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Preparing Tomorrow's Workforce in Lightweight Materials: Properties, Optimization and Manufacturing Processes

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Abstract

The use of lightweight materials has been widely driven by the aerospace industry, ship building and wind turbine productions. In the automotive industry, the share of lightweight materials is expected to increase from 30 to 70 percent by the year 2030, primarily due to the aggressive new Corporate Average Fuel Economy (CAFE) standards. Therefore, the use of lightweight materials in manufacturing has caught massive attentions and emerged as a transforming innovation. Lightweight materials range from high strength steel and aluminum to carbon fiber composites, polymers, foams and plastics. Understanding their various material properties is driving the development of new and modified manufacturing processes. Lightweight materials are changing the nature of advanced manufacturing, and concurrent with this shift in materials and the corresponding changes in design and manufacturing processes is the need to train the workforce of today and tomorrow in these technologies. This paper presents the collaboration between Wayne State University and Washtenaw Community College on an NSF project to develop an integrated curriculum in the emerging technologies surrounding lightweight materials properties, optimization and manufacturing processes. The goal of this project is to engage industry and educators in developing a talent pipeline and initial curriculum addressing the material properties, design for manufacturability and manufacturing processes, as well as optimization and manufacturing processes associated with lightweight materials at the high school, community college and university levels to meet emerging industry needs for engineers and technicians in the manufacturing industry. This paper is a report that majorly represents the development progresses and results of workshops for K-12 teachers and community college faculty, including workshop agendas, lecture and laboratory materials, and analyses of participant feedback.

Introduction

To increase energy efficiency, save natural resources, improve product performances and explore new industry applications, the uses of lightweight materials and designs in manufacturing have emerged as a transforming innovation. Lightweight materials are changing the nature of advanced manufacturing, from designing for performances and manufacturability to the manufacturing processes (including 3D printing) to the repair of parts built with these materials. Concurrent with this shift in materials and the corresponding changes in manufacturing and design processes is the need to train the workforce of today and tomorrow in these technologies.

In the automotive industry, boosting the fuel economy of modern automobiles is essential while maintaining safety and performance. A 10% reduction in vehicle weight approximately results in a 6%-8% fuel economy improvement[1]. Lightweight materials can directly reduce the weight of a vehicle's body and chassis by up to 50%, allowing vehicles to carry additional systems, which is especially important for hybrid and electric vehicles to offset the weight of power systems such as batteries for improving the efficiency and the driving range[1]. Due to the ambitious new Corporate Average Fuel Economy (CAFE) standards, the share of lightweight materials for passenger cars and light duty trucks is expected to increase from 30 to 70 percent by the year 2030[2]. With an unyielding timeline for implementation of this new CAFE standards, 88 percent of original equipment manufacturers (OEMs) have indicated that they are actively pursuing strategies to increase the use of lightweight materials in automobiles[3]. On the other hand, vehicle manufacturers face real-world challenges in finding cost-effective ways to continue implementing further mass reduction solutions needed to off-set weight gains due to increased demand for comfort, convenience, and safety technology[4].

Michigan was ranked by the Bureau of Labor Statistics number one in the country in terms of concentration of industrial designer and engineers, R&D professionals and skilled trade workers[5], and the second most attractive state for aerospace manufacturing and R&D facilities[6]. In addition, Michigan is celebrated as the center of the North American automotive sector, receiving more than three-quarters of the continent's automotive research and development funding[7]. As a member of the Southeast Michigan Workforce Intelligence Network (WIN), the institute is a participant in the American Lightweight Materials Manufacturing Innovation Institute (ALMMII) consortium, one of the founding institutes in the National Network for Manufacturing Innovation. ALMMII recently announced its new program name, LIFT (Lightweight Innovations for Tomorrow), a public private partnership to develop and deploy advanced lightweight materials manufacturing technologies and implement education and training programs to prepare the workforce. LIFT and the Institute for Advanced Composites Manufacturing Innovation (IACMI), another federally-funded innovation hub, have recently established facilities in Detroit. This further endorses and enhances Southeast Michigan's pre-eminence as a focal point for lightweight manufacturing in North America.

