Integration of Additive Manufacturing Technology in Curricula to Enhance Concept-Based Learning

Dr. Aditya Akundi, University of Texas, El Paso

Aditya Akundi is currently affiliated to Industrial Manufacturing and Systems Engineering department, and Research Institute for Manufacturing and Engineering Systems at University of Texas, ElPaso.

He earned a Bachelor of Technology in Electronics and Communication Engineering from Jawaharlal Nehru Technological University, India. He earned a Master of Science in Electrical and Computer Engineering at the University of Texas at El Paso (UTEP). Intrigued by Systems Engineering , he earned a Ph.D in Electrical and Computer Engineering, with a concentration in Industrial and Systems Engineering (ISE) at Unniversity of Texas in 2016. His research is focused on undersanding Complex Technical and Socio-Technical Systems from an Infromation Theortic approach. He has worked on a number of projects in the field of Electrical & Computer Engineering, Systems Engineering, Additive Manufacturing and Green Energy Manufacturing. His research interests are in Systems Engineering & Architecture, Complex systems, Systems testing and Application of Entropy to Complex Systems.

Dr. Eric D. Smith, University of Texas, El Paso

Eric D. Smith is currently an Associate Professor at the University of Texas at El Paso (UTEP), a Minority Serving Institution (MSI) and a Hispanic Serving Institution (HSI), He works within the Industrial, Manufacturing and Systems Engineering (IMSE) Department, in particular with the Master of Science in Systems Engineering Program. He earned a B.S. in Physics in 1994, an M.S. in Systems Engineering in 2003, and his Ph.D. in Systems and Industrial Engineering in 2006 from the University of Arizona in Tucson, AZ. His dissertation research lay at the interface of systems engineering, cognitive science, and multi-criteria decision making. He earned his J.D. from Northwestern California University School of Law.

Prof. Tzu-Liang Bill Tseng, University of Texas, El Paso

Dr. Tseng is a Professor and Chair of Industrial, Manufacturing and Systems Engineering at UTEP. His research focuses on the computational intelligence, data mining, bio- informatics and advanced manufacturing. Dr. Tseng published in many refereed journals such as IEEE Transactions, IIE Transaction, Journal of Manufacturing Systems and others. He has been serving as a principle investigator of many research projects, funded by NSF, NASA, DoEd, KSEF and LMC. He is currently serving as an editor of Journal of Computer Standards & Interfaces.

INTEGRATION OF ADDITIVE MANUFACTURING TECHNOLOGY IN CURRICULA TO ENHANCE CONCEPT BASED LEARNING

Abstract

Concept based classroom teaching and instructions undoubtedly enable students to think as practitioners by utilizing knowledge at both theoretical and practical levels. Concept based learning increases student technology and applicability readiness levels, along with increasing student engagement in Science, Technology, Engineering and Mathematics (STEM) classrooms. In this twenty first century of globalized economy with an emphasis on product sustainability, curricula must be significantly expanded to enable future workforce with the concepts of sustainable product development. As a part of this effort, this paper discusses on introducing undergraduate and Graduate students of Green Energy Manufacturing class at The University of Texas at El Paso to the Design for X (DfX), a concept widely used in manufacturing industries for product design and development. We discuss on our experience of the course, where in to enhance student understanding of DfX, additive manufacturing technology was used to analyze how the theoretical concepts learnt by students in class were reflected upon their product design and development in real time.

Keywords: Additive Manufacturing; Design for Environment; Green energy; Green Manufacturing; Concept Based Learning

