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Active Learning and Student Engagement via 3D Printing and Design: Integrating Undergraduate Research, Service Learning, and Cross-Disciplinary Collaborations

Lon A. Porter, Jr.

Department of Chemistry, Wabash College, 301 W. Wabash Ave., Crawfordsville, IN 47933, U.S.A.

ABSTRACT

In order to provide students with the training required to meet the substantial and diverse challenges of the 21st Century, effective programs in engineering, science, and technology must continue to take the lead in developing high-impact educational practices. Over the past year, faculty across several departments collaborated in the establishment of a campus 3D printing and fabrication center. This facility was founded to offer opportunities for exploring innovative active learning strategies in order to enhance the lives of Wabash College students and serve as a model to other institutions of higher education. This campus resource provides the infrastructure that will empower faculty and staff to explore diverse and meaningful cross-disciplinary collaborations related to teaching and learning across campus. New initiatives include the development of courses on design and fabrication, collaborative cross-disciplinary projects that bridge courses in the arts and sciences, 3D printing and fabrication-based undergraduate research internships, and entrepreneurial collaborations with local industry. These innovative approaches are meant to open the door to greater active learning experiences that empower and prepare students for creative and practical problem solving. Furthermore, service learning projects, community-based opportunities, and global outreach initiatives provide students with a sense of social responsibility, ethical awareness, leadership, and teamwork. This paper shares initial successes of this effort and goals for future enrichment of student learning.

INTRODUCTION

The accelerating improvements in 3D printing methods capture the imagination as this additive manufacturing technology finds new applications in fields ranging from construction and surgery to prosthetics and rapid prototyping [1-4]. The growing popularity and decreasing price point of current 3D printers has increased accessibility via local makerspaces, universities, high schools, and community libraries. Recognizing that there was great potential for harnessing this new technology for enhanced student engagement [5], an exploratory 3D design, printing, and fabrication steering group was convened with faculty and staff from a diverse range of academic and support departments. Deliberation and collaboration led to plans for a campus 3D printing and fabrication center. This facility, ultimately made possible by an Independent Colleges of Indiana - Ball Brothers Venture Fund Grant, provides the infrastructure and technical expertise required to serve as a nexus for innovative high-impact educational activities across campus. The center currently hosts a diverse range of 3D printers, 3D scanning equipment, a 90

Watt laser engraver/cutter, vacuum forming instrument, and a computer numerical control (CNC) router.

THEORY

Historically, innovation was coupled with traditional approaches to science, technology, engineering, and mathematics (STEM) education. While the STEM disciplines are necessary, they are insufficient in addressing the myriad challenges facing society in the 21st Century. STEM emphasis on critical thinking, experimental design, modelling, and data analysis must be coupled with student growth in creativity, innovative thinking, effective communication, and the ability to recognize connections across intellectual disciplines. This is often achieved by the marriage of STEM with art and design, known as STEAM (STEM+Art). It represents a more holistic and interdisciplinary approach to problem solving, one that advocates high-impact educational practices that aim to explore opportunities where complex design problems require skills beyond the traditional STEM arena [6].

Traditional lecture-centered approaches are inadequate for preparing students for the challenges of creative problem solving. Instead, learner-centered and other high-impact pedagogies are gaining prominence. Work by George Kuh and others cite compelling evidence from the National Survey of Student Engagement (NSSE) that these educational approaches increase student engagement and retention [7-8]. Programs must also provide students with educational opportunities that prepare them for collaborative and innovative problem solving. The work described here seeks to explore the introduction of 3D design, printing, and fabrication activities into STEM education and experiential learning opportunities at Wabash College.

DISCUSSION

Undergraduate research and internships

Wabash College is fortunate to host multiple campus internships, entrepreneurial experiences, and undergraduate research programs. These high-impact opportunities provide students with direct experience, most often related to career interests, and gives them the benefit of supervision and mentoring from professionals. The goal is to involve students with actively contested questions, empirical observation, cutting-edge technologies, and the sense of excitement that comes from working to answer important questions. One major aim of this work is to introduce 3D design, printing, and fabrication in support of student internships, entrepreneurial experiences, and undergraduate research collaborations with faculty and staff. Furthermore, by connecting students in these programs together via logical collaborations, they will be equipped to tackle significant problems using design and fabrication tools.

