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Educational Challenges in Design for Additive Manufacturing

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Educational Challenges in Design for Additive Manufacturing

Abstract

The unique capabilities of additive manufacturing (AM) enable any complex topological form in a design without manufacturing difficulty or additional cost. Complex geometric shapes, multi-material, and/or multi-functional parts can be additively manufactured in a single operation which is a big advantage over conventional manufacturing processes. In order to benefit from these advantages, designers for AM need sophisticated skills and tools that integrate material information with geometry, for example simulation and topology optimization tools, materials databases, and manufacturing process analysis and simulation tools. While the future use of AM is uncertain, it is expected to expand in industries that need highly customized and multi-functional parts with complex shapes. Therefore, students need to learn how to design for customized and complex products for the future applications of the additive manufacturing. The long-term success of additive manufacturing depends on designers that can conceptually think different than the conventional way. In order to improve design skills with complex geometries used in products manufactured with additive technologies, MET1172 CADD/CAE class assignments are modified. This paper discusses the results of this attempt.

1. Introduction

In recent years, there has been an increasing interest in advanced manufacturing processes such as additive manufacturing. Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. Some call it the new industrial revolution[1], some are hesitant since this technology is not mature enough to benefit from all of its advantages. However, additive manufacturing is a paradigm shift in manufacturing. Additive manufacturing is shifting manufacturing business models towards mass customization, responsible production, and sustainable consumption[2]. It can lead to low material use, light weight, and integral design of multi-functional components. As additive manufacturing technologies advance, even more new materials will become available and technologies will be further developed significantly changing the product design and development process. Conventionally, to design for manufacturing meant designing better products by eliminating manufacturing complexities, difficulties, and minimizing the manufacturing cost[3]. Design for additive manufacturing (AM) has a fundamentally different meaning because AM's unique capabilities enable complex geometric, multi-material, multi-functional parts in a single operation without any additional cost[4]. This point is a big advantage over conventional manufacturing processes. However, in order to benefit from this advantage, sophisticated designer skills and tools that integrate material information with design and manufacturing simulations are necessary. Complex geometric shapes are three-dimensional structures that often have undercuts or hollow spaces within them. Organic structures are an example of such complex structures. Conventional technologies like turning, milling, molding, and casting have only limited success in creating complex structures and may involve excessive cost and time. While the future use of additive manufacturing is uncertain, it is expected to expand based on surveys [5] in industries for highly customized and multifunctional parts with complex geometric shapes. The long-term success of AM depends on the STEM workforce that can think conceptually different from the conventional way.

In this paper the attempt of improving the student visualization and design skills for additive technologies with complex geometries in product development are discussed. In this paper, two student challenges, while designing for AM, has been addressed. Those are (i) visualization of the complex geometries, (ii) design with complex CAD features. In the MET1172 CADD/CAE, class assignments are modified by adding more requirements to the term projects so that the students will design by looking from the aspect of additive manufacturing technology. Inquire-based learning activities during the course helped students learn by doing. Finally the author discusses evaluation and recommendations for future.

2. Design Project for Additive Manufacturing

MET 1172 CADD/CAE class is a required course at the University of Pittsburgh at Johnstown for all mechanical engineering technology students. This is typically taken during the junior or senior year by students. This course stresses modeling techniques to create parametric solid models with appropriate design intent and parametric relations. The course content of MET 1172 is delivered in a format that has lectures and project based class activities. The class meets three times a week. In the classroom the main emphasis is on exercises that help to understand and use the design intent and constraints in parametric modeling. Students analyze their design ideas using the parametric models. A term project to design a product is assigned. An inquiry-based approach is used in this project (Figure 1). An open ended project with design requirements has been assigned to the students. After having the advantages and disadvantages of the AM discussed, students are asked to design with complex features to use the advantages of the AM. The concept of mimicking the nature and design with the complex geometries are introduced. Students are left free but their efforts are systematically observed during the class presentations. While they design and communicate their design they inquire for more and learn more.

