

Development and Assessment of New Biobased Materials Courses for Engineering Students and Practicing Engineers*

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The use of biobased materials for industrial and consumer products has received more and more attention because of the need for sustainability and to address the climate change. Biobased materials are renewable and derived from agriculture, silviculture, and terrestrial/aquatic microbial systems and have been used by humans for thousands of years in many aspects. To pursue technological edges and environmental benefits, the United States Government has been pushing for further development and applications of biobased materials. For further growth in this area, we have seen that there is a strong need for professionals from various backgrounds, including biology, chemistry, and engineering. However, to our knowledge, there are no exiting course series or degree programs on biobased materials in the US for engineering students and practicing engineers, as compared to the international counterparts. To address this issue, we developed and offered a new series of biobased materials courses to both college students and practicing engineers to provide them introductory information on biobased materials and potential opportunities. This series contains six courses including topics of biobased stock, bio-economy, bio-based materials and fuel, material properties and testing, as well as additive manufacturing and applications. These courses were taken in Fall 2015, Spring 2016, and Summer 2016 by more than 62 community college students (some of them have full time jobs) and 11 practicing engineers from General Motors. Four of the courses were integrated into a formal semester course delivered to Wayne State University students in Summer 2016. The participants in individual short courses obtained certificates of completion for potential career opportunities and advancements. In this paper, we present the contents and student feedback of this new series of biobased materials courses and discuss the future direction of this project.

Keywords: make it in America challenge; biobased materials; manufacturing engineering

1. Introduction

The global interest in biobased materials has significantly increased due to the urgent need to replace materials based on fossil resources for sustainability and to address the climate change [1]. As estimated by McGlade and Ekins, the cumulative carbon emissions between 2011 and 2050 must be limited to 1,100 gigatons of carbon dioxide, which means globally one third of oil reserves, half of natural gas reserves, and more than eighty percent of known coal reserves must stay unused to keep the global warming below 2°C [2]. Biobased materials come from agriculture, silviculture, and terrestrial/aquatic microbial systems. They are renewable by planting or cultivation and have been used by humans for thousands of years in many aspects, such as clothing, fuels, and construction. With advances in biological sciences and process engineering, products based on these materials, “biobased products”, have been developed and found applications in different areas, including commodity chemicals and fuels (e.g., plant oils, solvents, and

liquid/gas/solid fuels), specialty chemicals (e.g., enzymes, paints, cosmetics, and pharmaceuticals) and materials (e.g., plastics, foams, and composites). The development and use of products derived from biobased materials grew rapidly after WWI and reached its peak during WWII. For example, George Washington Carver developed many products, such as adhesives and synthetic marble, from peanuts, soybeans, pecans, and sweet potatoes [3]. Henry Ford made his soybean car from biosynthetics, including 70% cellulose, 20% soy meal, and 10% formaldehyde resin, and the car ran on pyrolysis methanol from cannabis. Although they came with satisfactory performance, many biobased products have been replaced with their low-cost counterparts derived from crude oils in the 1970s.

Starting in the 1990s, the use of biobased materials for industrial and consumer products again received attention because of the needs for sustainability and economic benefits. New policies, such as the Lead Market Initiative (European Union) [4] and BioPreferred (USA) [5] have been put in place to support these efforts. To ensure that the United States gains the technological edges and environmental benefits, the President and Congress have

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been pushing for further development and application of biobased materials [6, 7]. The National Research Council has outlined a roadmap, which expects the biobased industry to [8]:

- By 2020 provide 25% of organic carbon-based industrial feedstock chemicals and 10% of liquid fuels (compared with 1994).
- Eventually satisfy over 90% of U.S. organic chemical consumption and up to 50% of liquid fuel needs with biobased products.
- Form the basis of U.S. leadership of the global transition to biobased products and potential environmental benefits.

The ongoing efforts of developing biobased industry have resulted in steady growth in the U.S. economy in terms of 4.22 million jobs, a product value of \$393 billion, and a jobs multiplier of 2.76, as reported in 2016 [9]. The “Make it in America Challenge” was issued on March 18, 2013, under President Obama’s leadership, to accelerate job creation and encourage business investment in the United States. The programs are designed to encourage U.S. companies to keep, expand or restore their manufacturing operations, and jobs in America, and to entice foreign companies to build facilities and make their products here [10]. There were ten funded institutes in nine states, and the funded project in Michigan is titled “Building Capacity and Capability in the Biobased Materials Manufacturing Sector”.

