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# 3D Prototyping and Various Programs of Study

**William S. Richman, Ball State University, IN**
**Tarek Mahfouz, Ball State University, IN**
**James W. Jones, Ball State University, IN**

*Richman is a research assistant in the Department of Technology. Mahfouz, Ph.D., is an Associate Professor in the Department of Technology, and Jones, Ed.D., is an Associate Professor in the Department of Technology's Construction Management program.*

## Abstract
Three-dimensional prototyping is not a new concept to the world. Now, more than ever it is possible to use a course in prototyping to advance the knowledge of students in a plethora of different fields of study. This article explores the use of a core course in prototyping at a university level to show how this technology can be applied to students' different fields of study. To that end, the article addresses (1) prototyping technology applicability to various disciplines; (2) planning and implementation mechanisms of the course; and (3) discussion of the students' experience in the class. The methods introduced could be used by other educators and institutions of learning in implementation of a similar program.

## Introduction
Prototyping is not a new concept to the world; it is used to show a concept of an idea, and is able to show a physical representation of a possible product to hopefully encourage innovation or creative thought (Pniewska, Adrian, and Czerwoniec, 2013). The idea of putting together a model to test for efficiency or problems before mass production is a common practice. Similarly, the development of prototypes is typical within certain majors at the university level. A student who graduates with a degree in industrial technology, manufacturing, or other related fields would be expected to have skills in prototyping. These experiences could take place on various technologies including but not limited to laser scanners, mills, lathes, laser cutters, fused deposition modeling 3D printers, color solid object printers, etc. Laser scanning technology is more specifically a sub-technology of prototyping; it can be used to make digital 3 dimensional models that then can be manipulated to make prototypes. The listed examples are commonly thought of to be typical to specific technology and engineering career fields; however a multitude of other disciplines directly use these technologies.

The purpose of this article is to illustrate how the knowledge gained through a course in prototyping can be useful in a plethora of career fields outside of typical industrial, manufacturing, and technology based programs. To achieve the aforementioned purpose, the authors utilize a set of lessons learned from a working example of a course that was developed and taught within the Department of Technology at Ball State University. Furthermore, insight into the course development and implementation is provided. This article provides a point of departure with which the reader can understand how these technologies can be applied to a variety of majors, and even show the department the sources that are provided.

To that end, the content of the article addresses the followings.

- Applicability to various disciplines: this section highlights the importance of prototyping to various fields;
- Implementation: this section introduces the reader to different sub-technologies of prototyping and provides essential information about the development and implementation of a university level course;
- Discussion: this section illustrates some lessons learned through the course implementation period with a reflection on the students feedback; and
- Conclusion.

**Applicability to Various Disciplines**

The use of prototyping in some fields is expected, but the usefulness of these technologies extends beyond that in many ways. Outside of these expected fields (e.g. manufacturing, technology, engineering), this technology can be used in a variety of ways within various medical fields, in multiple forms of art, in construction, architecture, and much more. Some of these domains share characteristics that are directly translated which make the applicability of prototyping technology feasible (Lipson, 2011).

Successful examples of implementing prototyping, also known as “Additive Manufacturing” (Lipson, 2011) and “Rapid Prototyping” (Kai, Meng, Ching, Hoe, and Fah, 1998), can be seen within the medical field. One specific case involves a patient who was diagnosed with a bone tumor that was cancerous, and the surgery required would most likely result in losing vision in one eye. However, using computerized tomography (CT) scans to build a 3 dimensional model of the patient’s skull, the surgeons were able to figure out that the tumor could be removed through the jaw, which saved the patient’s eyesight (Mahoney, 1995). A student in the medical field can clearly see the advantage given to the surgeons through the use of prototyping, which could give an appreciation for the technology. Dentistry is another example of efficient utilization of prototyping capabilities. Soares et al. (2013) performed a study on the effectiveness of using prototyping in teaching cavity preparation to dental students. The use of the 3 dimensional models increased the quality of education that was obtained, because students were able to visually analyze cavities instead of looking at 2 dimensional pictures. Finally, one major aspect of this technology in the medical field involves the development of prosthetic parts. In one of the most advanced researches, the U.S. Veterans Affairs Center of Excellence for Limb Loss Prevention and Prosthetic Engineering is utilizing rapid prototyping for the manufacturing of prosthetic feet to study foot-ankle stiffness (U.S. Department of Veterans Affairs, 2014). In an earlier research, prototyping has been used for the generation of physical model of the moth and facial models for the proper development of a treatment plan in the area of maxillofacial surgery (Gateno , Allen, Tiechgraeber, and Messersmith, 2000).

