FPA. Sharing those resources is an obvious benefit to both colleges.

Efforts to acquire additional resources for CoLab will initially focus on providing students with the ability to generate physical prototypes of designs from a variety of materials. The use of rapid prototyping and computer numerically controlled (CNC) equipment will allow students autonomy in the early phases of their design development. The ability of these processes to convert computer models to artifacts with final geometries means that the students can focus on design intent without a comprehensive set of skills related to the fabrication. In cases where the capabilities of the rapid prototyping equipment are inadequate, the students have access to a full complement of support personnel and equipment in two colleges.

CoLab is not intended just as a single physical laboratory. It is, rather, a concept for establishing shared resources and cooperation between faculties from dissimilar fields to create an educational experience that is broader than is possible within a single department or college. It is intended to develop, in students and faculty, an appreciation of the value of synergistic cooperation.

Collaboration is at the heart of academic development, yet, the spirit of collegiality in many institutions does not extend beyond the corridors of a particular college or even department. The intense territoriality that is prevalent in most universities is partly motivated by the competition for scarce resources and partly rooted in a contempt held between practitioners working in fields that outwardly seem to have very little in common. In fact, however, the territoriality leads to academic isolationism. Resources, ideas, and opportunities that might otherwise be shared are lost.

In practice, engineers cannot work in isolation. Business and finance majors will control the purse strings. Marketing will push for saleable features. Local municipalities will impose environmental constraints on an operation. The list of stakeholders in any real-world engineering problem is long, and the educational backgrounds and perspectives represented in the process are widely varied. By creating an environment in which students must work with colleagues who come from other, very different disciplines, the students are forced to make design compromises that consider factors beyond just their own area of expertise. Consideration of such factors will frequently lead to an entirely different design than would be conceived independently. Though the process of working in a cross-functional design team is frequently uncomfortable at first, it is generally more effective in the long run.

Providing engineering students with the experience of working in a cross-functional design team benefits them in terms of valuable non-technical skills. In terms of creativity, it pushes the students to consider answers that lie outside of the obvious solution space for their discipline. It also forces them to communicate with team members who do not share their common vernacular.

There are reasons to assert that communication ability is closely tied to creativity. Engineering students who learn to communicate the important aspects of their technical considerations to a non-technical audience are demonstrating a higher level of understanding. They are able to apply their concrete skills to abstract problems and then communicate and justify their conclusions to team members who do not share the same underlying skills or assumptions. In the process, they are also developing communications skills that will make them considerably valuable in the workplace.

A key element of the CoLab is the development of a shared workspace where design teams can meet, collaborate, and work on designs. Ideally, this space should be "neutral." That is to say that it should not be more familiar to one group of students (or faculty) than another.

The CoLab that is under development at YSU is taking advantage of a facility housed in a privately endowed museum on campus, the Butler Institute of American Art. Housed within that museum is the Beecher Center, a facility dedicated to the interface between art and technology. Through the generosity of the Beecher Center, CoLab faculty have been allowed to use a portion of their space.

That space affords CoLab approximately 1,400 sq. ft. of workspace in a display wing of a public museum.

The goal of the CoLab faculty is to gather appropriate shared equipment in this area to facilitate the ideation and early development stages of the interdisciplinary collaboration. Teams will be granted access to the facility throughout the week. Within the facility, student teams will be able to use meeting facilities, computing facilities, multimedia, and small-scale freeform manufacturing (rapid prototyping) equipment.

PROGRAM OUTCOMES TO-DATE

The K-12 aspect of the collaboration is under active development. Program implementation in grades K-6 is already active, and development is underway for grades 7-8. Implementation of an overlapping STEAM curriculum as an alternative to the traditional curriculum is currently being undertaken as part of a funded pilot program. That project will begin with two initial cadres of students in grades 7 and 8. Each subsequent year, as those groups progress through the curriculum, an additional year of the new curriculum will be added. These curricula are being developed with input from STEM faculty at YSU and will be designed to complement efforts to develop STEAM activities at YSU.

Assessment activities for the K-12 portion of the program are ongoing. Traditional metrics are being employed consistent with requirements applicable to the public school district. Because of the nature of the program as a pilot, additional metrics related to college matriculation, choice of major, and long-term success are being explored.

The CoLab project has yielded several successful collaborative projects. Most recently, a team of students from Mechanical Engineering Technology (STEM) and Sculpture (FPA) partnered to work on a design for a retro-styled cell phone. The idea was to bring to life the artist's vision for a functional rotary-dial cell phone. The team worked together from concept through prototype. Through the process, the FPA student became aware of a wide range of manufacturing technologies with which he had previously had no experience. The student from Technology was challenged to apply engineering principals to address a poorly constrained, creative problem.

CONCLUSIONS AND FUTURE WORK

Complementary activities in the Liberty School District and at Youngstown State University are actively exploring the potential benefits of an integrated curriculum that merges influences from art and engineering. This merger has a historical basis as well as increasing support from current business and pedagogical literature. The structure challenges what have come to be the accepted educational paradigms in hopes of addressing some of the most significant challenges currently facing engineering education.

These activities include funded pilot programs for which assessment is crucial. Over the next 5-10 years, as students progress through the various levels of the integrated programs, assessment data will be aggregated. It is hoped that these data will provide compelling evidence in support of the benefits of this integrated multidisciplinary approach.

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