Lightweight materials used in these manufacturing industries range from high strength steel and aluminum to carbon fiber composites, polymers, foams and plastics. They basically provide similar mechanical properties as the material they are substituting, but possess smaller masses, and have different cost for raw materials, manufacturing tooling and processing. High strength steel, or high strength low alloy steel (HSLA), is a type of alloy steel with a carbon content between 0.05–0.25% and small quantities of other alloying elements for strengthening purposes. The yield strengths range between 250–590 MPa, larger than the values of low-carbon (mild) steel with similar carbon content, around 220 MPa. When used in structures needing large stress or a good strength-to-weight ratio, HSLA steel cross-sections and structures are usually 20–30% lighter than a carbon steel with the same strength[8]. Aluminum alloys are composed of aluminum as the predominant metal with alloying elements, including copper, magnesium, manganese, silicon, tin and zinc typically. They are classified into casting alloys and wrought alloys. Wrought alloys have eight series (1000-8000) for different properties and usage purposes, and the 6000 series are commonly used for lightweight structures with yield strengths around 100-360 MPa[9], with only1/3 weight of steels. A composite material has significant different physical or chemical characteristics from two or more constituent materials it is made of after combined. The most popular composite materials in structural engineering are fiber-reinforced plastics, including fiberglass and carbon-fiber polymer, which are widely used in aerospace, automotive and construction industries. Their advantages are significant weight reduction under the same strength and components reduction by combining parts into fewer simple molded parts.

Most of recent lightweight material researches are very advanced, requiring years of fundamental knowledge training and high-end research equipment. For example, the Center for Automobile Lightweighting (NCAL) and the National Institute of Standards and Technology (NIST) are currently studying lightweight materials and their corresponding testing protocols. Current projects include crystal plasticity modeling, yield surface measurement, cruciform multiaxial Testing, marciniak multiaxial Testing, etc.[10] These are pioneering research projects, but they are not accessible to community college or undergraduate students. Education addressed on material integration in the field of manufacturing were developed by the National Resource Center for Materials Technology Education (MatEd), the National Center for Manufacturing Education (NCME), and the Society of Manufacturing Engineers (SME)[11,12]. There were some resources for graduate education and research in lightweight automotive materials and processes[13], however very few are available for undergraduate or K-12 learning and research activities.

Now that lightweighting is being implemented on a larger scale in production, the focus of education needs to expand to include training. This funded NSF-ATE project developed for the community college and high school levels aims to train workers in various lightweighting applications, including material structure design and optimization using software, 3D printing and joining methods. The goal of this project is to engage industry and educators in developing a talent pipeline and initial curriculum addressing the material properties, design for manufacturability and manufacturing processes, as well as optimization and manufacturing processes associated with lightweight materials at the high school, community college and university levels to meet emerging industry needs for engineers and technicians in the manufacturing industry. Key activities include: (1) Developing introductory multi-disciplinary and project-based course modules on lightweight materials around existing curricula; (2) Creating interdisciplinary community college faculty and K-12 teacher professional development centered on lightweight materials properties, optimization and manufacturing processes; (3) Establishing a talent pipeline extending from K-12 to community colleges and four-year universities; and (4) Developing and contributing to a repository of lightweight curricula.

This paper is a report that represents the development progresses and results of a workshop for K-12 teachers in activity (2) held in June 2017. A brief description of the NSF-ATE project will be presented, followed by the workshop agenda and lecture materials. The workshop survey questions are listed and analyses of participant feedback are discussed. The content of the upcoming workshop for community college faculty is represent in the last section.

Project Description

This project aims to develop an industry-based learning environment for lightweight material technicians, engineering technologists, and K-12 students and teachers. Washtenaw Community College and Wayne State University are partnered to develop integrated curriculum in the emerging technologies surrounding lightweight materials properties, optimization and manufacturing processes and have an articulation agreement in place for a two-plus-two program in which the expectation is that students enter with an associate degree. The community college is also partnering with Square One (SQ1) to develop a pipeline into lightweight manufacturing with K-12 students.

- Goal
  The goal is to engage industry and educators in developing a talent pipeline and initial curriculum addressing the material properties as well as optimization and manufacturing processes associated with lightweight materials at the high school and community college levels to meet emerging industry workforce needs in the manufacturing industry.
- Objectives
  1. Develop an introductory multi-disciplinary course featuring lightweight materials, optimization and manufacturing processes as they relate to the following technology areas: joining and fastening, additive and subtractive manufacturing processes, automotive testing and performance evaluation.
  2. Create professional development workshops related to lightweight materials and

processes for community college faculty and high school teachers.

Activities:

i. Develop and update one-day workshops for community college faculty and high school teachers.
ii. Offer annual workshops for faculty and teachers.

3. Establish a pipeline for high school to community college to university articulation
4. Participate with LIFT in developing a repository for available curricula addressing lightweight materials and manufacturing processes.