Introduction

To shape and influence the trends of technological emergence in United States, there is a significant push observed in steering the current emerging workforce towards Science, Technology, Engineering and Mathematics (STEM) careers. It is estimated that by 2018, STEM based job opportunities would be among the top 10 rapidly growing careers[1]. Developing evidence based solutions, Identifying underlying factors for a given problem, Holistic thinking, Understanding problem dependencies, are a few but not an exhaustive list of industry ready skills acquired by STEM students. However, educational environment plays a very significant role in shaping the understanding of a given concept among the students. Current research trend is observed on identifying effective teaching methodologies and developing innovative ways to keep students engaged in a classroom. With different classroom structural settings in place, it is observed that traditional teaching approach is failing to impart the required competency and skills needed by the students for preparing them to be industry ready[2]. This indicates that there is a need to identify effective teaching methodologies that incorporate individual student critical thinking and which push the horizons of a student's imagination on applying the concepts imparted in the class to real world scenarios. We believe this effective translation of theoretical concepts to real world applications will act towards improving student knowledge applicability skills, thereby making them industry flexible and technology ready.

On a quest to explore methodologies that enhance in-class student learning and keeping students in pace with the current emerging technological trends in the field of Green Energy

Manufacturing, this paper discusses on a Concept based learning approach used in the Green Energy Manufacturing class offered by the Industrial Manufacturing and Systems Engineering (IMSE) Department at the University of Texas at El Paso (UTEP).

Concept Based Learning

Traditional educational settings are currently becoming more inadequate and there is a need for new teaching models that encourage critical thinking and application. It is of high importance that students are trained to be problem solvers and critical thinkers rather than just remembering concepts. In order to be a true innovator, one need to have a good understanding of being able to interpret a problem, find dependencies, and develop models that address problems of a given scenario. Contrary to many approaches, concept based learning is mainly based on Simulating abstract/high level systems thinking of concept, Using examples to impart a concept and on Drawing connections to look at problems from different perspectives.
According to Anderson and Krathwohl, based on their work on redefining the Bloom's taxonomy of educational objectives[3]:

"Students understand when they build connections between the "new" knowledge to be gained and their prior knowledge. More specifically, the incoming knowledge is integrated with existing schemas and cognitive frameworks. Since concepts are the building blocks for these schemas and frameworks, conceptual knowledge provides a basis for understanding." (p 70)

Introducing students to active concept based instructions and learning helps to establish relevance with a student's prior experience in a given field, enhances student learning, helps in facilitating an unparalleled understanding of content, and helps students to apply the knowledge in real life scenarios[4].

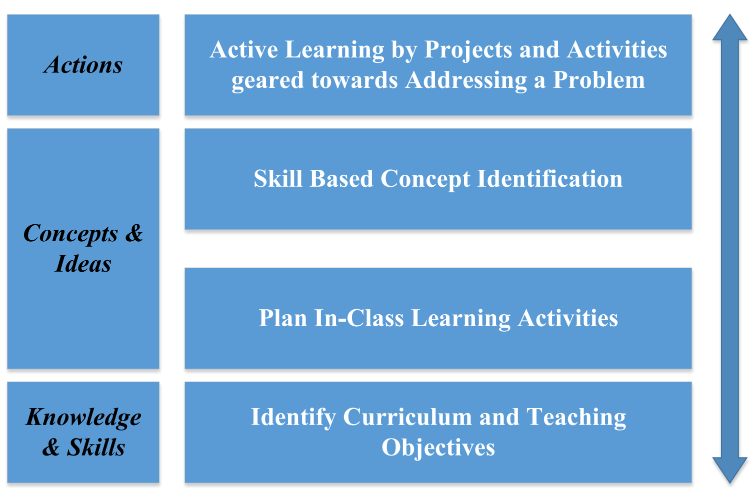


Figure 1: Multilevel Teaching Approach

Based on the fact that concepts enable in providing a context for students to solve problems, figure 1 presents the multi level teaching approach adopted for teaching Green Energy

Manufacturing (GEM) class at IMSE UTEP. It is important to note that concept based instructions must always be anchored by a curriculum and teaching objectives. To introduce the importance of learning, educators should plan in-class learning activities to be engaging and meaningful. The main concepts to be covered upon should incorporate skills that help in solving issues the student can act on based on their learning. Following this would be to design projects or activities where in students can use their understanding of the concepts learned in classroom to address a given problem, thereby allowing students to master a concept and apply their learning.

