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Dr. Eisazadeh joined Old Dominion University (ODU) in Fall 2018. Before joining ODU, he was a faculty member at the County College of Morris for one year, and a faculty member at the Chabahar Maritime University over four years. Dr. Eisazadeh received his Ph.D. (2017) in Mechanical Engineering from Clarkson University in New York, his MSc (2005) in Manufacturing Engineering from Tehran University, and his BS in Manufacturing Engineering from Mazandaran University. He has several years of research and teaching experience, and he is a member of the American Welding Society.

His work involves studying residual stress formation in dissimilar weld and additive manufacturing using finite element modeling and neutron diffraction measurement. He has examined and practiced various modern techniques to mitigate weld residual stresses and their consequences. Through his work, he has presented at several conferences and co-authored papers on the reduction of residual stress in dissimilar weld.

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Expanding a Mechanical Engineering Technology Curriculum to Include Additive Manufacturing

Abstract

Additive Manufacturing (AM) has become a game changer for the manufacturing industry. With growing implementation of AM in various industries, it is the responsibility of different levels of education to expose students to AM technologies and to integrate AM into their curriculum. It is well known that students who gain the skillsets of today's industry have a better chance in getting a competitive job. In response to this need, a new senior level elective course on AM, has been developed for the first time in Old Dominion University (ODU) region in the South. The course was developed and taught by the Mechanical Engineering Technology faculty with the expertise in manufacturing processes, welding, and material science. The course was available to a wider university population of undergraduate students, from different majors ranging from the Mechanical Engineering Technology program, Industrial Technology program, Career and Technical Education teacher program, and Mechanical Engineering program students at ODU.

This course is a part of manufacturing concentration for MET students. The course curriculum includes an overview of various AM processes. It explains how AM enables the creation of complex geometries from the bottom-up, without many of the constraints of traditional manufacturing methods such as machining, molding, and casting and commonly taught machinist approach CAD modelling methodology. This paper discusses the development and implementation of AM course and provide recommendations for improving the course contents (both theory and lab). For comparison purposes, the contents of a similar course developed at a different university is also provided in this study.

Introduction

Additive Manufacturing (AM) is an emerging technology that encompasses numerous three dimensional (3D) printing technologies for joining materials layer by layer to make objects from 3D computer-aided design (CAD) model data [1]. Through AM technology, complex geometric shapes, multi-material and multi-functional parts can be additively manufactured in a single operation which is a big advantage over conventional manufacturing processes. Over the past two decades, the intensive research carried out on AM technologies has yielded significant progress in the development and commercialization of new and innovative AM processes such as Fused Deposition Modeling (FDM), selective laser sintering, and other rapid prototyping methods, as well as numerous practical applications in aerospace, automotive, biomedical, civil, energy and other industries [2]. Large portion of the manufacturing industry has realized the benefits of the AM technology and started utilizing AM as an integral part of their processes. For example, General Electric (GE) Corporation has invested approximately $1.5 billion in advanced manufacturing and additive technologies, in addition to building a global network of Additive centers focused on advancing the science [3]. The company uses the additive manufacturing processes for manufacturing its jet engine nozzles because it uses less material than conventional techniques. That reduces production costs and, because it makes the parts lighter, yields significant fuel savings for airlines. Conventional techniques would require welding about 20 small pieces together, a labor-intensive process in which a high percentage of the material ends up being scrapped [4]. The increasing use of AM technologies in the industry has created a stable demand for a skilled workforce of engineers and engineering technologists who are proficient in all aspects of the AM processes, from software-driven 3D designs to hands-on execution of these designs using modern 3D printing platforms [5]. In order to be competent, the training of modern engineers will need to include more advanced skills in CAD and optimization that focus on construction of 3D structures with a growing number of metals, plastic and gel materials through AM processes. One main issue that has been identified in academic institutions is that students are only taught how to submit an STL file into a plastic 3D printer. However, they do not acquire the various skills of 3D printing in universities before hiring at industries. Some of these skills are: determine the cost of various AM process, know the material properties and their dependence on various AM processes and process parameters, vaerious AM softwares; AM's industrial potential such as prototyping, tooling, production customization, spare parts, art, design, architecture and construction. Our analysis has shown that not only Old Dominion University (ODU) has attempted to address this issue before Spring 2020, but also at a broader level no institution in Hampton Roads area was offering any university course related to 3D printing.

