MAKER: A New Course on the Changing World of 3D Printing and Prototyping for Non-Engineers

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In recent years there has been a big push to get students into the STEM fields. However, what seems to be lacking in this academic push is the hands on side of it. Engineering simply just isn't about equations, but actually developing and building physical prototypes towards a final goal of developing and/or improving a product. Something you can touch and in most cases see work. This newly developed course is designed for non-engineering majors as well as engineering students as an introduction and survey of rapid-prototyping, especially centered on the advent, impact, and utility of 3D printers and supporting digital technology: computer-aided design (CAD) and computer-aided manufacturing (CAM) software. The course covers both the concepts and practice of 3D printing and prototyping, emphasizing hands-on work developing computer-based design models ("drawings") and fabricating prototypes ("parts") using current tools for desktop manufacturing including 3D printers, laser cutters, desktop engravers, and micro-molding and printing. With this knowledge and skill set, students are able to design, develop and demonstrate a working product suitable for commercialization. Expected student learning outcomes assessment in this course is performed using mid-term and final exams and written reports and oral presentations as well as an evaluation of each student's contribution to a term project.

Introduction Background

At the undergraduate level, many courses related to robotics, design, and materials are offered to the students in the Bachelor of Science in Engineering Technology program. Courses such as Robotics and Mechatronics, Quality Control, Manufacturing Materials, Microcontrollers, and Applied Mechanics can benefit from the laboratory experience in applications of mechatronics, robotics, and rapid prototyping. As well as helping in the teaching of various courses, such experience benefits students who are pursuing degrees in the engineering field. Students in the Mechanical, Electrical, and Industrial fields along with many others can learn many new skills from multi-disciplinary projects such as the rapid prototype design of consumer products, a walking robot or various designs related to capstone senior design projects^{3, 4}. Such projects show students how to use different types of technology, and demonstrate how advanced technology can be used in an actual application. Overall, many different fields of engineering can benefit from this application, enabling the development of skill and knowledge in many different engineering aspects and processes.

Making

According to Technically Philly, about 13 percent of Philadelphia School District's graduates earn four-year degrees in a STEM-related field [6]. The statistics are on par with national averages, whereby in the years between 2003 and 2007, only 15% of bachelor degrees were awarded in STEM-related fields. Furthermore, "less than one percent of African-American students — who make up more than half of the [Philadelphia School] District's enrollment — graduate high school and go on to earn college degrees in a STEM major." Nationally, African Americans and Hispanics are consistently underrepresented in STEM employment with African Americans representing 6% of STEM workers and Hispanics representing 7% of STEM workers [7].

Traditional efforts to increase participation in STEM fields have been largely focused on improving the math and science curriculum through better recruitment and training of teachers with scholarships, loan-

forgiveness, and higher pay. However, “not enough STEM graduates means not enough STEM teachers, regardless of incentives [8].” An alternative is to expose students to STEM fields early and induce them to choose STEM careers. For example, 65% of scientists with advanced degrees developed their science interest before middle school [9]. However, in underserved populations, it is not necessarily lack of the awareness of STEM fields but the socio-economic barriers that prevent students from choosing STEM fields. Solutions for these students are social support in terms of counseling, nutrition, and after-school care and social services such as mental health and health care that are brought to the students [10]. While libraries and museums or informal science institutions are at the forefront for engagement in STEM [9], creating MakerSpaces and establishing STEM collaborations with schools [11], in the context of underserved populations and aforementioned barriers, they do not provide the support and social services. On the other hand, community centers play significant parts in the lives of the communities and offer educational, welfare, and social activities and services including access to informal STEM learning [12]. Teachers have found Making to be a great way to get students excited and engaged in their classrooms and have incorporated Making in math and science classes [13]. Making allows students to follow their own interests and create while applying their STEM education. MakerSpaces connect the digital world to the physical world and can be a combination of computer lab, science lab, woodshop, metal shop, and art room that enable project-based learning [14].

Technology Education at Drexel

For the Engineering Technology Department, Drexel University has invested more than \$700,000 in electronic test and measurement equipment, workstations, and simulation trainers for the electronics laboratory, and equipment for the Internet-based teleconference teaching facility. Grants from NSF and the US Department of Education totaling more than \$1,200,000 have provided additional equipment and laboratory development support. As shown in Figure 2, laboratories feature state-of-the-art equipment and software, and in particular, employ MakerSpace equipment and software that students are likely to encounter in industry. Laboratory work prepares students to make an immediate contribution to the commercial efforts of their first employer after graduation. MakerSpace related facilities for research and teaching include: Dimension UPrint Plus 3D printer (FDM), Ultimaker 2.0 (FDM), Form2 (SLA), Universal Laser Systems 30-watt CO2 laser cutter, EMCO Concept Turn 250 CNC Turning Center, Haas OM1 CNC Office Machining Center with automatic tool changer, JET GH1440 lathe, JET JMD-15 milling/drilling machine, Grizzly Model 17 milling machine, Jet ZYT-150 Mini milling machine, Proxxon MF50 micro milling machine, Grizzly Model 60561 Metal Cutting Horizontal Bandsaw, Bridgeport Mill, MasterCAM CAM, FeatureCAM CAM software packages, SolidWorks CAD software package.