Workshop for high school teachers

1. Agenda

It was a one-day workshop, and the agenda is shown in Table 1.

Table 1 Workshop agenda.

Time	Topic	Subtopic	
9:00	Welcome		
9:30	Introductions	Overview: Who, What, Why	
		Lightweight Topics	Design
			Materials
			Manufacturing Processes
			Lifecycle
10:45	Lab Tour	Welding	
		Advanced Manufacturing	
		Automotive	
11:45	Lunch		
12:15	Software	Solid Thinking	
1:50	Wrap up		
2:00	Close		

2. Workshop lecture material

In the 75 minutes lecture, five main topics were discussed:

(1) Introduction to lightweighting. Three questions were asked, who, what, and why. Examples of products lightweight materials and design applied on were demonstrated for the first question, including the areas of automotive, wearables, aeronautics,

military, space exploring, medical, and consuming. In the “what” question, a list of methods and concepts to achieve lightweighting, such as using alternative materials, combining different materials, and removing materials, was introduced. The answers to the last question are sustainability, cost, and better product performance.

(2) Manufacturing. Several advanced manufacturing processes for lightweighting were introduced, including additive manufacturing (3D printing), composites manufacturing, multiple-axis machining (5 axis), and hybrid manufacturing systems. Videos and photos were represented for participants’ better understanding of the subject.

(3) Fastening. Threaded fasteners, adhesives, welding, and riveting are the fastening methods for lightweighting purposes. Many threaded fasteners such as screws, bolts, and clip nuts with different materials were introduced. Three types of adhesives for various uses, structural, semi-structural, and non-structural with several advantages of use of adhesives were represented. Similarly, types of rivets depending on the needs, such as strong joints, tight joints, and strong tight joints, as well as multiple rivet properties, including sizes, shapes (hollow or solid), and head shape thickness, were demonstrated. In addition, factors of welding (heat and pressure etc.) with different welding methods, such as percussion welding, friction welding (inertia welding), and dissimilar metal welding were discussed.

(4) Design. Basic design concepts were introduced, including form-fit-function, organic shapes, manufacturing processes, costs, materials, weight and structure optimizations, and lifecycles. Strategies to lightweight with structure optimization while maintaining part strength were emphasized. Traditionally structures like posts, ribs, trusses, gussets and hollows are used to reduce the weight, while wall thickness and usage of I-beams are also taken into consideration. By assistance of modern software structure, weight optimization can be achieved by using the following strategies: topology, lattice, and combining strategies. For example, Topology is regarded as “Swiss cheese effect” by cutting irregular shaped holes into the part at partial or full depth to minimize material, hence lightening the products overall weight. Lattice is hollowing the material interior to the “skin” of the material, as “Cardboard effect”. This design technique allows variation in the thickness of the lattice throughout the structure to optimize the mechanical structure of the part. Combining strategies utilize combinations of variation in part wall thickness, topology and integrated latticing.

(5) Materials. Ashby material selection chart (strength-density) was demonstrated and discussed. High strength steel and aluminum alloy were introduced, and composite materials were specifically addressed, whose types include polymer matrix composites (PMC's), metal matrix composites (MMC's), and ceramic matrix composites (CMC's).

Several fibers were introduced, such as glass fiber, aramid (Kevlar) fiber, carbon fiber, and other artificial and natural fibers. Fabric constructions (unidirectional, woven, hybrid, and chopped strand mat) and core material structures were demonstrated. In addition, mechanical and physical properties of composites were discussed and some manufacturing processes were represented. In the end, many examples of composite material applications were represented.

3. Lab tours

Three lab tours were arranged after the lecture. They are

(1) Autoclave Class / Lab:
Students' carbon fiber work and autoclave for Innovative Vehicle Design (IVD).

(2) Additive Manufacturing Classroom
3D printing facilities.

(3) Advanced Manufacturing Lab
5 axis machining CNC.

4. Software demonstration – solidThinking Inspire

solidThinking Inspire is a software allowing design engineers, product designers and architects to investigate structurally efficient concepts quickly and easily. This can lead to reduced costs, development time, material consumption, and product weight[14]. The software company representative, Jaideep Bangal, demonstrated the concepts and functions of Inspire. What follows is the outline of the representation.