Concept Based Teaching and Learning in Green Energy Manufacturing Class

Green Energy in industries and academia is being seen as a high impact venue that helps to address environmental and sustainable issues. With an observed increase in environmental consciousness, manufacturing industries are looking at improving their processes and design to reflect positively upon the carbon footprint. To keep up with the current trends and to train students to be technically ready at Green Energy and benign Manufacturing methodologies, the main objective of GEM class offered at UTEP was to introduce students to the fundamental concepts of green manufacturing and design.
To initiate concept based learning based on the model illustrated in figure 1, once the main core objectives of the GEM class on what students are expected to learn were identified, the next step was identifying an industry specific concept that addresses the intent of GEM class curriculum. To stress upon the engineering design guidelines that guide towards better outcome of a given product, imparting the concepts of Design for "X" was deemed important to increase student understanding on designing better industry ready designs.

Design for "X" implies to a set of tools and guidelines that help engineers to develop efficient and reliable designs of a product with respect to "X". DfX can be defined as *"methodologies, techniques and working practices that cause a product to be designed and manufactured for the optimum manufacturing cost, the optimum quality, and the optimum achievement of lifecycle support"*[5].
The term "X" refers to a particular design aspect that is determined based on the importance given by a stakeholder[6]. Mentioned below are a few design aspects of DfX based on different X:

1. Design for Environment (DfE): Design for Environment explores upon the design approach that addresses to reduce the impact of a product, process or a service throughout the life cycle on human health and environment. The main goals of DfE are:
    a. Encouraging and recognizing safer and green industrial products.
    b. Identifying best practices in several industrial areas.
    c. Identifying and addressing safer life cycle practices based on valued alternatives.

2. Design for Manufacturability (DfM): Design for Manufacturability, also known as Design for Manufacturing is a principle that enables in efficient design and engineering of a product for facilitating cost efficient manufacturing processes. The design phase is given a high importance here to reduce an inherent reengineering cost after designs freeze stage.

3. Design for Assembly (DfA): Design for Assembly is based on engineering a product with an ease of assembly principle (simplification of a product) where, a product with less modules takes less assembly time and cost.

4. Design for Disassembly (DfD): Design for Disassembly is based on designing products so that they can be easily, rapidly and cost effectively taken apart with a goal of recycle and reuse of the components.

5. Design for Reliability (DfR): Design for Reliability is based on economically manufacturing the products to perform their intended functions through out the life cycle over use phase. Accelerated systems tests are given importance here after a system is design, fabricated and assembled.

Table 1: Mapping Matrix to identify a DfX concept to Teach

Objectives / ***DfX Methods***	Green Energy Concepts	Environment Conscious Manufacturing	Energy Issues	Environment Issues	Product/ Process Design Decisions	Environmentally Responsible Decisions	LCA
Design for Manufacturing (DfM)		x			x		x
Design for Assembly (DfA)					x	x	x
Design for Environment (DfE)	x	x	x	x	x	x	x
Design for Disassembly (DfD)		x		x	x	x	x
Design for Reliability (DfR)					x		x

A mapping matrix represented in Table 1 is developed to facilitate the instructors in identifying a specific DfX concept that correlates with the GEM class objectives. This helped in identifying Design for Environment (DfE) to be the core concept where in, the student in-class projects were geared towards using the Principles of DfE to design and engineer a product. Also, the concepts of Additive Manufacturing were introduced to the students for them to design and develop their products in Computer Aided Design software to be realized in real life using 3D printers.

Following the multilevel framework and the identified DfX concept, the required course materials to teach the class were developed. This course is offered to undergraduate and graduate students pursuing bachelors and masters degree in Industrial Manufacturing and Systems Engineering. Green energy and Green Manufacturing being the core of the course, students were exposed to information on Green Energy tools and principles, Green Manufacturing Principles, Life Cycle impact assessment, Design Structured Matrix (DSM), Design for Environment, Failure Mode Effect Analysis (FMEA), and Energy Generation using Solar Panels, Wind Turbines and other renewable energy sources.