For further growth in this area, we have seen that there is a strong need for professionals from various backgrounds, including agriculture, biology, chemistry, and engineering. From 2003 in U.S., preparing students for working in the bio-based product economy has been planned [11], and the attempts to integrate agriculture with biological and chemical engineering for undergraduate education on biobased products have been made [12, 13]. Some educational initiatives in the Netherlands to prepare professionals working in the biobased materials area have been set up [14]. It has been pointed out the subject of biobased products requires multi-disciplinary and ‘lateral’ thinking for students [15], and they need additional knowledge and use new approaches, particularly for the ones in chemical

engineering that were usually considered equipped enough education [16]. However, to our knowledge, there are no exiting course series or degree programs in the U.S for engineering students and practicing engineers, as compared to the international counterparts [17–21]. To address this issue, with funding from the “Make it in America Challenge” grants [22], we developed and offered a new series of biobased materials courses to both college students and practicing engineers to provide them introductory information on biobased materials and potential opportunities. This series of courses includes not only biobased materials knowledge, but also fundamental material properties, ASTM standards, and applications in additive manufacturing.

In this paper, we present the contents and student feedback of this new series of biobased materials courses, which were offered in Fall 2015, Spring 2016, and Summer 2016 to both college students and practicing engineers from nearby industries in Michigan, USA, and students from Wayne State University.

2. Course contents

This training program intends to inspire and educate potential companies to use biobased materials as sustainable sources. It consists of six short courses, introducing essential knowledge and key technical skills of biobased materials and their applications in the automotive industry. These short courses also include laboratory experiments to provide hands-on experiences in processing and testing biobased materials and products. The total time of the six courses is 88 hours including lectures and labs. Students are expected to have the prerequisites in general physics and chemistry to take these courses (Table 1). They are recommended, but not required, to complete all six courses. The contents of the courses and labs are described as follows.

B1. Introduction of biobased materials, specifications, and industry applications

A biobased material is defined as “non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms. It

Table 1. Proposed courses for the “Building Capacity and Capability in the Biobased Materials Manufacturing Sector” training program

	Course Name	Lec. Hrs	Lab Hrs
B1	Introduction of Biobased Materials, Specifications, and Industry Applications	12	4
B2	Overview of Biobased Material Productions	12	4
B3	Overview of Experimental Testing and Industry Standard Testing of Biobased Materials	8	0
B4	Introduction of Modeling and Simulation of Biobased Products	12	4
B5	Introduction of Additive Manufacturing	12	4
B6	Applications of Additive Manufacturing Using Biobased Materials	12	4

includes products, by-products, residues and waste from agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes. Students will learn about the basics of biobased materials including their types, specifications, and industry applications, and further learn about the related standards, acceptance criteria, and technical guides on biobased materials.

B2. Overview of biobased material productions

Overview the designs and production techniques of biobased products from feedstock to biomaterials, chemicals and biofuels. There exists a wide variety of biomass resources available for conversion into biomaterials. This will require an intimate understanding of the composition of raw materials—whether it is whole plant, constituent, or byproduct—so that desired functional elements can be obtained for bio-material production. Introduction of thermal and catalytic processes for the conversion of biomass to biobased products. Topics include fast pyrolysis, hydrothermal processing, syngas to synfuels, and bio-oil upgrading.

B3. Overview of experimental testing and industry standard testing of biobased materials

The chemical, physical, and mechanical behaviors of several biobased materials will be discussed. The methods presented in this course address three key issues: Identification and selection of potential products for technical evaluation, bench-scale technical characterization of potential biobased materials, and piloting testing of the products.

B4. Introduction of modeling and simulation of biobased products

Overview of computational and analytical tools for modeling and simulation of biobased products. Multiscale models for prediction of mechanical response of a variety of biobased materials will be presented. Student will simulate both the macroscopic physical/mechanical behaviors and the molecular scale chemical and physical phenomena for their application purposes.

