The Community FabLab Platform: Applications and Implications in Biomedical Engineering

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Abstract—**Skill development in science, technology, engineering and math (STEM) education present one of the most formidable challenges of modern society. The Community FabLab platform presents a viable solution. Each FabLab contains a suite of modern computer numerical control (CNC) equipment, electronics and computing hardware and design, programming, computer aided design (CAD) and computer aided machining (CAM) software. FabLabs are community and educational resources and open to the public. Development of STEM based workforce skills such as digital fabrication and advanced manufacturing can be enhanced using this platform.**

Particularly notable is the potential of the FabLab platform in STEM education. The active learning environment engages and supports a diversity of learners, while the iterative learning that is supported by the FabLab rapid prototyping platform facilitates depth of understanding, creativity, innovation and mastery. The product and project based learning that occurs in FabLabs develops in the student a personal sense of accomplishment, self-awareness, command of the material and technology. This helps build the interest and confidence necessary to excel in STEM and throughout life. Finally the introduction and use of relevant technologies at every stage of the education process ensures technical familiarity and a broad knowledge base needed for work in STEM based fields.

Biomedical engineering education strives to cultivate broad technical adeptness, creativity, interdisciplinary thought, and an ability to form deep conceptual understanding of complex systems. The FabLab platform is well designed to enhance biomedical engineering education.

I. INTRODUCTION

One of the foremost challenges in the 21st century has been that of equipping students and others entering the workforce with a set of skills and knowledge, which will enable them to thrive in their chosen professions. This is especially true of those who would potentially enter career pathways related to science, technology, engineering and math (STEM).

The challenge of sufficiently equipping potential practitioners with the technical and soft skills needed to excel in Biomedical Engineering (BME) is especially compelling. As Einstein is reported to have said, "the greatest scientists are also artists". This idea is particularly true of biomedical engineers. In BME, technical adeptness is imperative, while daring creativity is a must. Developments in BME are driven by the nimble understanding of the minutia of a complex, moving system, coupled with a vibrant imagination of what could be.

In the traditional paradigm of formal education, the spectrum of scientific and mathematic understanding developed over many decades and centuries is reduced to a core of theory. This theory is typically not strongly connected with the situations where the discoveries that led to the theory were made. This disembodied theory is presented to students in a rapid fashion, since theory sufficient for a career is seemingly being attempted to be transferred to the students. Students are expected to learn, recall details, process the relations, and build logical structures.

This traditional educational approach when used exclusively, falls short in two primary aspects. First, the approach rewards primarily the small student population who thrive in this abstracted environment. For the other student populations, this approach tends to cause frustration, lack of mastery, and disengagement. This observation can be substantiated by the low matriculation and high attrition rates of STEM students at the college level. Second, the approach does not cultivate the creative and expressive aspect within the student, which is so vital to achieving success in the BME field. We note that, in sharp contrast to the traditional educational approach, many of the individuals who made a major impact by STEM activities during their lifetimes, learned much of what they utilized through experimentation, trial and error, and self-directed learning.

The FabLab platform is well suited to support the interdisciplinary, multifaceted and integrated skill development that is central to BME. In a FabLab, students implement scientific knowledge while gaining relevant technical skills and developing the art of creative thought. The labs provide a platform for discovery based, authentic educational experiences. By using accessible, relevant, creator technology and project based instruction methods, students do and build their way through various concepts, developing intimate experiences with theory and the modern tools for design, engineering and prototyping. In this environment, conceptual thinkers and practical doers can engage equally.

II. OVERVIEW

The Community FabLab platform was widely introduced about 10 years ago by Neil Gershenfeld of MIT's Media

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Lab, now director of the Center for Bits and Atoms (CBA). While the central activating principal of the FabLab platform was not revolutionary, Gershenfeld's implementation was.

The platform is simple. Each FabLab contains a suite of modern, computer numerical control (CNC) manufacturing and fabrication tools, computing and electronics hardware and enabling software. The application itself is arresting: these suites of tools and software are installed in commonly accessible venues such as two- and four-year colleges, K12 schools, libraries and community centers. In these places, many FabLabs function as community resources, readily available for general use. Figure 1 shows children engaged in summer STEM programming at their local FabLab.