- We all know additive manufacturing offers many benefits, some of these include design flexibility, on-demand production without tooling, lightweight production, less waste, short lead times, and more. However, just because we CAN produce something additively, does not mean we SHOULD. Producing current parts without modifications or specific design alterations can not only lead to more costly production, but can also minimize or even erase many of these benefits. Coupling Concept Generation/Optimization with additive manufacturing not only helps users to achieve the many benefits inherent with additive manufacturing, but can also help to amplify these benefits.
- We will discuss new methods of optimization that are helping companies achieve great success with additive manufacturing. Learn from our experts and see real-world examples of this being achieved today.
- Attendees will learn:

- Optimization and design methods helping companies take full advantage of additive manufacturing.
- How those designs can be much lighter, using less material while simultaneously being stronger and safer.
- Real-world case studies of companies producing optimized part.

Table 2 Questions of the pre-workshop survey.

Today's event is to make our surrounding community aware of what is happening in manufacturing on the topic of design, usage, alternative materials and manufacturing processes for lightweighting.
1. Are you familiar with activities in lightweighting in your local industry?
2. Are you using lightweighting in any materials you currently teach?
3. What is your hope to gain from today's event?

Workshop Evaluations

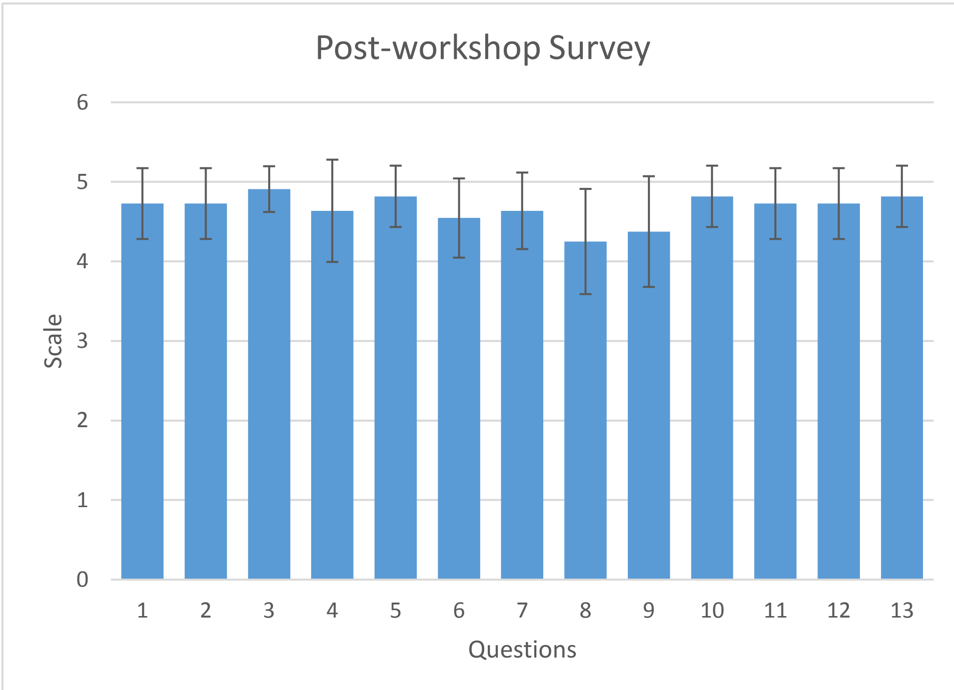
This workshop was evaluated by two surveys, one was taken before the workshop with three questions needed to be answered in descriptions, and the second was taken after the workshop forming on a five-point Likert scale with 5 being Strongly Agree and 1 being Strongly Disagree[15], as well as two questions for comments and suggestions. The questions of the pre-workshop survey are majorly for the participants' knowledge and expectation of the workshop, as shown in Table 2, and the questions of the post-workshop survey are listed in Table 3. The statistics results of the scaled question survey are summarized in Figure 1. In general, the responses are very positive, as supported by average scores ranging from 4.25 to 4.91 (out of 5).

Table 3 Questions of the post-workshop survey.

Category	Question
Instructor Methods	1. The Instructor provided and explained class outline or agenda.
	2. The instructor stated the learning objectives clearly.
	3. The instructor had the knowledge and information needed to teach.
	4. The instructor encouraged student interaction and questions.
Class Content	5. The class content followed the learning objectives.
	6. The class was taught in a way that helped me learn.
	7. The class was taught at an acceptable pace.
Training Materials	8. The student manual contained sufficient technical information.
	9. The student manual is formatted to be a useful reference document.

	10. The PowerPoint slides aligned with the content in the student manual
Learner Benefits	11. Were your expectations for attending the class met?
	12. The course information is useful for my current job assignment.
	13. I would recommend this class to others.
Comments	

Figure 1 Mean and standard deviation of the scaled questions of the post-workshop.