B5. Introduction of additive manufacturing

3D printing is an additive manufacturing process creating three dimensional objects by adding a material layer by layer. A 3D printer is regarded as an additive manufacturing version of CNC (computer numerical control) machines, involving multidisciplinary subjects such as robotics, mechatronics, and control systems. The biggest advantages of the 3D printing technology are that it can easily create inner structures such as hollows without breaking the exterior surface, as well as produce

customized objects for different needs. In addition, it is usually clean during printing and saving materials without generating scrap, which is eco-friendly. Students will learn about the background and mechanism of 3D printing, the current types of 3D printers and the corresponding printing materials, CAD software and graphical design, and 3D printing software and file formats.

B6. Applications of additive manufacturing using biobased materials

3D printing has been a well-developed technology since the 1980's used in product development, rapid prototyping, and customized manufacturing. 3D printed biobased materials can be applied to almost all the fields, including automotive, aerospace, military, medical industries, biomedical technology, architecture and construction, and even apparel and food industries. Students will learn about selecting the proper biobased materials for their application purposes, and adopt the corresponding printing processes such as thermal extruding, wet extruding, or even light polymerizing, as well as some necessary aftermath processing.

3. Laboratory description

The following laboratory activities and demonstrations were designed to help our students and participants better understand the course contents of biobased materials and additive manufacturing. They are given depending on the locations of the courses held and the availability of equipment.

- Lab 1. Safety Training.
Introduction to material safety data sheets (MSDS), personal protective equipment (PPE), and laboratory safety protocols.
- Lab 2. 3D model design and 3D printing operating.
PLA plastic, a biobased material, is easily accessible for it being one of the major filament materials used in desktop and industry 3D printer. Students were encouraged to use the software demonstrated (AutoCAD, Sketchup, and 123D Design) to design 3D models and convert them into the stl format. Students also have opportunity to operate and adjust the parameters of a 3D printer to make their design. Activities are:
 1. Design a mold using Autodesk 123D Design or any 3D CAD software package. Export the design to a stl file.
 2. Control a 3D printer (Replicator compatible or RepRap machine) to make the designed mode by using Slic3r, Cura, or other software.
- Lab 3. Molding with Biodegradable Polycaprolactone.

Polycaprolactone (PCL) is a biodegradable polymer that has a low melting point at around 60°C and a glass transition temperature of -60°C. It is prepared by the ring opening polymerization of caprolactone. Polycaprolactone is biocompatible and therefore finds many biomedical applications, such as drug delivery devices, sutures, and scaffold for tissue engineering. The monomer, caprolactone, can be produced by the conversion of 5-hydroxymethylfurfural (HMF) from D-glucose or cellulose. Commercially available polycaprolactone pellets are used as materials for molding in this lab.

Molding with Polycaprolactone:

1. Combine boiling water and PCL pellets. Wait until the pellets become soft, transparent blobs.
2. Remove the PCL pellets from the hot water, squeeze them into a block, and let it cool until you can touch it with bare hands. Be careful with the hot water possibly trapped in the PCL block.
3. Shape the softened PCL block with your mold, and let it cool to the room temperature to solidify.

- Lab 4. Biobased Material Testing.

Mechanical properties of biobased materials are essential when applied them in industrial applications. Universal testing machine and Rockwell hardness testing device were introduced that students were capable to comprehend how the properties of biobased material can be measured and compared with other materials. The lab activities include:

1. Identify and prepare biobased specimen (PLA plastic) whose dimensions satisfy the requirements by ASTM standards [23].
2. Operate the machines to obtain the stress, strain, and hardness data etc (Fig. 1).

- Lab 5. 3D scanner operating and 3D printer filament recycling.

3D scanning can reconstruct and digitalize a 3D object, which has many applications in 3D printing. Filament recycling can reduce environment impacts by collecting the printed plastic wastes and melting them to remake new filament. Special property filament can be made and modified by this way as well. In this lab, students will:

1. Operate 3D scanners (Cubify's Sense, BQ

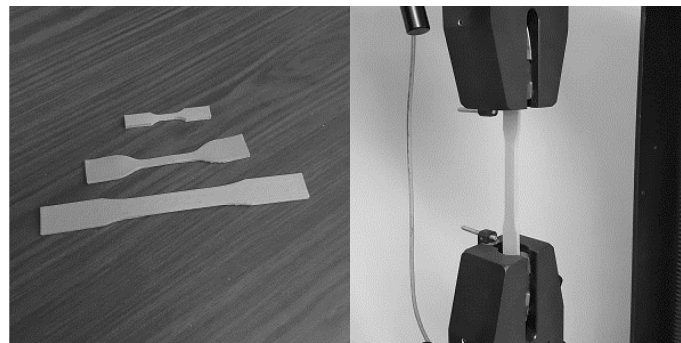


Fig. 1. Printed PLA specimens sized under ASTM D638 “Standard Test Method for Tensile Properties of Plastics” and their tensile testing on a universal testing machine. The testing is measuring the strain-stress curve to identify the PLA plastic tensile properties including its Young’s modulus. The measured values of Young’s modulus ranged from 1.5 to 2 GPa and the yield strength is around 27MPa, less than the standard values due to the printing structure and quality.