This paper presents an effort of developing a new 3D printing course in Engineering Technology Department at ODU. This course includes basic principles of AM, difference between traditional manufacturing processes (subtractive manufacturing, SM) and AM, recent advances in the AM technologies that specialize in rapid prototyping of three-dimensional objects such as photopolymerization, powder bed fusion, extrusion, beam deposition, sheet lamination, direct write technologies, and direct digital manufacturing; design for AM, process selection, postprocessing, software issues, rapid tooling, applications of AM and business opportunities. It also shows how the skills obtained from this course can be implemented in senior design projects. One successful project conducted by Engineering Technology undergraduate student at ODU is demonstrated in this paper. In addition, the contents of a similar course developed at Clarkson University is also provided in this study for comparison purposes.

New course

One main issue that has been identified in academic institutions is that engineering and technology students do not acquire various skills related to 3D printing, beyond submitting a STL file to a plastic 3D printer, in universities before hiring at industries. Our analysis has shown that not only ODU has attempted to address this issue before Spring 2020, but also at a broader level no institution in Hampton Roads area is offering any university course related to 3D printing. To address this issue, an assistant professor from Engineering Technology offered the new course called Additive Manufacturing in Spring 2020 for the first time. Since many of students have not hear about this course, the instructor distributed a flyer across the campus. The flyer shows application of AM in several industries, as shown in Figure 1.

This is a three-credit course which has two hours of lectures and two hours of labs. There are lectures at the beginning of most classes followed by open lab. Students are expected to make use of the open lab hours to read through and work the examples provided by the instructor before completing the assignments listed in the syllabus.

Some of the topics covered in the new course include fundamentals of polymer, composite, metal AM processes; review of different AM technologies such as photopolymerization, powder bed fusion, extrusion, beam deposition, and sheet lamination. The course also included various topics related to the design and manufacturing engineering and how different AM settings are related to the final product precision and surface finish. The topics are design for AM, process selection in relation to the different materials, technologies, time needed for printing, or other manufacturing process constraints. The following important factors are discussed: process capabilities such as rate and resolution. Quality of AM parts are benchmarked against those of traditionally manufactured in the class and potential failure modes. In the hands-on labs, design and making of simple to complex parts using various AM processes are illustrated for students. They design a product that is difficult or impossible to fabricate using tradition technology, and then utilize the AM technologies available in the lab to fabricate the product.

Figure 1. A flyer that was designed by the instructor at Old Dominion University, and distributed throughout the campus to inform students about the new course and its applications.

The students' performance in the new course were evaluated through homework, quizzes, midterm, final test and project. The weight of each evaluation is provided in Table 1. Since this course was also offered to graduate students, it was a challenge for the instructor to balance the contents of the course for students with different backgrounds. One acceptable solution that the instructor came up was to assign a new project, called term project for graduate students. The main objective of this extra work was to motivate grad students to implement their research skills to investigate challenges in AM industries and report them in a paper. They were required to review at least 20 journal papers in AM field.

Table 1. The weight of student's performance in the new course, based on homework, quizzes, midterm, final test and project.

	MET406 / MAE 495	MAE595
Quizzes (8)	20%	15%
Homeworks (5)	25%	20%
Midterm	15%	15%
Final Test	25%	25%
Project	15%	10%
Term paper	-	15%
Total	100%	100%

A sample of class project in Old Dominion University (ODU)

In the hands-on labs, the instructor illustrated for students how to design and make simple to complex parts using various AM processes. In the class project, they were assigned to design a product that is difficult or impossible to fabricate using tradition technology, and then utilize the AM technologies available in the lab to fabricate the part. These projects, which assist students to become leader in AM, will be improved continuously over semesters.