An initial cohort of four summer research students used digital design and 3D printing to produce a working colorimeter instrument (Figure 1) [9]. This functional analytical tool can be used to determine the concentration of analytes in solution. Commercial devices of this type typically cost hundreds or thousands of dollars, yet the 3D printed version costs under $20 to produce and is highly portable. Digital models were constructed by students using simple computer-aided design (CAD) programs, such as Tinkercad and Inventor Professional. These software packages are simple to use and available to students and educators. The instrument is powered by batteries and is compatible with a variety of commercially available light-emitting diode sources (LEDs) and solid-state detectors. The 3D printed colorimeter performs well when compared to commercially available spectrophotometers and the digital design is easily modified in order to explore a variety of concepts inaccessible to more conventional instruments. These devices will be used in the classroom, where teams of students employ them in laboratory learning. This is an attractive alternative to commercial instruments, which are often limited to one per class due to their expense. The student produced 3D colorimeters will also be employed in science and engineering outreach projects involving local middle and high schools.

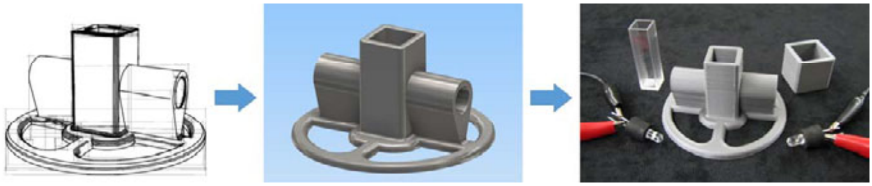

Figure 1. The 3D printed colorimeter instrument designed and produced by Wabash College undergraduate summer research interns [9]. The images above display the evolution of the design from 2D sketch (left) to 3D-rendered CAD model (center). The final 3D printed colorimeter (right) was fabricated from polylactic acid (PLA) plastic using a consumer-grade 3D printer (Ultimaker 2). A cap, LED source, sample cuvette, and phototransistor detector are displayed.

During the academic year, three to six students are employed in the 3D printing and fabrication center as instructors and consultants. These student interns train users and provide important project support in the form of CAD design and fabrication assistance. Additionally, collaborations with the Wabash Center for Innovation, Business and Entrepreneurship (CIBE) look to provide opportunities for students across the sciences, in conjunction with industry and manufacturing professionals, to work on solving real-world prototype and manufacturing challenges for local businesses.

Service learning

Several high-impact “experiential learning” activities aim to give students direct experience with issues they are studying in the curriculum and ongoing efforts to analyze and solve community-identified problems. A key element in these programs is the opportunity students have to both apply what they are learning in real-world settings and reflect in a classroom setting on their service experiences. In this role, the 3D printing and fabrication center is an important tool used by students to model the idea that giving something back to the community is an important college outcome, and that working with community partners is good preparation for citizenship, work, and life. For example, our current flagship outreach project involves collaborations with health professionals and non-profit organizations to produce 3D printed prosthetic devices. One in 1,000 infants is born with missing fingers, and others lose fingers and hands to injury. Traditional, complicated prosthetic devices cost thousands of dollars, are difficult to maintain, and children quickly outgrow them. Using 3D scanners and printers, customized and inexpensive prosthetic hands can be produced for children in Indiana and across the globe. The nonprofit group, Enabling the Future (e-NABLE), has produced several prototype hand designs. Using these as models, students collaborate to develop new prosthetic designs at Wabash (Figure 2). 3D printed prosthetic devices are fabricated for around $30 a unit. These devices are shipped to e-NABLE, where they are ultimately sized and provided to recipients, free of charge. Recent efforts in developing new collaborations with other campus initiatives, such as the Wabash Global Health Initiative, look to develop prosthetic devices for children in both Peru and Ecuador, where 3D printing facilities are significantly less available.

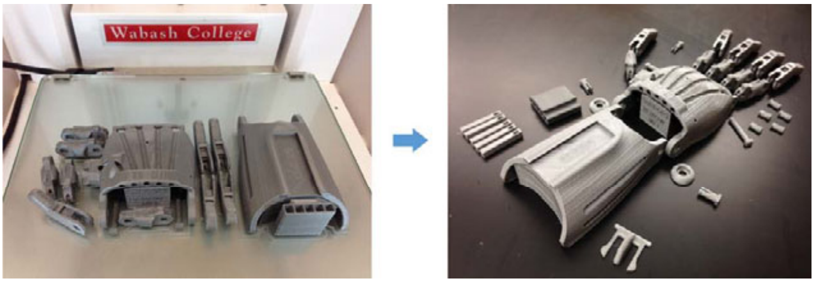

Figure 2. The 3D printed prosthetic hands produced by Wabash College students. The device was 3D printed (left) from polylactic acid (PLA) plastic using a consumer-grade 3D printer (Ultimaker 2). The individual components are removed from the printer, trimmed, and prepared for assembly (right).