FabLabs thus provide a powerful context for STEM education and development, by stimulating engagement and catalyzing authentic learning experiences through personal expression and investment. The platform supports a variety of student types and facilitates development of a wide range of skills that are essential to BME education and development.

This paper describes CNC technology as the enabling technology behind the FabLab, explores the history and context of the FabLab platform, and discusses potential applications within BME education.

Figure 1. Young children performing renuewable energy project uisng FabLab tools – FABLabs for America, 2012

III. A BRIEF OVERVIEW OF CNC TECHNOLOGY

CNC machining technology has been in existence for more than half a century. Starting in the 1950s [2], machines were automated by connecting their motion controls to a computer.

To this day, the technological idea remains the same. CNC technology has been applied to an impressive range of machines. From the common office printer; to sophisticated milling machines that chisel powerful, high end engines from a single block of steel; to digital sewing and embroidery machines; to bio-printing of organs and tissues, CNC technology has become an integral part of 21st century productivity [2]. Since the 1950s, the generation and processing of the data sent to the machines has been greatly expanded in both ends of the complexity spectrum. Both very simple hand drawings, to highly complex 3-dimensional (3D) scans can be converted into a set of data points and printed on a variety of CNC machines. For example, complex, 3D scans of trauma victims are used to quickly create custom made, CNC machined implants. Additionally, more sophisticated Computer Aided Design (CAD) tools have been developed to allow various classes of end users to generate and build their own objects using CNC technology.

A. *Applications and Implications of CNC Technology*

CNC technology paved the way for the advent of rapid prototyping: low cost, iterative engineering and precision machining, allowing items to be designed and built to tight specifications [2]. CNC machining allows the automated and precise manufacture of a single part *en masse*. These enabling attributes of the technology have made CNC a cornerstone of the modern industrial complex, similar in some ways to the earlier cornerstone of the assembly line as breakthrough in the optimization of production to meet large-scale and global demand.

CNC manufacturing technology falls broadly into two categories: subtractive manufacturing and additive manufacturing. As the name suggests, subtractive manufacturing involves cutting, drilling, grinding and carving a larger block of the substrate material to make a smaller object having the desired shape. Additive manufacturing employs the opposite approach, building up an object in a precise way out of some desired material. A recently recognizable example of this technology is 3D printing. Subtractive manufacturing is the longer standing of the two methods and the most widely used in industrial settings, but additive manufacturing is expanding into many traditional and nontraditional applications [2].

B. *CNC Technology in Medicine and Medical Devices*

CNC technology has long been a standard technique utilized by the medical device manufacturing industry [2]. Recently, advancements in imaging of organs, tissues and extracellular matrix structures, along with advances and data processing technology have been utilized as the design for 3D printing. These imaging originated and fabricated structures enable personalized medical solutions at both the macro and micro scale. In general, additive manufacturing has enabled the further expansion of personalized medicine, providing a more direct and less expensive method of making one-of-a-kind items. For example, osteoconductive cranial implants for trauma victims have been reported [7]. Additive manufacturing is being utilized by many researchers working toward production of organs and tissues [3]. Moreover, subtractive manufacturing techniques are used to build molds for casting items such as personalized dental implants.

IV. THE ADVENT OF OPEN SOURCE MEDICAL TECHNOLOGY

If solving the problems of society required the efforts and contribution of only a small subset of workforce who were capable of and engaged in STEM, then the traditional approach to scientific education and technological problem solving would be sufficient. However, the needs of society, particularly within the medical realm, are growing increasingly complex, and solutions are not being developed or implemented by the current workforce. Additionally, individuals who are not engaged in STEM activities and careers not only do not contribute toward STEM based solutions to society's problems, but they themselves do not benefit in salary and connectedness with the STEM based activities. This lack of benefit extends to their families and communities. A society with complex problems and large segments of the society not engaged in the development and implementation of solutions is not optimally organized. Democratized access to manufacturing technology through the FabLab platform and other related initiatives is changing the landscape of where and how medical devices are developed.