The ability of the physician to better visualize a physical model has expanded its use into orthopedics (Frame and Huntley, 2012; and Blakeney, Day, Cusick, and Smith, 2014), craniofacial surgery (Gioato et al., 2011), and neurosurgery. The medical field has many applications for rapid prototyping, and students in this domain could benefit from learning the use of these technologies.

Outside of the medical field other domains, such as construction and architecture can benefit from the use of this technology. Through the use of rapid prototyping and laser scanning an individual in construction can make a computer model of an existing building, recreate it, and then be able to evaluate the building in a multitude of ways, (Goedert, Bonsell, and Samura, 2005). In 2008, Michele Chiuini, Professor of Architecture at Ball State University, and his team of students have utilized laser scanning technology to develop a 3-D Digital Model of S. Maria Antiqua church. The reconstructed model was divided into horizontal plans and vertical sections to create a set of six interior images. These images were later used for the development of a conservation model, despite the burial of some section of the original church (Chiuini, 2008). These technologies can give students in construction and architecture practical experience that can translate to future job tasks.

Similarly, many other disciplines use laser scanning technology. Within the field of archeology, Karasik and Smilansky (2008) performed a study on how to improve laser scanning within the field to yield more accurate results of pottery artifacts.  In one of the most recent works, “archeologist Ashley Richter and computer scientist Vid Petrovic are planning to launch an art exhibition in San Diego, California, with a little help from the Kickstarter community. Richter and Petrovic, as part of the Center for Interdisciplinary Science for Art, Architecture, and Archaeology (CISA3) at the University of California in San Diego”, work includes prototypes of some of the most important worldwide landmarks and art works (Helsel, 2014). In addition, mining represents a fertile domain for the implementation of laser scanning technology. Some scanners within the field are used where miners work to tell if there is a shift in the rocks to let personnel get to safety, and others are used to make 3 dimensional maps of areas that are unsafe for people (Hunter, 2009). With these examples, it is clear that the benefits of laser scanning technologies could apply to various fields beyond manufacturing.

As stated earlier, prototyping can be used in multiple forms of art. According to Seymour, digital fabrication technologies can be used towards the development of graphic design products, “Material can be cut, molded, lathed, lasered, and printed in three dimensions through industrial technologies such as laser cutting, computer-controlled routing, and rapid-prototyping,” (2011). Graphic design is just one area of the art that is looking at the use of prototyping, but others are considering the possibilities as well. “Ceramics artists are particularly adaptable to digital technologies because the tools are process based. As ceramics is a multi-layered process, so are fab lab techniques - often the end result is less predictable than one would imagine,” (Pattee, 2013). These disciplines as well as many other previously listed ones can be benefited by the use of prototyping technology.

Although not every discipline can be directly impacted by the benefits of such technology; its implementation can still be useful. A course in prototyping gives students a chance to design, and work on their creativity through the design process. Those who have the competency to be creative have an increased resourcefulness towards a variety of situations within academia, and outside it (Runco, 2004; Desrosier, 2011; and Hornick and Roland, 2013). The curriculum alone is not going to provide this opportunity; a lot of dedication comes from the instructor. “It is important for technology teachers to help students build prototypes to see their ideas become reality; this can help to empower students,” (Flowers and Moniz, 2002). Empowering students is a main goal of many university core curricula. According to a study on what students learn as part of a university core curriculum it was determined, “An excellent core curriculum, in short, gives students the essential skills and knowledge needed for success after graduation,” (Bako et al., 2010). As further highlighted by the American Council of Trustees and Alumni (ACTA) in the What Will They Learn report of 2013-2014, “Nearly every one of the 1,091 colleges and universities included in What Will They Learn? recognizes the importance of general education and describes its program as a central part of its educational mission.” (American Council of Trustees and Alumni, 2014). A course in prototyping gives students a chance to push their own limits of creativity, and learn about different ways prototyping technologies can be applied to many different fields of study. A core curriculum is supposed to give students a well-rounded education that can be applied after graduating.

**Implementation**

Knowing that a course in prototyping can be applied to a variety of majors is just the first step in designing such a course. In addition to a good syllabus and course structure, instructors will also need specific materials and equipment. If a university already has equipment such as 3D printers, laser cutters, mills, lathes, and laser scanners, then a course will probably be easier to implement.