Interdisciplinary teaching and learning

Liberal arts colleges were some of the first institutions to demonstrate educational enrichment related to student engagement and learning achieved through cross- and interdisciplinary learning programs. These efforts regularly bridge academic departments via explorations of multifaceted or global subject matter. The majority of risk taking in education is happening on the very fringe of academia, at the convergence of non-traditional departments collaborating. This is also where the largest gains might be achieved, as students are challenged to abandon traditional thinking and collaborate to solve issues. However, at many liberal arts colleges, this rarely happens; STEM disciplines often fail to incorporate the more creative and collaborative approaches to problem solving. While still in its exploratory stage, this work seeks to provide the opportunity to develop a number of exploratory programs, employing high-impact educational approaches aimed at fostering collaborations, while pushing the academic boundaries of the traditional liberal arts college by assisting faculty, staff, and students to innovate courses and teaching methods.

Wabash's first-year seminar (The Wabash College Freshman Tutorial) program brings small groups of students together with faculty in the exploration of a topic chosen by the instructor. A requirement for all entering freshmen, the program places strong emphasis on critical reading, frequent writing, information literacy, collaborative learning, oral communication, and other skills that develop students' intellectual and practical competencies. Tutorial courses also establish an early learning community for freshmen. The 3D printing and fabrication center enables the development of new tutorial sections focused on STEAM-appropriate subject matter, such as digital design and fabrication. One specific pilot freshman tutorial course, *Design, Make, Play: Building All Things Great and Small*, will explore design and fabrication spanning the atomic scale of molecules to the grand architectural wonders of the ancient and modern world. The course will be coordinated and taught by the current director of the fabrication facility, along with significant incorporation of faculty from biology, physics, art, music, mathematics, and computer science. These faculty will integrate personal and professional applications of creativity, fabrication, and problem solving into the course. Students will develop digital design expertise in the form of introductory computer aided design and develop collaborative fabrication projects related to a public outreach effort of their choosing. All of the final projects will be put on exhibit for campus and community audiences.

To help further develop and sustain these high-impact educational opportunities, the 3D printing and fabrication center has established competitive curricular mini grants for faculty in support of work related to developing collaborative cross-disciplinary projects that bridge topics in the arts and sciences for new or redesigned existing courses. The mini-grants will provide selected faculty with a stipend and funds for course supplies. Several Wabash faculty have already expressed interest in this opportunity. Potential projects include collaborations between theater and physics, where students may explore scenic design for theatrical productions; computer science and art, where students may engage in computer aided design and programming to fabricate robotic components involved in art installations; and physics and music, where teams of students may explore acoustics in the design and fabrication of nontraditional musical instruments. These experiences aim to challenge faculty to think beyond their traditional content expertise and engage their students in creative and collaborative problem solving activities.

Assessment and dissemination

The work discussed above requires systematic assessment employing a variety of instruments. The cross- and interdisciplinary STEAM teaching and learning goals will be assessed by collecting data on student interest through freshman seminar enrollment numbers; student retention, engagement, and achievement related to course activities and course exam grades; and survey instruments targeting both faculty and student evaluation of the experience. Course implementation success will be measured using student and faculty surveys and reflective learning outcome evaluations related the course projects. Internships and extracurricular goals will be assessed through student surveys, reflective essays, campus and national symposium presentations, publications, and campus interest. Service learning success will be evaluated based on the level of campus and student involvement, number of prosthetic devices created and successfully paired with recipients, and survey responses obtained from campus participants and device recipients where possible.

The strategies developed as a result of this work will provide opportunities that are generalizable to other institutions of higher learning. Dissemination and outreach efforts will take the form of workshops, peer-reviewed publications, and national conference presentations. Much of the 3D design experience will be shared via online instruction through the use of

YouTube video tutorials, the Wabash College website, and online "maker" communities. Here, 3D printer projects for the classroom, technical tutorials, and digital designs can be accessed by educators and students at institutions across the globe.

CONCLUSIONS

While still in its early stages, the Wabash College 3D printing and fabrication center is already beginning to provide opportunities for new and innovative active learning strategies in order to enhance teaching and learning. The approaches described above are meant to empower and prepare students for creative and practical problem solving. Service learning projects, community-based opportunities, and global outreach initiatives aim to provide students with a sense of social responsibility, ethical awareness, leadership, and teamwork. Future efforts will focus on implementation, assessment, and dissemination work.

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