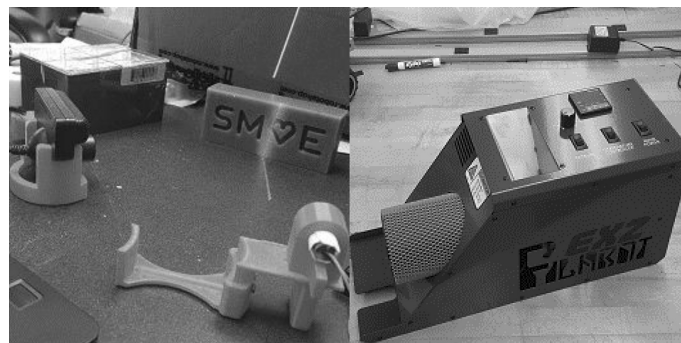


Fig. 2. MakerScanner 3D scanner [24] and Filabot.

Ciclop, and MakerScanner) to build digital 3D models.

2. Use Filabot machine to recycle the wastes and make a spool of new filament (Fig. 2).

4. Materials and methods

Polycaprolactone (PL) was purchased from Walmart (Bentonville, AR, USA). The CTC 3D printer was purchased from eBay. 3D scanners, Cubify's Sense was purchased from 3D Systems (Rock Hill, SC, USA), and BQ Ciclop is a RepRap project by BQ (Madrid, Spain) and the parts was purchased from eBay. MakerScanner was built in-house. The filament maker, Filabot, was purchased from Filabot (Barre VT, USA). Sketchup, and 123D Design were downloaded from Google (Mountain View, CA, USA) and Autodesk (San Rafael, CA, USA), respectively.

5. Course assessment and discussions

Most of the course participants are community college students with full time or part time jobs. Students seemed to have more interest in introductory level courses B1, B2, B3, and B5 and took the courses with advanced topics (B4 and B6) as their

second choice. Course B1, serving as the introduction of the entire series of the courses, were delivered most frequently. B2 and B3 were delivered once, respectively, and B5 was offered twice. Particularly, B5 covering the popular topic recently, additive manufacturing and 3D printing, attracted the most attention of the people from industry and was delivered once at General Motors (GM) Technical Center. In addition, WSU obtained additional funds to provide tuitions to senior undergraduate and first-year graduate students on campus for a seven-week summer course ET5995 "Special Topic on Biobased Materials, Specifications, Industry and Additive Manufacturing Applications", which was a combination and rearrangement of B1, B2, B5, and B6. Only B4 did not have an opportunity to be delivered during the entire project period.

After the completion of each course, students were given a survey on a five-point Likert scale with 5 being Strongly Agree and 1 being Strongly Disagree [25] and two questions for comments and suggestions. The questions of the short course survey and ET 5995 course survey are listed in Table 2 and Table 3, respectively. The statistics results of the short course scaled question survey are summarized in Fig. 3 in a chronological order,

Table 2. Questions of the short course survey

Category	Question
Instructor Methods	The Instructor provided and explained class outline or agenda. The instructor stated the learning objectives clearly. The instructor had the knowledge and information needed to teach. Class examples/illustrations were used to enhance the learning outcomes. The instructor encouraged student interaction and questions. Students were encouraged to practice skills.
Class Content	The class content followed the learning objectives. The class was taught in a way that helped me learn. The class was taught at an acceptable pace.
Training Materials	The student manual contained sufficient technical information. The student manual is formatted to be a useful reference document. The PowerPoint slides aligned with the content in the student manual. The review exercises at the end of each module reinforced the learning objectives.
Learner Benefits	Were your expectations for attending the class met? The course information is useful for my current job assignment. I would recommend this class to others.