3D Printing Course and Curriculum Development

Today, K-12 schoolchildren learn how to use PowerPoint and Excel as part of their computer class, and they still learn to draw and sculpt in art class. But how much better it would be if they could choose a third option: a design and make class. In collaboration with Stratasys, we are developing a series of maker centered courses where students would learn to use free 3D CAD tools such as Sketchup, Autodesk 123D or SolidWorks 3D design applications. Face to Face as well as Web-based courses will incorporate step by step instructions with audio-visual components. In this series of courses, students will learn about the evolution of digital fabrication with a full overview of the manufacturing industry and related

Figure 2: Department of Engineering Technology's 3D Design & Process Laboratory

technologies. Hands-on, project-based learning (PBL) course development let students design and fabricate 3D objects such as building a gear system (Figure 3) using computer-aided design (CAD) software and 3D printers. They experience the design process and become familiar with the advantages and limitations of 3D printing technology in terms of precision, resolution, and material capabilities. Students apply 3D printing technology appropriately while gaining hands-on experience with one of the leading 3D printing technologies employed in manufacturing today: Fused Deposition Modeling (FDM).

Figure 3. Da Vinci case study CAD design designs (left and middle), 3D printed prototypes.

We address some informal learning issues through the following challenge and corresponding solution approaches.

Challenge: Maintaining engagement in formal learning

When individuals are engaged, they are better able to discover their talents and develop the mental resources they need to think critically. But maintaining engagement can be a challenge. Engagement is a well-known predictor of academic achievement. Students who stay engaged are better prepared for

college and have greater confidence to pursue challenging majors in STEM fields such Engineering Technology. Still, some strategies to boost achievement, like heightened standards and high-stakes testing, overlook the role engagement plays, and can further discourage low-achieving students.

Solution: Practicing active learning

Active-learning practices — those that compel student participation — show a strong impact on performance for students of all backgrounds and achievement levels. 3D Printing and active making activities will help students apply design thinking to build excitement and momentum behind any project.

Challenge: Improving college and career readiness

The skills needed for post-secondary coursework naturally reflect the demands of today's information-based economy. So, those who master 21st-century skills like critical thinking, effective communication and information literacy will be more likely to make a successful transition into universities, technical schools and the workforce. Studies have found that up to 40 percent of students who enter U.S. colleges and technical schools need remedial coursework, which adds time and expense to their college education. Not surprisingly, these students are less likely to earn a degree or certificate than their better-prepared peers, putting them at a significant disadvantage in the workforce.

Solution: Solving real-world challenges

To build skills for success, we are embracing active-learning strategies like Project-Based Learning. Through collaborative, hands-on projects, students can actively explore, respond to and engage with real-world challenges. When the challenge calls for a physical solution, 3D printing empowers students to navigate the entire design cycle from idea to finished product. Through inquiry and iteration, students learn as much by what goes wrong as what goes right, building their capacity for critical thinking and analysis, improving their judgment, and increasing their perseverance through applied learning.

Changing World of 3D Printing and Rapid Prototyping

This course simulates design, analysis and prototyping cycle currently used in product design and development^{5, 6, 9, 12, 13}. The course is designed for non-engineering majors as an introduction and survey of rapid-prototyping, especially centered on the advent, impact, and utility of 3D printers and supporting digital technology: computer-aided design (CAD) and computer-aided manufacturing (CAM) software. The course covers both the concepts and practice of 3D printing and prototyping, emphasizing hands-on work developing computer-based design models ("drawings") and fabricating prototypes ("parts") using current tools for desktop manufacturing including 3D printers, laser cutters, desktop engravers, and micro-molding and printing. With this knowledge and skill set, students will be able to design, develop and demonstrate a working product suitable for commercialization.

Course objectives:

- To provide competence with a set of tools and methods for product design and development.
- To provide confidence in your own abilities to design and create a new product using 3D printers.
- To provide product development experience using Computer Aided Design (CAD)-Mechanical Design tools.
- To provide an overview of current product and prototype development issues.
- To provide a guideline and necessary tools for rapid product realization and prototyping.