The instructor provided several questions for students that can help them find an appropriate project. The answers of eight questions provided by one student are demonstrated in the Table 2.

Table 2. A series of six questions to help the student to come up a suitable project

Questions	Student’s answers
1. What are you your decision drivers?	Quality/Design: The headphone stand is a very simple product and I wanted to keep it that way when designing it
2. What are your design objectives?	High Volume: Because of the size and design of the stand, it can easily be mass produced
3. What are the AM applications of your part?	Prototyping/Product Development: Because this is my first time designing something like this, I hope to create this

	as the first prototype and improve on the design of the product
4. What AM processes can be utilized to manufacture your part?	FDM: Because we are limited to using an FDM printer for the project, it would be easiest to create this part using this process for prototyping. For mass production, it may be best to use FDM as well because of the build volume and lack of a need for strength in the product
5. What industry might be interested in investing your part?	Consumer Electronics: While this product contains to electronic parts, it will be used for electronics
6. What are the typical materials that can be used to make your part?	Polymer/Multimaterials The cheapest and easiest material to print this product in would be polymer since there is not much of a strength requirement While the magnets obviously aren't being printed, they will need to be inserted after printing

One student chose a headphone mount for his project. He wanted to design a headphone mount that can be magnetically mounted to a computer case. He had been planning on buying one but was dissatisfied by their formfactor and overcomplication. The ones that he was looking at were typically bulky and couldn't be easily mounted to a case. As such he wanted to design something that was relatively small, could easily hold the weight of headphones, and would magnetically mount to the front of his computer case.

In the next task, students were asked to draw your 3D part in CAD program. The rough draft is shown in Figure 2 drawn by Autodesk Inventor.

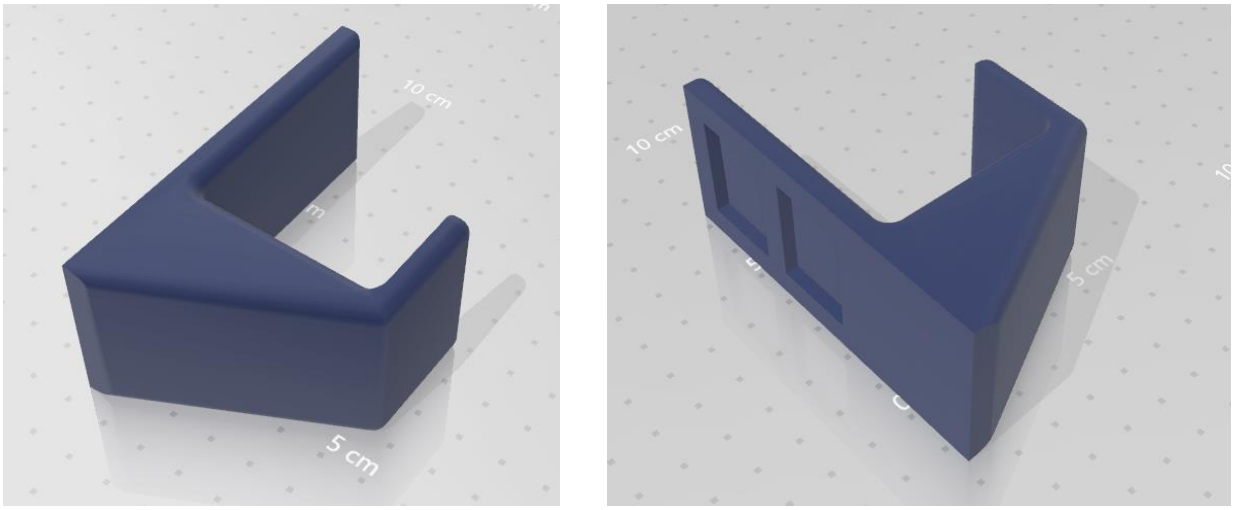

Figure 2. Original Design of a headphone mount prepared by an undergraduate Engineering Technology student