Table 3. Questions of ET5995 summer course survey

Type	Question
Likert scale	My expectations for attending the class were met. The course information is useful for my current job assignment. I am interested in learning more about biobased materials. I would recommend this course. Biobased materials will become commercialized.
Free express	What inspired you to take this course? What knowledge of biobased material did you have prior to this course? What course topics were most valuable to you? Why? How will you use the knowledge gained in this course?

and the results of ET 5995 scaled question survey are summarized in Fig. 4. In general, the responses are positive, as supported by the average scores of over 4.0 out of 5.0. During the course delivering period,

the course materials were modified and updated according to the participants' feedback. The increasing average scores and decreasing standard deviation reflected the efforts of course improving.

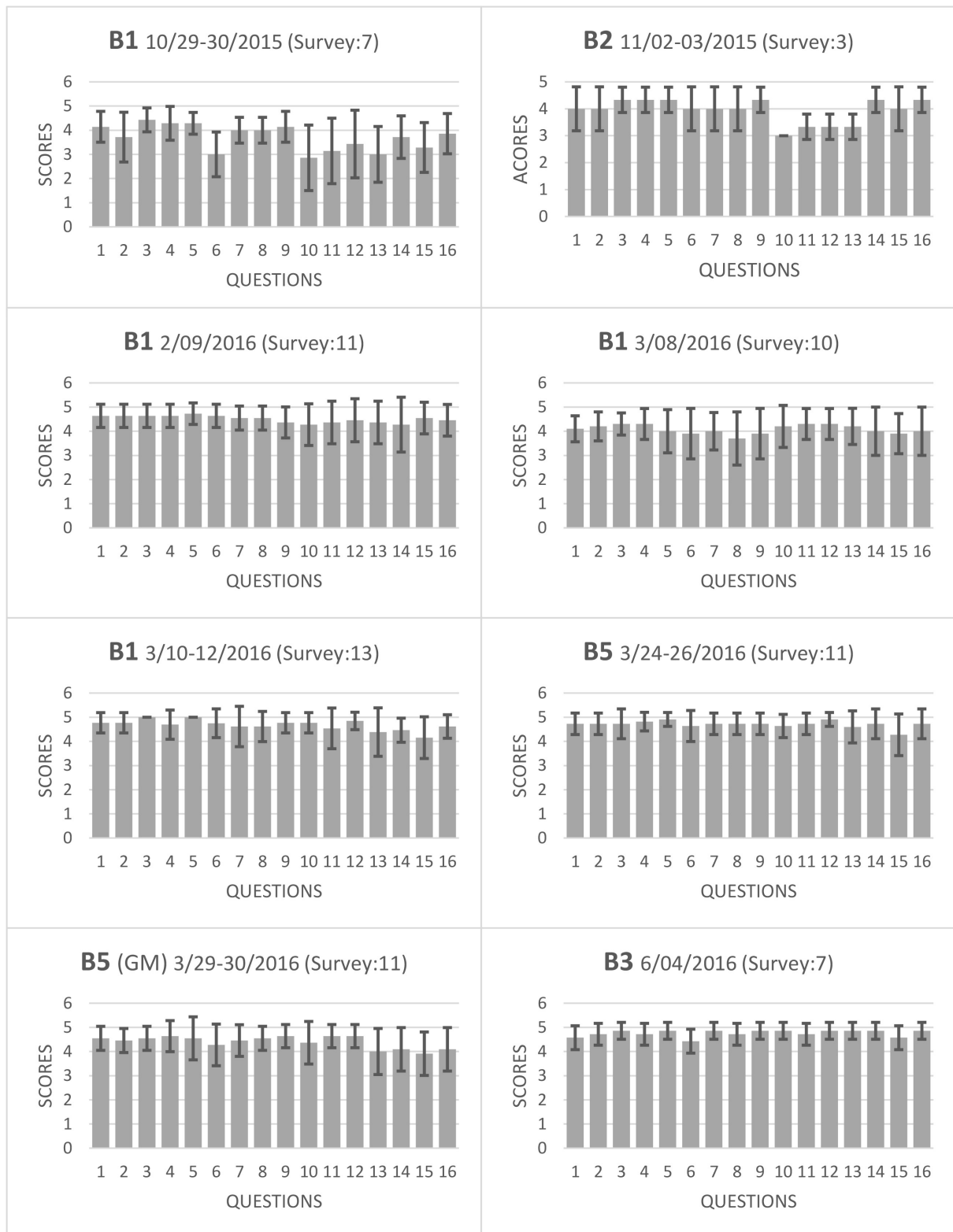


Fig. 3. Community student responses to the course outcome survey. The average score for each question is shown, where all the questions are listed in Table 2.