Laser scanners, a sub-technology of prototyping are used to create a virtual model that then can be modified or changed to have a new function. This is used a lot in a process known as reverse engineering. Reverse engineering is used to take one product and deconstruct it to see how it works, usually in an effort to find ways for enhancing its performance. In a recent study, Meadati, Irizarry and Liou (2013) highlight the importance of the aforementioned technology in fostering better education environment for students in the Construction Management domain. In contrast, Laser cutters can be used to cut or engrave delicate patterns in wood, acrylic, paper, glass, among other materials. Mills operate on an X, Y, and Z axis, and the product is created by cutting away at the material in small increments to create its final form. A lathe is similar to a mill, except it operates on an X and Z axis, and the stock is turned at a high speed, and then cut to make the final product. Printers come in many shapes and sizes, as well as the other listed machines. The printer takes a virtual object and builds it layer by layer. The distance between these layers is very little, so that all layers bond together (Cohen, 2014).

Unfortunately, at this time it is still quite expensive to purchase some of the listed examples of equipment. Depending on the quality of printers a university would want to purchase one could be looking at a price tag of at least $2000, and up to $40,000 or even more. On top of the equipment, the material consumption can be quite costly as well; some spools of Acrylonitrile Butadiene Styrene (ABS), which may cost over $100.

Once an instructor has the needed materials and equipment, developing an inclusive course structure is the most important aspect. Instructors need to evaluate a set of parameters for successful design of an effective course, namely the audience, instruction technique, and the nature of assigned work (Desrosier, 2011). To that end, if the course is taught as a core curriculum class in which students are from many different majors. Some have a great amount of experience with these technologies, and others may have never heard of them. That being said, the course should not be designed in an attempt to make the students masters at these technologies, but instead to introduce them to the technology, showing them how it operates, and how to make a successful product (Mahfouz, Jones, and Bhattacharjee, 2011). For example, when instructing how to use a modeling software the goal is to show the functions of the various tools so that the students can work their way around the program, not to create a fully functioning virtual model of a car. This thought process should apply when designing the course in its entirety. For more illustration, in one lesson on the use of the mill, the instructor provides students the information needed to create a project, but they only show how to create basic shapes, and how to operate each tool for a different style of cutting. This gives students the ability to create their own project, instead of testing if they can follow procedures.

Each assignment for the class should also be open to the competency of the student (Pask and Scott, 1972; and Amhag and Jakobsson, 2009). To achieve this, the instructor requires that each student submits a demonstration piece of work that the student made on each prototyping device, along with a paper about their experience. This paper can include explanation of the technology used, the procedures, any encountered problems, adopted mechanisms to solve them, and possibly research on the device. The openness of these assignments allows students to take pride in their work by designing a component of interest to themselves and/or fields. The structure of the assignment also gives students who have experience in this field to build more advanced projects, and students who are new to the subject to build projects at their own skill level. The goal in the class is not just a successful product, but to learn something even if the product fails. For example, in one class a student developed a robot with movable arms, legs, and knees; however, the arms really couldn't move but the legs could. The student showed in their report that they learned from this by stating that in their design they lacked the amount of space needed in the socket for movability, and recommended methods of improvement.

**Discussion**

Students who take the course need to accomplish the goals that are set by the university core curriculum. Each university has its own specific standards, and staying in line with these is important to the continued success of the course. In a recent class taught at the Department of Technology at Ball State University in which the described methodologies were adopted, the students' evaluations about the course structure and content were positive. Many students within the class highlighted that the material was interesting, but at times difficult. From an instructor's point of view, it was clear that such methodologies are effective as the difficulty and complexity of the students' projects grew, showing that they were becoming more involved in their own work and more comfortable with the various technologies. Once again it is important to keep the goal of the class focused on learning while fostering the freedom to create a product that is challenging to them yet interesting. Prototyping technology can help students from a variety of backgrounds academically and through life skills.

**Conclusion**

The article presented an initial step in developing a robust methodology for a successful class of prototyping at the university level. To that end, the presented information included (1) the importance of such technology to different domains including but not limited to technology, engineering, medicine, art, archeology, and mining; (2) essential key ideas and methodologies to be kept in mind when developing a core course at a university level; and (3) a reflection on students' feedback in a recently taught class while adopting these methodologies. Through this experience, it was found that a successful course development and implementation can be achieved by maintaining the understanding that students come from different majors with various backgrounds and interests. Consequently, the class material and assignments should not be focused on successful completion of a specific project, rather on allowing the students to engage their creativity and relate to their fields of study.

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