In the next task, students were instructed to slice their parts with one of the AM softwares available in the market. They picked Unltimaker Cura since it is relatively easier to install on their own PC and use. Then, they printed their parts with 3D printers available in laboratory. One of the important tasks was to optimize their part shape with Fusion 360. In this program, they can use various geometry from the nature and redesign their parts by making an analogy with the organic shape. Through the optimization task, students generate a part with similar mechanical performance yet reduced weight, which is very important for industry as they always tend to reduce the cost of production. The main objective of this task is that students get familiar with the capability of AM. Unlike traditional manufacturing, it becomes surprisingly cheaper and quicker for AM process to produce parts with higher complexity rather than solid shapes. The result of optimized headphone mount part is shown in Figure 3. According to the results obtained from Fusion 360, students redesigned their models. One of modified design is shown in Figure 4. The new design can perform the same service that original design was capable; however, the new design used less amount of material which makes is very attractive for industry.

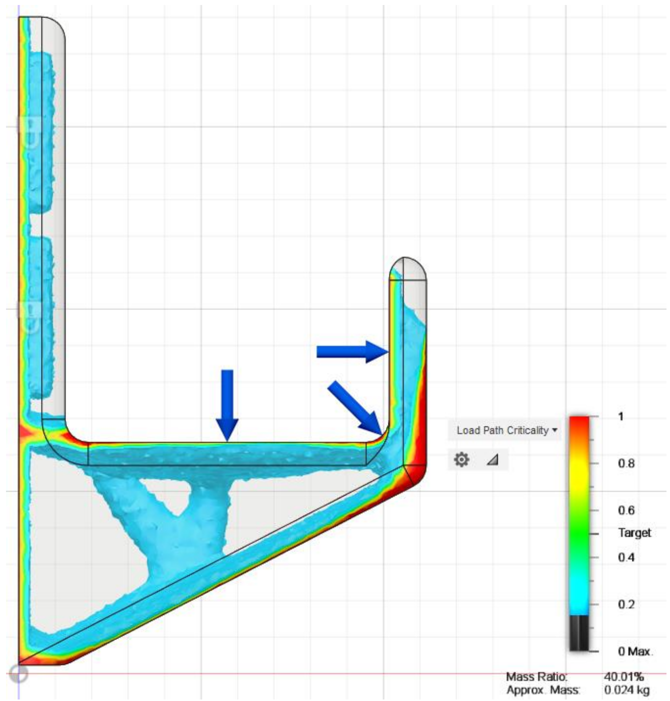

Figure 3. The optimized headphone mount prepared by an undergraduate Engineering Technology student. The program is Fusion 360. Boundary conditions were introduced in the model, shown by arrows in this figure. Mass reduction was set to 40%. Red color shows region with higher stress concentration.