Course outcomes:

1. Generate and evaluate conceptual design solutions using functional analysis and prototype testing given a design problem definition.
2. Produce a product that meets functional requirements.
3. Conduct prototype cost estimation.
4. Develop skills to design products using virtual prototyping techniques and 3D Solid Modeling CAD software.
5. Select appropriate rapid prototyping material and method for rapid prototyping and product realization.
6. Produce a prototype with originality, regulatory, and aesthetic considerations.

A tentative weekly schedule is provided in Table 1 below. The course is team taught by the authors and was offered two times until now as a special topic in engineering technology. Our overall goal was to develop a minor in Product Development that is open to all students at Drexel. This course is one of the core courses in that minor which is currently in approval process through the university system for AY 2017-18 course catalogue.

Table 1. Overview of weekly topics for MET321- Changing World of 3D Printing and Rapid Prototyping

Week	Topics
1	Introduction to the Next Industrial Revolution: The New World of 3D Printing & Rapid Prototyping, Consumer safety, environment, green manufacturing, ethical issues.
2	Introduction to Computer Aided Design: SolidWorks, Google Sketchup, AutoCAD, Generating stl files
3	Personal Fabrication, Do-It-Yourself Product Development, Additive vs Subtractive Manufacturing, Molding, Laser cutting
4	3D Printing Technologies, Materials for 3D Printing
5	Bioprinting /Midterm Exam
6	FDM 3-D printer, Catalyst software, Haas CNC, FeatureCAM
7	Rapid prototyping for microsystem, soft goods, textiles, jewelry, art, design, fashion, food.
8	Economics, Cost estimates, and digital manufacturing
9	Post-Processing and Finishing
10	Projects; test & evaluation of rapid prototypes

At the end of the quarter term, using CAD software, students generated CAD models in STL format and converted CAD models into 3D printer's native format (cmb file format, Figure 4i-j) using Catalyst® 3D printing software. Then, using Drexel University's Virtual Private Network (VPN) access, students would upload necessary part files into a Fused Deposition Modeling (FDM) rapid prototyping machine housed in ET mechanical laboratory (Figure 2). The connection to the Drexel University's (DU) prototyping machine was established by the utilization of Winsock components and various ActiveX controls that communicate through IP addresses. After students uploaded their files for prototyping into the machine queue, FDM machine was prepared for 3D printing by the laboratory technician who is in charge of setting up and starting the machine for safe operation.

Figure 2. Student project samples for term project: Adjustable Cycling Phone Case (left), DIY Clock Kit (middle), Multifunctional Laptop/Tablet Stand (right)

The laboratory technician was also responsible for the monitoring of prototyping process for successful completion. This very well simulates rapid prototyping assets owned by a technological company in several locations worldwide. By directing prototyping efforts to locations with available machine time, under-utilized prototyping assets are used more efficiently, therefore prototyping productivity can be tremendously improved. In an actual industrial setting, rapid prototyping machines are supervised by operator technicians. After finishing and cleaning process, prototype models were used in demonstrations by the students during their term presentations. Please see Figure 4 for examples of student design projects. Prior to finishing the course, students filled out evaluation forms using Drexel's Academic Evaluation, Feedback and Intervention System (AEFIS). Based on this evaluation system the overall course rating was 3.7 out of 4.0 (max. scale). The best aspects of this course, as perceived by students can be summarized as follows: They were highly satisfied by the opportunity provided by this class to be creative and to use interesting materials and software. Students particularly embraced using SolidWorks® and team project for product design. The course really changed the way that they regarded prototyping and manufacturing. Quoting of several of the student reviews are provided below:

- The course material was interesting and very current with today's technology.
- We go through all the materials with the lab view. So we have much more understanding to the software and get the ability to actually use the software to design something instead to follow the instructions.
- Very informative slide shows.
- The final project was a huge learning experience. This was real world experience that can't be learned from a book.
- For me having to learn solid works, and doing the team project, those were two very hard assignments but well worth the time and effort. I will never look at manufacturing the same!

Conclusion and Future Work

Students in Engineering Technology program take a newly developed course in 3D printing and Rapid Prototyping course as an elective. Students' survey comments indicate that term project involving developing a new product and obtaining a physical prototype enhances their understanding of the concepts that are covered through the course. For students that had no experience with a parametric design software, the learning curve was generally quite steep. The course effectively integrates the

contemporary advanced design and manufacturing technologies such as solid modeling, CAE, rapid prototyping, rapid tooling and 3D printing in improving product design, analysis, prototype, and production processes.