With the concept of DfE being the main anchor for projects, students were provided with course sessions to learn on how to adhere their projects for developing products keeping in mind:

- Minimize resource consumption in Use phase
- Minimize resource consumption in Production and Transport phases
- Ensure Sustainability of resources
- Ensure healthy Inputs and Outputs
- Increase Durability of the product and Components
- Enable Disassembly, Separation and Purification
- Minimize the number of components
- Specifying lightweight materials and components
- Employing easy Disassembly

In-Class Student Projects

The students in class were divided into groups of 4 -5 students each and were assigned to design, conceptualize and develop a commercially of the shelf product. The main intent of the project was to utilize the available information of a chosen product to further improve its functionality and develop and computer aided design to be realized using a 3D printer.

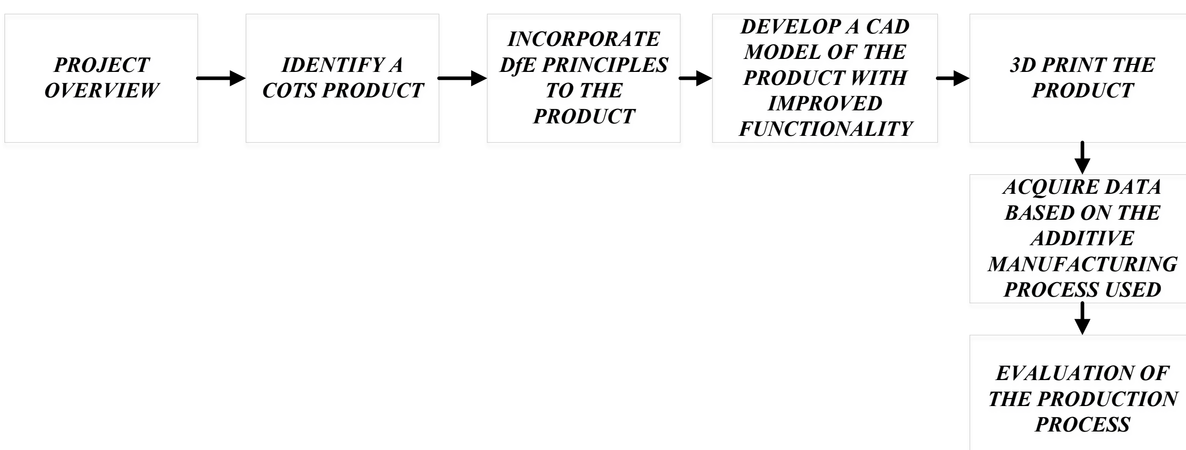


Figure 2: Students Project Approach

Additionally, the students were asked to incorporate the principles of Design for Environment to their projects. After successfully realizing the product, students were tasked to map the product manufacturing flow in order to identify bottlenecks and idle times in the process. Figure 2 illustrates an overarching methodology used by students to approach their group projects.

Based on the presented approach, flexibility was allowed among the teams to choose product they wish to work on and the projects were based on COTS products such as iPad holder, Solar Grill, Solar powered iPhone Case, Hydroponic System, and CFL Holder Casing. Given below are the details on the Product Design, Methodology used and Student team conclusions of a project based on redesigning an iPad holder with improved functionality.

Example: Full Motion iPad Holder Project

This project was based on identifying and utilizing information on cases and covers of iPads available in the market and thereby developing a better and more functional iPad case design that is realized using a 3D printer. Furthermore, the principles of DfE that were applied to develop the product were explored to analyze on the impact it has on the environment.

Initially a computer aided design of an iPad holder was developed, which was then printed using Fused Deposition Modeling technology. Acrylonitrile Butadiene Styrene (ABS plus P430) model material with a layer thickness running from 0.010 inch to 0.013 inch was used to print the product and SR-30 support material was used to successfully realize the product. Table 2 illustrates the mechanical properties and material specifications of the actual product (iPad Holder) build.