There were totally 11 participants in the workshop, where nine pre-workshop survey sheets and all post-workshop survey sheets were successfully collected. Although the answers of the three questions in the pre-workshop survey were expected to be descriptive, some useful information could still be inducted. Question 1 and 2 can be simplified to yes or no questions, and some opinions can be collected from question 3. Question 1 and 2 are related because being familiar with lightweighting is a prerequisite of using lightweighting materials in teaching. A summary of the pre-workshop survey is represented in Table 4, from which we learned participants' (high school teachers) knowledge of lightweighting and experiences of teaching related topics in class were little and consistent, and they hoped to obtain information of lightweighting from the workshop for their classes.

Table 4 Result analysis of the pre-workshop survey.

Pre-workshop Survey	Yes	No

Question 1	3	6
Question 2	4	5
Question 3	Better understanding of the topic, ideas for innovation, lesson plans to use in classes	

Although the post-workshop survey averages were high, there was an issue worthy to discuss. Three participants did not answer Problem 8 and 9 about the workshop manual/handouts. Actually, slides and other files were loaded in flash drives and distributed to the participants in the beginning of the workshop, however they were not available to the participants during the workshop because USB outlets are needed and not usually equipped on cell phones and tablets. Therefore, printed handouts still show their advantages and should be provided in the following workshops to improve the learning efficiency.

Comments/suggestions in the post-workshop survey were all positive, and the constructive ones appeared more than once are summarized in Table 5. They are basically expectations of the participants (high school teachers) for activities in future similar workshops, such as field trips or boot camps for their students to try 3D printing, welding, and CNC machining, as well as use carbon fiber composites to build car bodies. These ideas can be reasonably assumed as the effectiveness of lab tours in the workshop. Therefore, including high school students and developing hands-on practices will be the emphasis in future high school level workshops.

Table 5 Summary of the comments of the post-workshop survey.

Post-workshop Survey Comments / Suggestions	Frequency
Field trip for students to access 3D printers	3
Field trip/boot camp for students to practice welding and CNC	3
Boot camp for students to use carbon fiber to build car bodies for IVD	3
Software training for 3D models and lightweight design	2

Planning of Future Workshops

The next workshop will be designed for community college faculty and the course materials will be basically enhanced. The experiences of this work are expected to improve the coming event. The planned topics and the comparison with this workshop is remarked in the following table:

The next workshop topics	Comparison with this workshop
Types of Lightweight Materials	
• Advanced high strength steel	• Basic mechanics will be reviewed

• Aluminum alloy • Magnesium alloy • Composite materials • Others	• Further information of mechanical properties and material types of all the materials will be represented. • Magnesium alloy is an additional topic
Applications of Lightweight Materials in Industry	
• Ground transportation • Aerospace • Consumer products • Medical devices • Military and defense • Costs	• More examples of applications in all area with detailed technical information will be provided • Costs of applying lightweight materials will be specifically addressed
Lightweight Design	
• Design optimization for lightweight • Structural material and joining methods • Case studies • Additive manufacturing (3D Printing) • Demonstration of solidThinking Inspire and other software	• Design, structure, and joining methods will be systematically studied • Case studies are additional and will provide students practical examples • 3d printing will be specifically addressed • Additional software will be introduced
Laboratory Tour and Demonstration	
• Lab tour of community college facilities • Demonstrations	• More hands-on practices will be included

Conclusion

This project recognized an emerging and imminent need for employees equipped with skills in advanced manufacturing and automotive technology in lightweight materials and design. 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 addresses the critical need to teach and train the high school teachers and college faculty who will pass that knowledge on to their students. Finally, this project tackles the sustainability of the advanced manufacturing industry by facilitating engagement and recruitment of youth into the talent pipeline.

We present in this paper our efforts and current progress of introducing lightweight technologies to the teachers by holding workshops and lab tours. A first workshop targeting high school teachers was delivered, where the outcome was accessed by surveys and the overall results were positive with scaled averages ranging from 4.25 to 4.91 (out of 5.00). Although it was successful, there is still space to make improvements. We are recently planning and developing lectures for the next workshop, targeting community college faculty to promote lightweight materials and design. It will focus more on theoretical aspects of the properties of lightweight materials with detailed technical information. The activities in the coming workshop will not limited to lab touring, instead, lab demonstrations and hands-on participating will be arranged. Certainly, the experiences and lessons we obtained from the first workshop will be applied in the following events, to make the program stronger and encourage more students to pursue advanced studies and careers in the growing lightweighting industry.

Acknowledgements

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