A recent news story reported by National Public Radio [6] illustrates the point, in that a useful prosthesis was developed not by the expected engineers and physicians at research institutions or within the medical device industry. Instead, seemingly ordinary people who were close to and involved in the need for the prosthesis used web resources and 3D printing to develop the prosthesis. The hand of a carpenter in South Africa became impaired due to an accident. He desired to return to work but could not afford a commercially available prosthetic hand. He collaborated with an American puppeteer who used a mechanical hand device in his shows. A third person, inspired by their efforts, utilized 3D printer to make a workable prosthetic hand for his son who was born lacking fingers on one hand. By utilizing web resources, 3D printing and their own ingenuity, seemingly technically unqualified, but motivated people developed medical innovations that helped people in need. This illustrates democratization of medical innovations. The Community FabLab platform should empower even more people to become engaged in life transforming activities.

V. THE COMMUNITY FABLAB PLATFORM

The Community FabLab platform was an incidental product of a federally funded exploration of the "boundary between the physical and digital worlds" [1]. Gershenfeld and colleagues received a National Science Foundation (NSF) grant to establish the Center for Bits and Atoms (CBA), to study the intersection between the physical and computational sciences. CBA brought together macro to micro scale technologies and machines. Figure 3 shows an example of the Fab House project, built with the machines of the FabLab. A common theme was each could convert a data model into physical model (digital fabrication and manufacturing tools), convert things into data (imaging technologies) or convert events into data (electronic, sensing and computational hardware) (see Figure 4). These assorted technologies had been typically segregated in different disciplines. CBA demonstrated that these technologies and machines could work in concert as a toolkit allowing an individual with an idea to design and build parts and complete systems, (Figure 2) [1].

A. How to Make (Almost) Anything

An early challenge was to train people who could operate the equipment in this new collection. For this purpose, Gershenfeld developed a class aptly named "How to Make (Almost) Anything" (HTMAA). HTMAA was a modular, project based course in which the student completed and documented a project utilizing each capability of this equipment suite. The final project was an integrated system chosen by the student.

When HTMAA was implemented, Gershenfeld and his team began to witness several unexpected results. 1) They received a deluge of applicants: (almost) everyone, it seemed, was interested. From artists with no technical background to engineering students. 2) Once in the course, technical background was not a determining factor in the success of the student. Students with no technical background were among those who excelled. 3) HTMAA resulted in an abundance of creative expression and personal fabrication. 4) The skills gained in HTMAA were portable. Students went on to integrate their new skills in whatever their original line of work or interest had been.

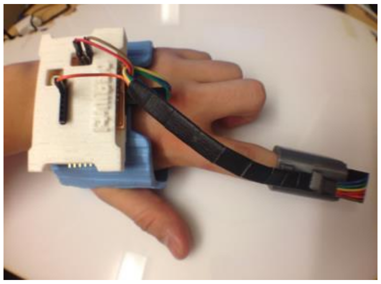

Figure 2. Integrated drawing glove system made by an artist in HTMAA

B. High-Tech Fabrication Goes Personal

The term "personal fabrication" became a hallmark of this course. Gershenfeld realized that students were not just solving technical and research problems, they were building things that they could not find commercially. Projects ranged from the quirky: a personal space for screaming; a dress that protects personal space; and a web browser for parrots. More practical designs were also created: a precision CNC mill fabricated at low cost; and digital materials for aerospace applications.

Figure 3. The Fab House project demonstrating the macro scale capabilities of the FabLab Platform

The NSF grant required the CBA to somehow provide public outreach programming. Gershenfeld took a nonconventional approach. They selected and installed a subset of the technologies and machines 1) in an urban community tech center in Boston USA, and 2) in a school for undereducated children in rural India. Community FabLabs were established.