Table 2: Mechanical properties and Material specifications of iPad Holder build

Property	ABS plus P430
Tensile strength	33Mpa
Tensile modulus	2,200Mpa
Elongation	6%
Flexural strength	58Mpa
Flexural modulus	2,100
IZOD impact	106 J/m²
Heat deflection @ 66 psi	96°C
Heat deflection @ 264 psi	82°C
Thermal expansion	4.9E - 05 in/in/F
Specific gravity	1.04

Figure 3 illustrates the engineering CAD designs developed using Solid works software with a goal of minimizing the number of inherent product components. The parts where designed individually aimed at their assembly once printed.

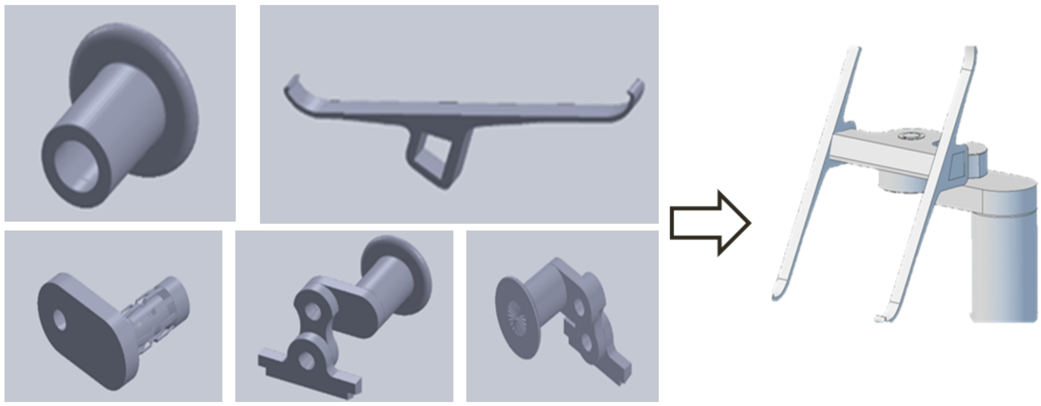


Figure 3: IPad Holder CAD Drawings

The Additive Manufacturing process chain of Creating a CAD drawing, Conversion to STL, Transfer and Manipulation of STL file on AM Machine, Machine Setup, Product Build and Removal and Clean Up were followed to build the prototype. Tables 3 illustrates the component parameters used for printing with their corresponding build times

Table 3: iPad Holder the component parameters and corresponding build times

Parts	Material (Cubic Inches)	Support Material (Cubic Inches)	Build Time (Minutes)
2 iPad Arms	1.096	0.291	130
2 Screws & 2 Nuts	0.652	0.118	65
Second Link Base & Base Shaft	5.147	0.664	319
First Shaft	2.476	0.25	155
Last Link	1.342	0.287	106
TOTAL	**10.713**	**1.61**	775

Mentioned below is the design for environment principles used in conceptualizing and developing the iPad Holder product by the team.

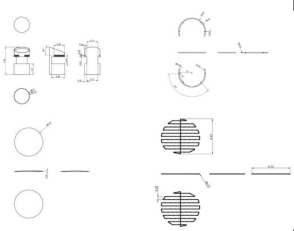
a) *Ensure Sustainability of Resources*: Virgin ABS is somewhat expensive, which makes it attractive for recycling. Recycled ABS can be blended with virgin material to produce products with lower cost while preserving the high quality. Since the material of the parts build is mostly built on ABS thermoplastic it is feasible to recycle when defects occur.
b) *Ensure Minimum Use of Resources in Production:* The iPad design developed was aimed to reduce as much material as possible. Instead of using a base plate to place the IPad, IPad arms were designed and built to lock the IPad lock this reducing material used. Also specified the build on the FDM machine was done with low density, aiding in reduction of material, minimizing volume and also creating lightweight product. Since the part is mostly build on 3D printing many traditional manufacturing steps are reduced.