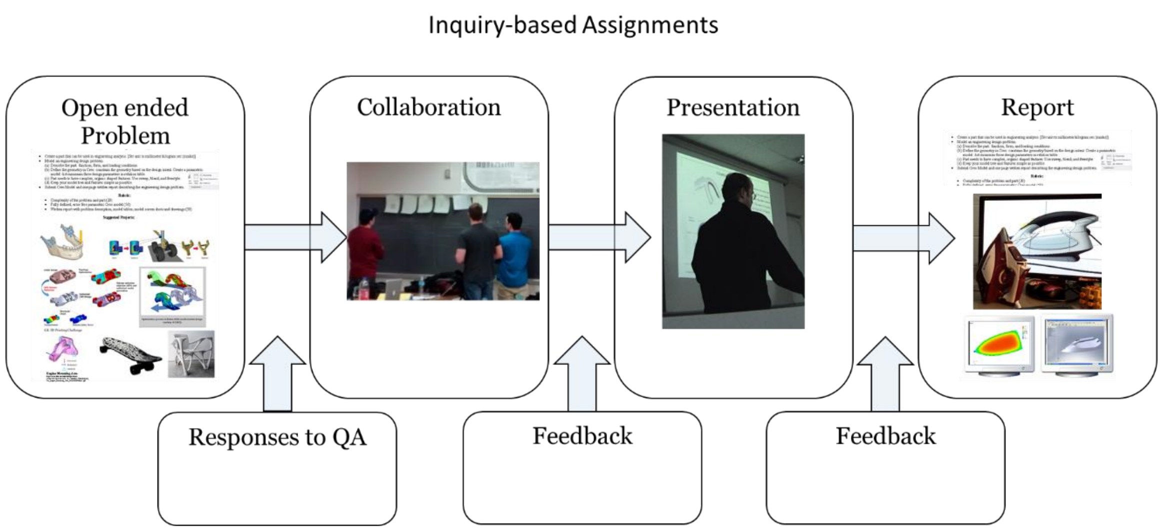


Figure 1 Inquiry-based Approach in Term project Assignment

Students are asked to create/modify a parametric model of a mechanical part that can be used in engineering analysis. Design principles for AM is introduced to the class. Complex, organic shaped features were required to be included in their models. They are challenged with two barriers to overcome. (i) Visualization of the complex geometries, (ii) CAD for complex features and design for a specific machining process (in this case AM). They are explained further in the following sections.

3. Visualization of products with complex geometries:

The complexities in AM give it an advantage over the conventional manufacturing processes since complex geometric, multi-material, or multifunctional parts can be additively manufactured in a single operation. The advantage of complexity in form and function will unlock the potential of lightweight, high performance, and strong-but-flexible parts (Figure 2). Engineering lightweight structures, designing sophisticated internal cooling channels, and combining multi-part assemblies into a single printed component are just some of the benefits known to additive manufacturing.
However, there are challenges in understanding the design and reliability of the material, and the process of additive manufacturing. A designer for AM needs sophisticated tools that integrate material information with geometry, simulation tools, topology optimization, materials databases, and tools for manufacturing process selection, manufacturability analysis and manufacturing simulation.

Figure 2 (a) Parts from GE 3D Printing Challenge[6], (b) Organic Shaped Brake Disc.

Creating a design with a complex geometry alone is a complicated challenge. Automated CAD tools do not exist for this process, so parts should be designed individually for complex shapes to benefit from the advantages of AM. For example, if a design is inspired by nature and mimics the principles, logic, and behavior of natural systems, the design is completed by observing the existing system (define the problem), finding out the math behind the geometry or function (generate solutions), programming and solving the mathematical equations of the geometry (evaluate), and finally transferring the optimized results [7] as tailor-made curves to CAD systems in order to generate the part with the necessary complex geometry (communicate). The resulting geometry can be used for the product concept after following these design steps, and once the product is fully designed, the outcome is a solid part and saved in a solid to layer (STL) file which can be used in additive manufacturing.
Traditionally, engineering students are expected to read 2D projection views of technical objects and visualize 3D models or start with isometric views and create principle orthographic views to mentally picture the concepts. Students tend to struggle with figuring out how to generate 3D objects or other necessary projection views of a product with complex geometries. Engineering design educators have developed a variety of approaches to improve the 3D visualization skills of engineering students, ranging from the use of modern solid modeling using computer-aided design (CAD) systems to augmented reality techniques[8,9].The most commonly used two approaches in education to help improve students' spatial visualization abilities are (i) real object models and (ii) simulations.

(i) Real object models: Conceptual ideas with complex geometries can be rapidly prototyped (Figure 3) and used to mentally picture the object. This technique is very effective for tactile learners who learn by touching and manipulating objects[10,11]. This approach is not suitable for large classrooms since it is difficult to let everyone try in a limited timeframe. Some students may find this rapid prototyping process not rapid enough and their attention span may decrease.