C. Answered Questions

These Community FabLabs were the next step of this progressively developing experiment. CBA was a high-level research organization, founded to answer sophisticated questions regarding the relationships between matter and data. HTMAA had provided Gershenfeld with an answer to a question he had not intentionally asked, a question of the relationship between individuals, products and tools.

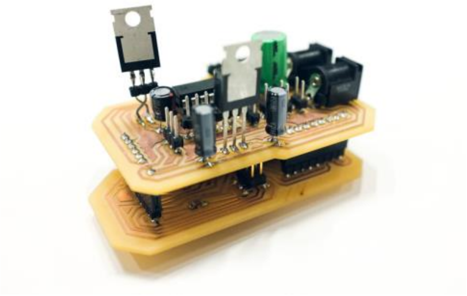

Figure 4. Circuit board built in the FabLab

Extending the platform to the public set the stage for another set of questions. If advanced technical training is not the enabling factor needed for one to take advantage of these tools, what is? If one does not need a technical degree to utilize advanced CNC equipment, build computing systems from scratch and develop the programs to run them, do you need a degree at all? What skills (technical and non-technical) does one develop through the process? How does all of this fit into the established paradigms of formal education, skill development and manufacturing? Development and Spread of Community FabLabs

As reports of this work spread, FabLabs or similar centers were setup and tried in many places across the globe. Gershenfeld and the FabLab team pushed the education and skill development through a course known as Fab Academy. The initial Fab Academy offering was a remake of HTMAA as a certificate course. This course, “Applications and Implications of Digital Fabrication”, is still taught by Gershenfeld through video conference. Local instructors at local labs guide participants through the coursework. Like HTMAA, this is a project based, modular course, requiring detailed documentation of each project and employing a capstone project. Applications and Implementations of Digital Fabrication is currently in its 5th year, and has grown from 5 sites to 14 sites this year (2014) [5].

VI. POTENTIAL APPLICATIONS TO BME EDUCATION

One vision of BME education might include the following characteristics.

1. Inculcate in the student an intimate, practical understanding of the human system, and the laws that govern function (physical sciences, mathematics, medical sciences)

2. Build broad technical competency (programing, CNC technologies, electronics, materials)

3. Cultivate creative thought and confidence of expression.

The FabLab platform has been used to successfully engage non-traditional audiences in engineering. Both inside and outside of formal educational venues, FabLabs allow nontraditional students and nonstudents to enter, innovate, and contribute toward BME solutions.

There are many potential ways to incorporate this platform in BME education. Students could be introduced to the FABLab in the beginning of their course of study in the context of an entry-level engineering design class. The students would learn the use of the FabLab tools and knowledge network by developing a relatively simple, project that integrates mechanical form, electrical function and biomedical application, and demonstrates the engineering best practices, which are being taught.

As students progress through an undergraduate course of BME study, the FabLab would remain readily accessible to the students would be encouraged to develop small projects, demonstrating the skills they are acquiring and the theories with which they are now familiar. These small projects would be counted for credit in a variety of classes. These classes might include Biology, Anatomy and Physiology, Circuit Theory, Physics, Chemistry, Statics, Dynamics, Thermodynamics, Computer Science, Motors and Controls and Embedded Communications.

In Biology, students might model a system being studied; in Medical Devices, develop an instrument to measure simple phenomena; and in Circuit Theory, design and build a circuit board to fulfill a specific purpose. These types of student design projects are typically hindered by lack of technological sophistication. The FabLab model would lower the expertise necessary and enable project development.

A course of study such as this would directly engage a larger portion of the student population from the beginning of their studies, and create a deeper culture of design and build engineering within the student population. These projects would provide valuable, tangible evidence of the student’s competency in numerous subjects, and coupled with traditional grading methods (such as paper exams) help to present a holistic picture of student achievement.

Finally, this approach would generate a much larger pool of practical approaches to common BME challenges that would lead to more rapid innovation, increasing the pace of technological discovery and improving the quality of life of many patients, while helping the innovators become productive, contributing members of the biomedical community.

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To my mother, for letting us stay in the FabLab when all my friend's mothers would have made them go home.

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