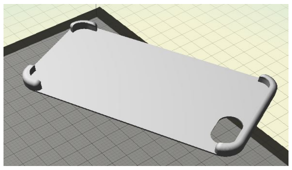
c) *Ensure Appropriate Durability of Products and Components*: The improvement of aesthetics and functionality of the iPad holder were done to ensure the aesthetic life of the product. Minimal maintenance would be required since the product is specifically design to support durability. Repair and upgrading of the components will prove easy based on the modular design of the product.

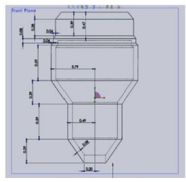
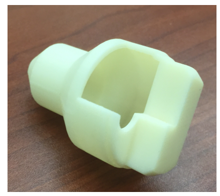
d) *Enable Disassembly and Separation:* The number and variety of joining elements are minimal due to its simplistic design. This also enables in easy assembly and disassembly of the product with few or even no tools.

Table 4 expands upon different student projects developed over the semester, product CAD designs and on what principles of Design for Environment they comply to.

Table 4: Description of Student Projects

STUDENT PROJECTS	***CAD DESIGN***	***3D PRINTED PRODUCT***	***DESIGN FOR ENVIRONMENT PRINCIPLES***
SOLAR GRILL			*A. Ensure sustainability of resources* • Layering recycled and virgin material where virgin material is necessary. • Exploiting unique properties of recycled materials. *B. Ensure healthy inputs and outputs* • Specifying non-hazardous and otherwise environmentally "clean" substances. • Specifying clean production processes for the product and in selection of components. *C. Ensure minimal use of resources in production and transportation phases* • Minimizing the number of components. • Specifying clean, high-efficiency production processes. *E. Ensure appropriate durability of the product and components* • Improving aesthetics and functionality to ensure the aesthetic life is equal to the technical life. • Specifying better materials, surface treatments, or structural arrangements to protect products from dirt, corrosion, and wear. *F. Enable disassembly, separation, and purification* • Minimizing the number and variety of joining elements. • Ensuring reusable parts can be cleaned easily and without damage.

IPHONE CASE			*A. Ensure sustainability of resources* • Using Recyclable ABS material for production *B. Ensure healthy inputs and outputs* • Non Hazardous input for production • Using Additive Manufacturing methodology towards greening the manufacturing process *C. Enable disassembly, separation, and purification* • Creating a single module design • Ensuring that the part can be cleaned easily and without damage.
HYDROPONIC SYSTEM			*A. Ensure sustainability of resources* • Prototype proving a safe and clean environment by reducing waste and providing possibility of growing hydroponics *B. Ensure healthy inputs and outputs* • Non Hazardous input for production *C. Ensure minimal use of resources in production phase* • Employing few manufacturing steps as possible, and minimizing the number of components *D. Enable disassembly, separation, and purification* • Condensing into minimal number of parts • Implementing reusable/swappable platforms, modules, and components
FULL MOTION IPAD HOLDER			*A. Ensure Sustainability of Resources*: o Since the material of the parts build is mostly built on ABS thermoplastic it is feasible to recycle when defects occur. *B. Ensure Minimum Use of Resources in Production:* o Design developed was aimed to reduce as much material as possible. o FDM machine build with low density, aiding in reduction of material, minimizing volume. o Traditional manufacturing steps are reduced. *C. Ensure Appropriate Durability of Products and Components*: • The improvement of aesthetics and functionality to ensure the aesthetic life of the product • Modular design of the product *D. Enable Disassembly and Separation:* • The numbers of joining elements are minimal due to its simplistic design • Easy assembly and disassembly of the

			product with few or even no tools
CFL BASE CASING			A. *Ensure Sustainability of Resources* • The base of the bulb can be recyclable, and can be reused in new bulbs once a bulb is disposed. B. *Ensure minimal use of resources in production phase* • Employing few manufacturing steps as possible, and minimizing the number of components. C. *Enable disassembly, separation,* Implementing reusable/swappable platforms, modules, and components.