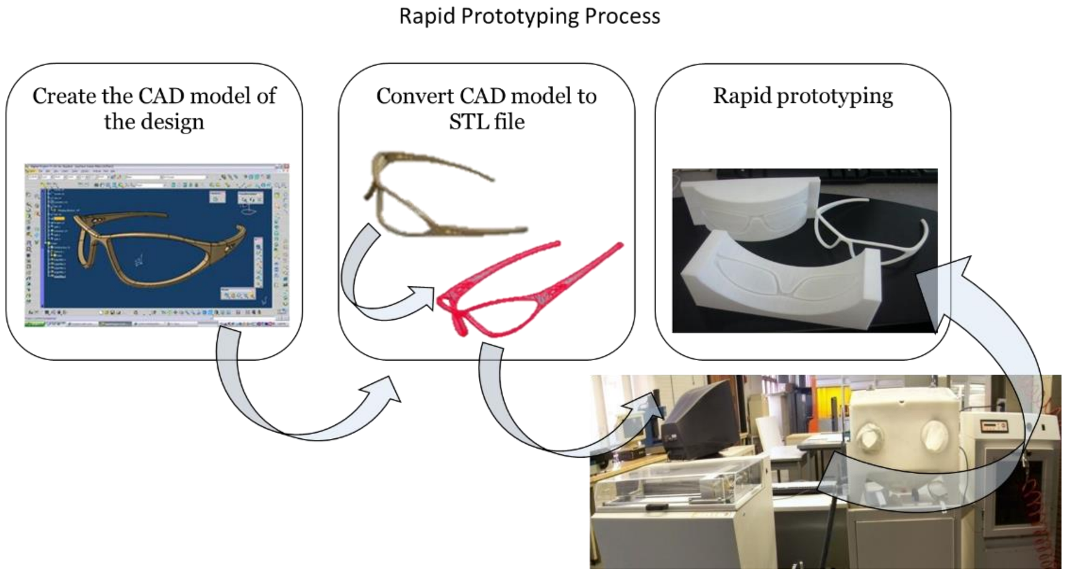


Figure 3 Rapid prototyped models

(ii) Simulation: Software can be used to visualize and inspect geometry from different points of view (Figure 4). Simulations are frequently used in large classrooms. They can be very effective for visual learners. The output on a 2D computer screen can sometimes lead to misperceptions, but renderings and photorealistic representations will help eliminate spatial misconceptions. Augmented reality (AR) techniques are also used in classrooms to engage the students' attention and help them visualize the geometry of objects. AR provides immersive views of 3D object models mixed with the real objects around them.

Designers create products using solid models where they attempt to visualize complex 3D geometries using two-dimensional (2D) monitors. It will be much easier to understand and work on solid part models if designers can see the designed objects in their surrounding through an augmented reality viewer. Digital 3D solid models (virtual models) become augmented and mixed reality (MR) if see-through glasses are used and virtual objects are controlled and mixed with the surrounding objects without markers. MR provides immersive control of the 3D virtual models in a real environment.

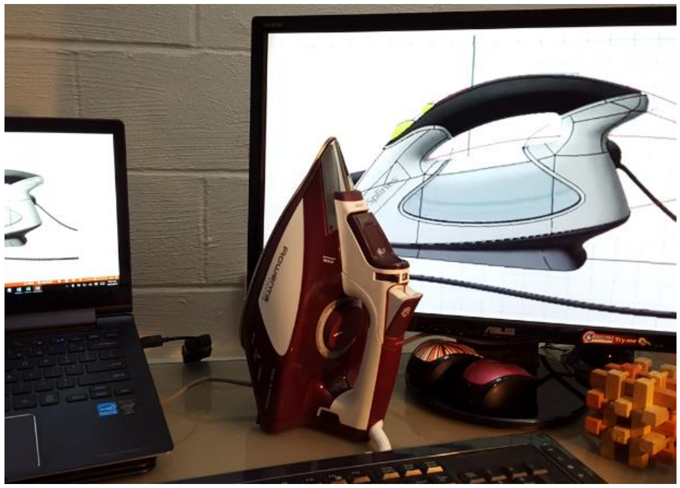


Figure 4 Simulation with CAD systems

An innovative approach has been used to augment the 3D virtual reality (VR), and a mixed reality (MR) application has been developed for digital see-through glasses (Figure 5) in an engineering drawing class to improve the visualization skills of the engineering students.[12]

Figure 5 digital see-through AR glasses with built-in camera [13]

Because digital see-through MR glasses are expensive to use with a large class, a Google Cardboard concept utilizing students' smartphones are used to visualize the complex design in the classroom (Figure 6). Students need to purchase just a controller ($3) and a Google Cardboard ($3).