Bibliography

1. SolidWorks® Customer Portal, 1-13-2012, < <https://customerportal.solidworks.com>>
2. C. Bartneck and J. Hu. "Rapid prototyping for interactive robots," the 8th Conference on Intelligent Autonomous Systems, pp 136-145. 2004.
3. Asiabanpour, B., Wasik, F., Cano, R., Jayapal, V., VanWagner, L., McCormick, T., "New waste-saving heater design for the SIS Rapid Prototyping Process," Industrial Engineering Research Conference (IERC), Atlanta, GA, 2005.
4. Chua Chee Kai, Leong Kah Fai, Lim Chu-Sing, "Rapid Prototyping: Principles and Applications," World Scientific Publishing Company, Singapore, 2003.
5. Liou, F., "Rapid prototyping and engineering applications, a tool box for prototype development", CRC Press, 2007
6. Laliberté T., Gosselin C. and Côté G., "Rapid Prototyping of Lower-Pair, Geared-Pair and Cam Mechanisms," Proceedings of the ASME Mechanisms and Robotics Conference, Baltimore MD, September 10-13, 2000, Paper DETC2000/MECH-14202.
7. Won J., DeLaurentis K. and Mavroidis C., "Rapid Prototyping of Robotic Systems," Proceedings of the 2000 IEEE International Conference on Robotics and Automation.
8. R. Noorani, "Rapid Prototyping: Principles and Applications", John Wiley & Sons, 2006

9. G Boothroyd, P. Dewhurst, W., Knight, "Product Design for Manufacture and Assembly", 3rd Edition, CRC Press, 2010.
10. Stratasys® Catalyst® 3D printing software, 1-13-2012, < <http://www.stratasys.com>>
11. Ullman, D., "The Mechanical Design Process", 4th edition, McGraw Hill, 2009
12. Pahl, G., Beitz, W., "Engineering Design: A Systematic Approach", 2nd edition, Springer, 1995
14. Miner, A., Padilla, F., Carbone, B., "Multi-Utility Knife Rapid Prototyping and Product Design Project", Unpublished work, 14 March 2011
15. Personal Discussions with Mr. Albert Frattarola, Director of Global Engineering & Technology, Southco Inc.
16. Thomas, A., "Encouraging students in the STEM classroom through Making," Maker Education, edutopia, September 7, 2012. <http://www.edutopia.org/>
17. Kirk, B. J., "STEM graduation rates show uphill battle with math and science in School District," December 5, 2011. <http://technical.ly/philly/series/state-of-stem>
18. Landivar, L. C., "Disparities in STEM employment by sex, race, and Hispanic origin," United States Census Bureau, Report ACS-24, September 2013.
19. Rotherham, A. J., "The next great resource shortage: U.S. scientists," Time Magazine, May 26, 2011. <http://content.time.com/time/nation/article/0,8599,2074024,00.html>
20. "Talking points: museums, libraries, and makerspaces," Institute of Museum and Library Services, June 2014. <http://www.ims.gov>
21. Kenning, C., "Solutions to high-poverty schools may lie outside the classroom," Courier Journal, April 23, 2011. <http://archive.courier-journal.com/>
22. "Connecting informal and formal STEM education," STEM Smart Brief, Community for Advancing Discovery Research in Education (CADRE), Education Development Center, NSF grant# 0822241.
23. Stamper, L., "What are MakerSpaces and how does it relate to STEM?," Pearson Communities, October 29, 2014. <http://www.teachability.com/community/>
24. "Manufacturing Makerspaces," American Libraries Magazine, February 6, 2013. <http://americanlibrariesmagazine.org/>
25. Aldana, D. et. al, "The maker movement at Bucknell: a plan for developing, launching, and managing on-campus MakerSpaces," ASEE Fall 2015 Mid-Atlantic Section Conference, Lewisburg, PA, September 18-19, 2015.
26. Tan, E., Calabrese Barton, A., Kang, H., & O'Neill, T. (2013), "Desiring a career in stem-related fields: How middle school girls articulate and negotiate identities-in-practice in science," Journal of Research in Science Teaching, 50(10), 1143- 1179.
27. Calabrese Barton, A. & Tan. E. (2010), "We be burnin: Agency, identity and learning in a green energy program," Journal of the Learning Sciences, 19(2): 187-229.
28. Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015), "Learning through stem-rich tinkering: Findings from a jointly negotiated research project taken up in practice," Science Education, 99(1), 98-120. doi:10.1002/sce.21151
29. Rosen, W.A., Ertekin, Y.M., and Carr, M.E., 2014, "An Autonomous Arduino-based Racecar for First-Year Engineering Technology Students." Proceedings of the 2014 Annual ASEE Conference, Indianapolis, IN June 15–18, 2014.