Green Energy Manufacturing Class Assessment and Student Feedback

Students were very interested in the course, especially with the introduction and use of Additive manufacturing technology in the class which helped their product designs come to life. Assessments is based on the level of interest observed before and after the course, followed by a survey on the topics introduced in the class which the students felt were more useful and interesting.

Students when asked in the survey to provide a self-assessment of their understanding on Green Energy and Green Manufacturing concepts, a significant increase of interest was observed when compared to before and after taking the GEM class.

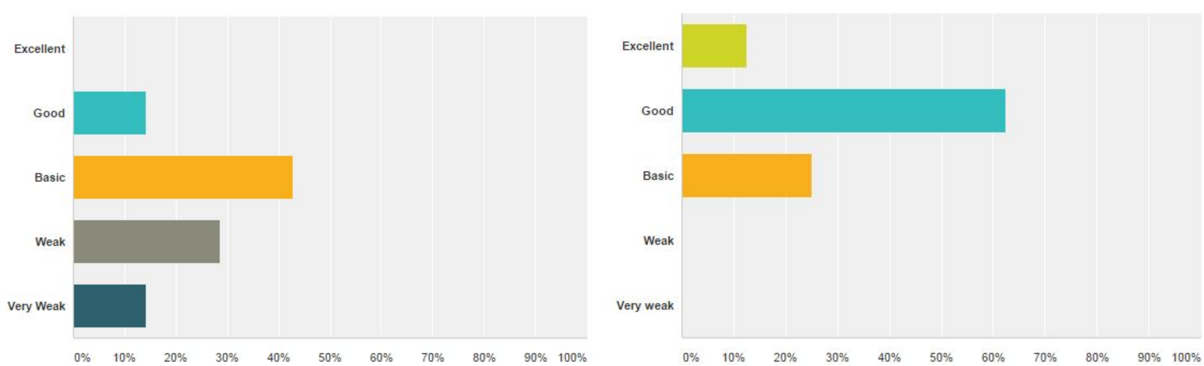


Figure 4: Survey Results on Students interest of Green Energy and Green Energy Concepts before and after taking the class. *Note: Leftmost Graph corresponds to results before taking the class and the right most with respect to after taking the class*

To understand the impact of using Additive Manufacturing technology to enhance concept based learning, students were asked if the use of 3D printing to realize their designed products had a significant impact in the learning of Design for Environment principles. Results show that 90% of the students had a better understanding of DfE and on how it is applied to realize an environmentally friendly product. It is also important to note that incorporating Additive Manufacturing into the class curriculum sparked more interest and increased student understanding of the Green Manufacturing principles.

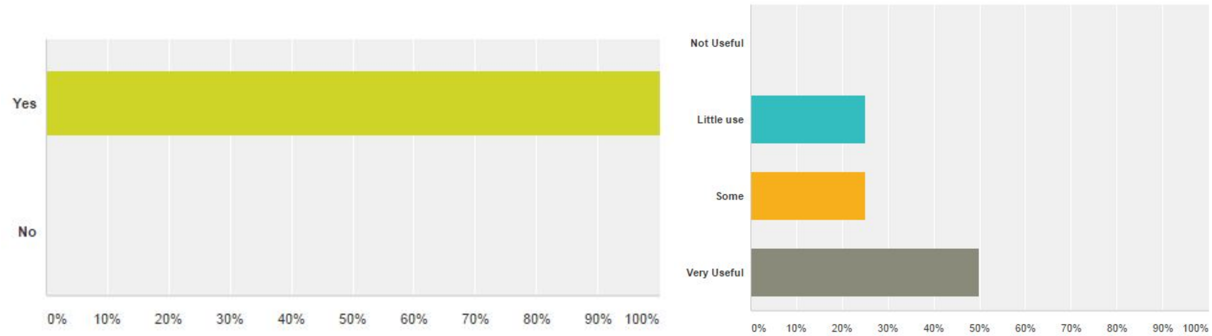


Figure 5: Survey Results on using Additive Manufacturing to understand the principles of DfE and Green Manufacturing. *Note: Leftmost Graph corresponds to results with respect to use of AM to enhance DfE concepts and the right most with respect to use of AM to enhance Green Manufacturing concepts*

In addition, students were asked to provide written testimonials and evaluation of the course at the end of the semester. Most students Commented on their experience of the class. These comments helped the instructors to understand on how well the students' grasped the concepts along with giving an insight on their knowledge enhancement.