Figure 6 Google Cardboard concept [14]

4. CAD for complex features and design for AM

Students of CAE & CADD class were assigned to observe and find analogies from nature and transfer the conceptual shape or function to an existing product or system. Novel complex design ideas are generated using analogies inspired by nature to be manufactured by using additive manufacturing (Figure 7).

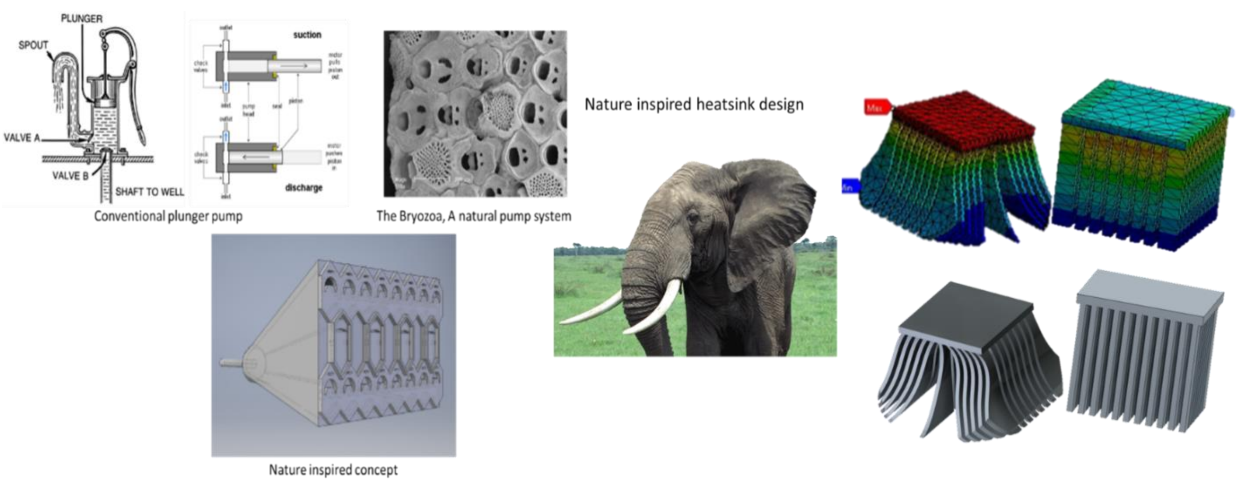
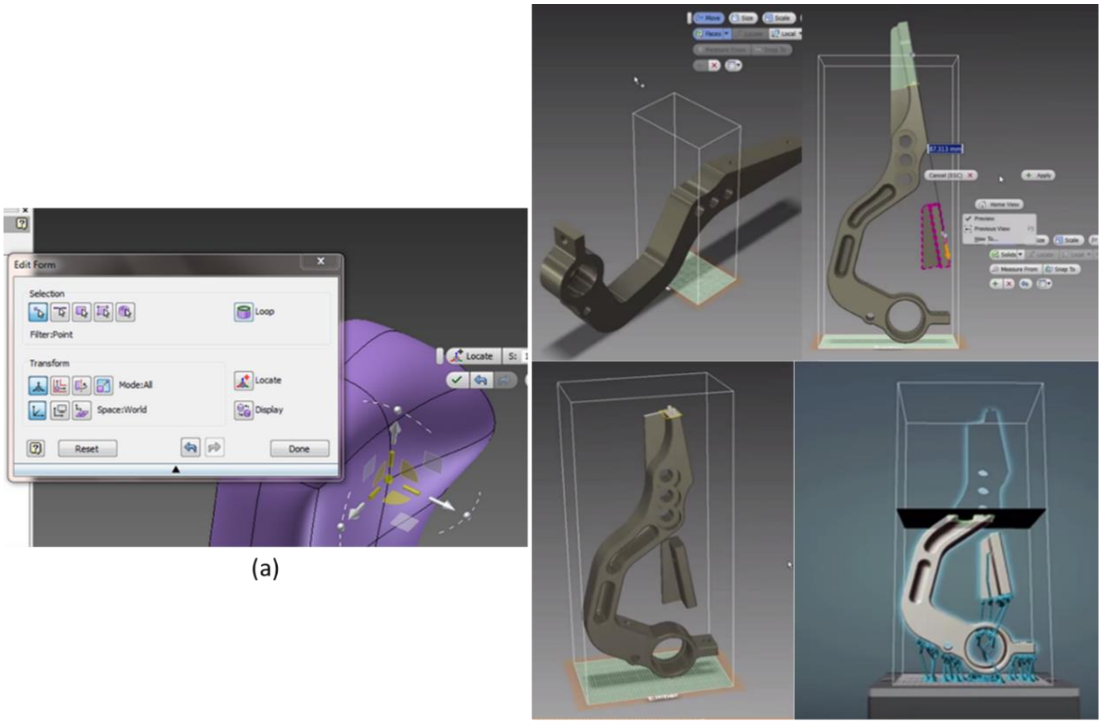