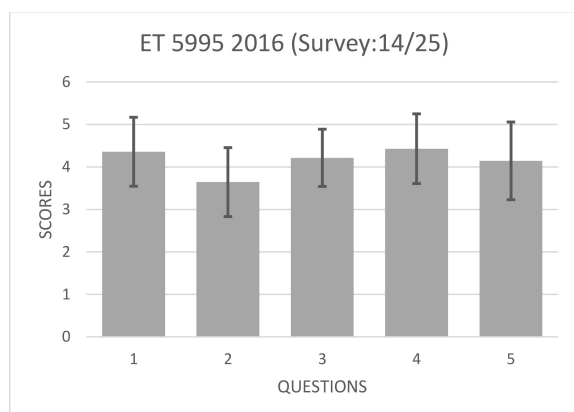


Fig. 4. WSU student responses to the course outcome survey. The average score for each question is shown, where all the questions are listed in Table 3.

The survey scores of course B5 delivered to GM participants are slightly lower than the scores delivered to community college students, as shown in Fig. 3, especially questions 13–16, which are about the relevance of the course to their jobs. The reasons could be multifold, such as that the course materials were designed to be introductory, the course emphasized more on biobased materials, and the course might not provide sufficient specific information of the participants' professional area. We learned the course materials should be modified to meet the need of different audiences, especially those from specific areas of industry, for future offerings.

As this course series was developed as an introduction for students and practicing engineers to the biobased materials and relevant topics, there are some limitations in our efforts here. First, the area of biobased materials is multidisciplinary that involves many fields, such as biology, physics, chemistry, and engineering. Therefore, it is difficult to include exhaustive information in only 88 hours, and the choices of course subjects may not meet every student's interest. Secondly, the area of biobased materials is very popular and active in both research and industry and thus requires constant updates on course contents to keep up with the latest development. We are currently developing a new strategy to address these issues for future course offerings.

6. Conclusion

Through this project, we recognized an emerging and imminent need for employees equipped with skills in advanced manufacturing and automotive industry from biobased materials and relevant technologies. While these technologies have been studied and used in prototyping for years, they are now being used more broadly in production. Consequently, there is a need to translate the advanced laboratory findings related to these

materials and how they are used in design and manufacturing, into applications and implementation in production, finishing and repair. In addition to educating workforces who will be directly applying these skills and knowledge in their work, this project also promotes the advantages of biobased technology to public and the impacts to the industry as well as society including the environment issues.

We present in this paper our efforts and the results of introducing biobased technologies to the potential workforces by short courses with lab hours and a WSU summer course. These courses were delivered in Fall 2015, Spring 2016, and Summer 2016 to more than 62 community college students (some of them have full time jobs) and 11 practicing engineers from General Motors. The WSU summer course ET5995 "Special Topic on Biobased Materials, Specifications, Industry and Additive Manufacturing Applications", which was a combination and rearrangement of B1, B2, B5, and B6, attracted 25 senior undergraduate and first-year graduate students. Course B1, serving as the introduction of the entire series of the courses, were delivered four times. B2 and B3 were delivered once, respectively, and B5 was offered twice. Only B4 was not delivered during the entire project period, and the reason could be that modeling and simulation of biobased products did not fit the needs of targeted participants, who were mostly from industry. We believe the course development and delivery were successful from the survey statistics being positive with improving scaled averages and smaller standard deviations.

Although the entire project "Make it in America Challenge" has ended, there are still opportunities to promote biobased related topics by delivering the developed courses. Certainly, the experiences and lessons we obtained from the courses already given will be applied and continuously improved, to make the program stronger and encourage more students to pursue advanced studies and careers in the biobased industry. We are looking for not only potential collaboration with local community colleges and workforce development agencies but also international partners to deliver these six courses. In future deliveries, course participants have freedoms of selecting courses best fitting their interests, and a certificate of completion will be granted after a student finishes each course, for the best practice of assisting students' careers and promoting biobased industry.

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Capability in the Bio-Based Materials Manufacturing Sector". ETA's investments help to develop a skilled workforce for specific industries.

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