- *"In my personal experience I have learned how to actually create and design a prototype, how beneficial is Green Manufacturing to our surrounding and the impact that is having in our lives."*

- *The class was focused on the manufacturing process, with considerations of the environment and sustainability. The project work was extremely enlightening, as it was possible to see the difficulties in taking strategic decisions in favor of the principles we learned during the semester."*

- *"This class helped me see production from a different perspective and will have a good impact on my vocational judgment, I have learned a lot about green energy concepts and applications.*

Students also mentioned the influence of the teaching methodology and about the importance of DfE on how they think it is an efficient tool to design and develop environmentally friendly products.

- *"Design for the Environment (DFE) principles is great to consider when designing a process or a product which also serves to design an effective process. Also the tools and analysis mentioned are useful in many if not in all manufactures to measure their performance and possibly improve to benefit them and the environment."*

- *"Method of teaching was really impressive and the course project was very innovative through which I learned many aspects of manufacturing methods and the use of design principles."*
- *"This project was very exciting, I had never developed a product from beginning to end thinking about the environmental factors along with using design principles, this helped me to open my vision and understand that products must be eco--‐friendly."*

Conclusion

This paper discusses upon the effect of integrating Additive manufacturing technologies to enhance concept based learning. Student project outcomes and learning activities introduced in the class suggest that the concept based learning proved highly effective to encourage critical thinking and application to make design critical decisions. There is a current unprecedented need for improving student skills and technical readiness levels for them to be successful. The effort put into identifying a hybrid concept based learning framework for effectively imparting knowledge in a classroom based on a given class curriculum, teaching objectives and perceived student learning outcomes is discussed in this paper. In addition, allowing students to individually explore and apply DfX principles (in this case Design for Environment Principles – DfE) to their developed product designs using Additive Manufacturing technology helped in providing a hands-on, real time experience to visualize their concept learning. The group projects developed demonstrated the student's ability of understanding and replicating the principles of DfE towards their designs.

Course evaluations by the students geared towards the approach used indicate that the use of Additive manufacturing technology positively influenced their learning. This shows that having hands-on real time product realization techniques when used alongside with concept based learning will prove effective. The approach presented in this paper is an initial effort by the authors towards making classrooms interactive and effective in teaching product design and manufacturing principles with the help of additive manufacturing technology.

The authors are currently looking into taking the same approach presented in this paper to the course curriculum for motivating students in learning several DfX tools and techniques that can be replicated as student project designs.

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References

1. "Science pioneers." Why STEM Education is important For Everyone. N.p.,n.d. Web.14 Oct. 2015.
2. Boahin, Peter, and Adriaan Hofman. "A disciplinary perspective of competency-based training on the acquisition of employability skills." *Journal of Vocational Education & Training* 65.3 (2013): 385-401.
3. Anderson, LW and Krathwohl, DR. 2001. A Taxonomy for Teaching, Learning and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. New York, USA. Addison Wesley Longman.
4. Erickson, Lynn. "Concept-based Teaching and Learning." (2012): n. pag. 2012. Web. 9 Oct. 2015. <http://www.ibmidatlantic.org/Concept_Based_Teaching_Learning.pdf>.
5. Abdul-Shukor, Abdullah. "Learning assessment on the effectiveness of teaching delivery in manufacturing engineering education." *UICEE Annual Conference on Engineering Education, Australia*. 2003.
6. Frost, G. S., & Foster, J. A., & Irish, R., & Sheridan, P. K. (2012, June), *The Development of a DfX* Paper presented at 2012 ASEE Annual Conference, San Antonio, Texas. https://peer.asee.org/22042