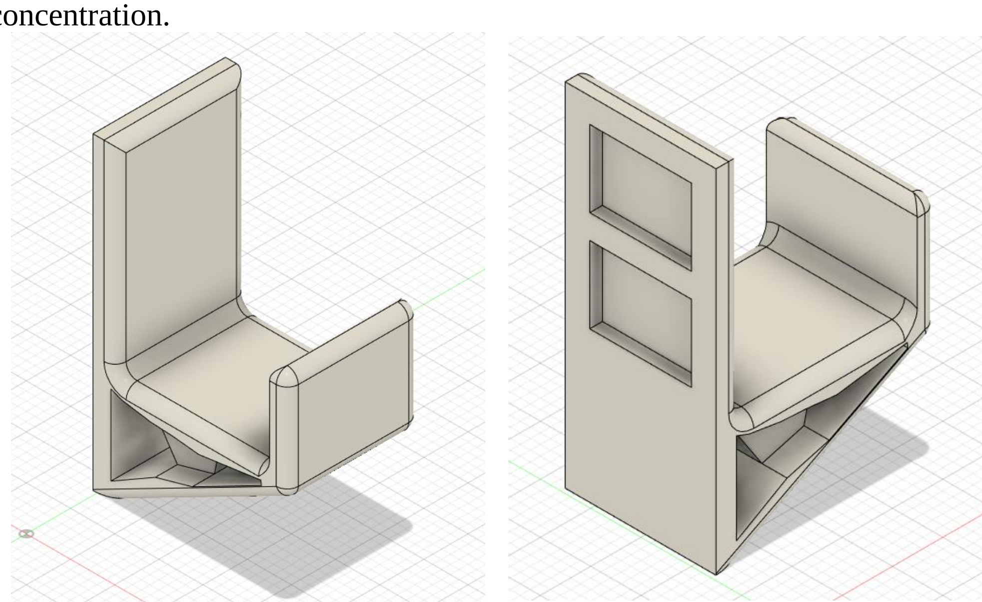

Figure 4. Part after Fusion 360 optimization. Some regions from original draft was removed to save material and reduce production time.

A sample of class project in Clarkson University

Clarkson University, a mid-size university in north, started offering additive manufacturing course in Spring 2016 for mechanical and aeronautical engineering students. The instructor covers materials properties and product attributes of subtractive and additive manufacturing process, including tolerances and, quality control. Solidification processes, powder metallurgy and additive manufacturing processes are covered in the course. As a term project, the instructor illustrates for students to design and make an elliptical shaped plate, as shown in Figure 5 using either subtractive processes, additive processes, or hybrid. The students can decide any material such as ceramics, metals, polymers, or a combination of them for their project. The dimensions of part and its tolerances were provided to students. One of objective of this project is that student can understand differences between traditional manufacturing and modern additive manufacturing such as their production rate and surface quality and tolerances.

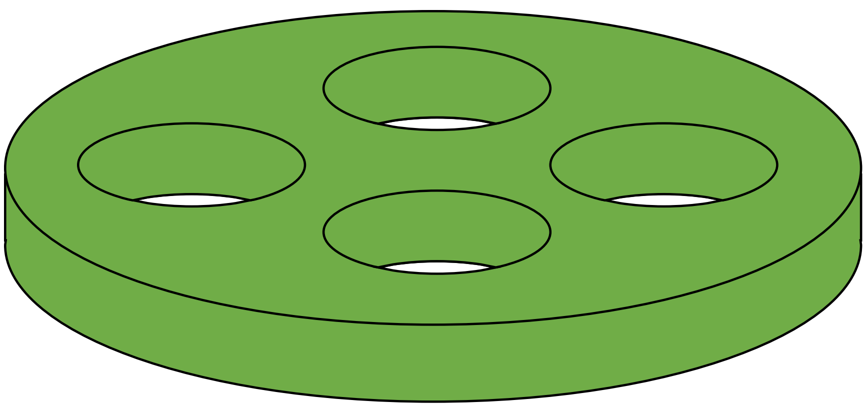

Figure 5. An elliptical shaped plate is assigned to students in Clarkson University b to manufacture with either subtractive processes, additive processes, or hybrid.

Conclusion

This paper presented an effort of developing and implementing hands on based course related to 3D printing for Engineering Technology students along with other engineering majors at Old Dominion University for the first time. The main objective was to introduce students to various capability of AM processes. This new course includes basic principles of AM, difference between traditional manufacturing processes (subtractive manufacturing, SM) and AM, recent advances in the AM technologies. Two teaching strategies from two universities were demonstrated in this study. Authors believe students' interest can be increased through a design and build strategy. Also, competition can be organized for students to design more complicated part geometry or better part performance. The work presented here can be adaptive by other instructors who are developing or currently teaching the additive manufacturing technologies.

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