Figure 7 Nature-inspired product concepts

CAD systems are aware of the challenges of designing for complex geometries. They have been developing a variety of approaches to improve the 3D design abilities of designers for more complex shapes than just primitives. New features are being added to the CAD systems in order to easily design parts for complex shapes and AM. For example, Autodesk Inventor has free form modeling tools and additive manufacturing enhancements (Figure 8) so that designers can easily interact with the solid model to create more complex shapes for their products[15,16].



(a)

(b)

Figure 8 Enhancements in Autodesk Inventor (a) create free form (b) position and orient your design within the print space of the selected 3D printer

PTC Creo has also very useful parametric surface modeling features. This freestyle surfaces can easily be converted to solid model features (Figure 9). However, good cognitive skills are still necessary to understand complex geometry. Students learn how to design product concepts with the complex geometries and structures in CAD systems to provide new engineering solutions.

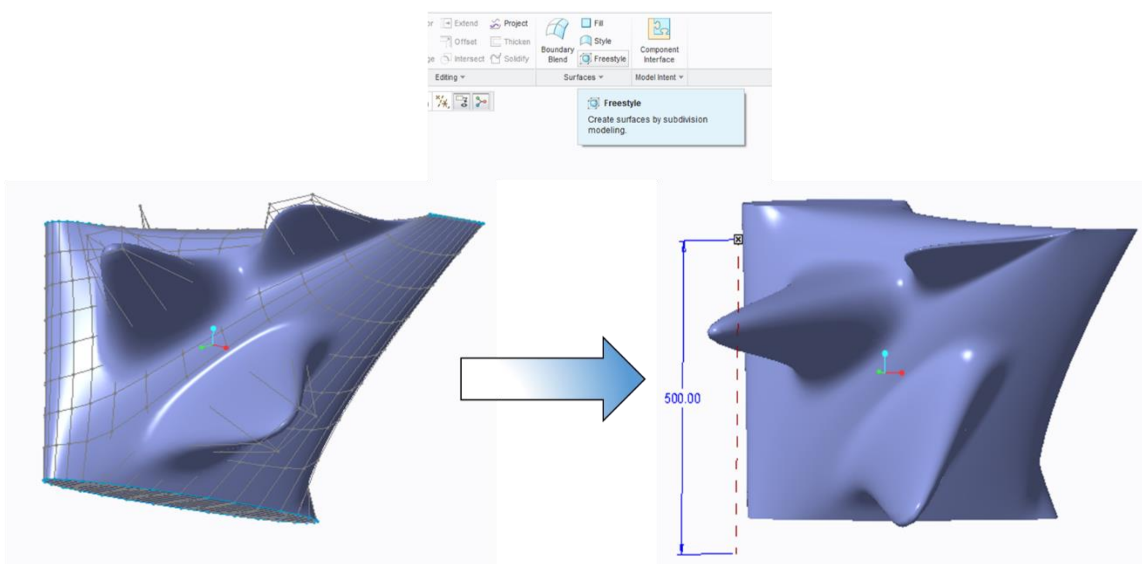


Figure 9 Parametric Freestyle Modeling in Creo

5. Course Evaluation and Student Reflection

Main objective of the course was to help understand and use modeling techniques to create parametric solid models with appropriate design intent and parametric relations.

Projects are assigned and an inquiry based approach is used to provide feedback. It was a challenge for the lecturer as he doesn't provide detailed instructions step by step. Students were offered help with their open ended problems if they inquire. They were encouraged to ask questions, but some were hesitant or may think the lecturer doesn't know the answer. Only 1/5 of the registered students participated in the student opinion of teaching survey. They indicated in evaluations that the assignments and class activities contributed to their learning. However, they were not a big fan of the projects. Some students indicated that the seek for information to find the knowledge to solve the project related problem provided motivation for them to think and learn, not only for the sake of exams. Those who did not enjoy projects had stated that there was too much work involved. Some of the students who felt that they learned more in lectures or step by step instructions stated "I could have learned more if he had shown me how to use a feature then given me an assignment using it, instead of just giving the assignment and naming the tool we should use..".

Project and inquire-based learning is a valuable strategy that improves student learning and student development. However this may be a new learning experience for the students after well-structured math and physics courses. Unlike math problems, engineering problems may have more than one acceptable solution and students need to know that the real world is less structured and problems of the real world are ill defined. Lecturers need to focus on this issue before such an attempt.

6. Conclusion

AM is expected to expand in industries that need highly customized and multi-functional parts with complex shapes. It is critical to learn how to design for complex geometries for the future applications of the additive manufacturing. The long-term success of additive manufacturing depends on designers that think conceptually different than conventional way. In order to improve design skills with complex geometries, MET1172 CADD/CAE class assignments are modified by adding more requirements to the term projects so that the students will design by looking from the aspect of additive manufacturing technology. One requirement in design project was to modify the product by finding a similar geometry from the nature and redesign the part by making an analogy with the organic shape. Examples are provided. Embellishment should add value to the function or properties of the product. Complex shaped components are designed for additive manufacturing and parametric CAD models are created. Students designed successful products with complex features to be manufactured using AM. Class evaluations indicate that the projects were also a valuable contribution to the learning experience. The author believe that teamwork benefits if cloud-based collaboration tools are used in design projects. Students are advised to use group collaboration tools in CourseWeb to improve the teamwork efficiency. However there is more room for improvement in team working skills.

7. Acknowledgments

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8. References

[1] Berman, B. (2012). 3-D printing: The new industrial revolution. Business horizons, 55(2), 155-162.

[2] Zanetti, V., Cavalieri, S., Kalchschmidt, M., & Pinto, R. (2015). The Role of Additive Manufacturing in the B2C Value Chain: Challenges, Opportunities and Models. In Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth (pp. 137-145). Springer International Publishing.

[3] Pahl, G., & Beitz, W. (2013). Engineering design: a systematic approach. Springer Science & Business Media.

[4] Lipson, H., & Kurman, M. (2013). Fabricated: The new world of 3D printing. John Wiley & Sons.

[5] Thryft A.R. (2015) "Future of Industrial 3D Printing Will Be Metals and End-Production, Say Engineers", Design News, http://www.designnews.com/author.asp? section_id= 1392& doc_id = 278492, accessed on 8/31/2015.

[6] GE, (2013), "Jet Engine Bracket from Indonesia Wins 3D Printing Challenge", GE Reports, http://www.gereports.com/post/77131235083/jet-engine-bracket-from-indonesia-wins-3d-, accessed on 8/12/2015.

[7] Liu, K., & Tovar, A. (2014) "An efficient 3D topology optimization code written in Matlab. Structural and Multidisciplinary Optimization", 50(6), 1175-1196.

[8] Technical Drawing with Engineering Graphics, 14th Edition by Giesecke, et al., Boston - Prentice Hall – 2012.

[9] Visualization and Engineering Design Graphics with Augmented Reality, Second Edition, Mariano Alcaniz, et al., SDC Publications, 2014.

[10] Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. Engineering education, 78(7), 674-681.

[11] Wehrwein, E. A., Lujan, H. L., & DiCarlo, S. E. (2007). Gender differences in learning style preferences among undergraduate physiology students.Advances in Physiology Education, 31(2), 153-157.

[12] R. Logan, B.Miller, S. Robb, S. Tumkor, (2015)"Mixed Reality Mobile Applications In Education: Visualizing Engineering Problems" UPJ, Fall into Research, 2015.

[13] Epson Moverio, http://www.epson.com/cgi-bin/Store/jsp/Landing/moverio-bt-200-smart-glasses.do , accessed on 10/23/2015.

[14] Google Cardboard, https://www.google.com/get/cardboard/, accessed on 10/23/2015.

[15] AutoDesk Inventor Products- Knowledge Network, (2014) "Freeform", http://knowledge.autodesk.com/support /inventor-products/learn-explore/caas/CloudHelp/cloudhelp/2015/ENU/Inventor-Help/files/ GUID-4DABAAC1-6C8F-4C8B-98E2-64B1F617B388-htm.html#, accessed on 10/25/2015

[16] AutoDesk Inventor Products- Knowledge Network, (2015) "Inventor 2016 Whats New - 3D Printing", http://knowledge.autodesk.com/support/ inventor-products/learn-explore/caas/video/youtube/watch-v-xKIRNH8Ai30.html, accessed on 10/25/2015