Filling the Skills Gap in U.S. Manufacturing

Promoting Internships and Co-Op Experiences and Integrating Industrial Engineering Courses to Improve Student Design and Manufacturing Knowledge

Paul Lynch and Faisal Aqlan
Department of Industrial Engineering
Penn State Behrend
Erie, PA 16563 USA
emails: PCL120@psu.edu, FUA11@psu.edu

***Abstract*—This paper discusses a framework for filling the skills gap in U.S. manufacturing by providing undergraduate students with practical experiences in design and manufacturing. The proposed framework is based on integrating product design and manufacturing processes courses through practical course projects. In addition, an initiative has been taken to establish collaboration between academia and industry by the manufacturing faculty in industrial engineering at Penn State Behrend. The paper also presents the involvement of the IE faculty in developing the design and manufacturing skills of the IE students. Data was collected through surveys and is used to validate the proposed framework.**

Keywords*— *Industrial Engineering; Product Design; Product Manufacturing; Teaching; Internship

I. BACKGROUND AND MOTIVATION

The work carried out in this paper focuses on a holistic approach being taken to attract, educate and train industrial engineering students to fill the technical skills gap that exists in various manufacturing industries. This approach combines curriculum changes and pedagogical changes to a product design course and a manufacturing processes course. In addition, the instructors are working with local manufacturers to provide internship and co-op opportunities to help improve efficiencies and competitiveness of the local manufacturing community while training the next generation of industrial and manufacturing engineers to work in manufacturing.

The project based, active learning pedagogical changes made to the manufacturing courses were taken from the experiential-learning theory (ELT) where Baker, Jenson, and Kolb recommend a procedure that moves students through a four-stage process of: experiencing, reflecting, abstracting, and acting [1]. The incorporation of case studies and projects in the classroom is one method of simulating experiencing, reflecting, abstracting, and recommending actions based on the real world scenario depicted by the case. Additionally, engineering education literature has continuously shown that collaboration with industry on projects can be helpful for undergraduate and graduate students, even the processes of soliciting, administering, and managing industry projects that reinforce academic topics in engineering, technology, manufacturing, project management, lean, and six sigma [2-6]. Other topics that are reinforced include professionalism (through interaction with industry), teamwork, and leadership [7]. Formally, these projects are also often assessed as students work to meet the established learning outcomes [8].

In addition to the curriculum and pedagogical changes made to these manufacturing courses, an emphasis is put on educating students on the ample career opportunities that exist in manufacturing today. The manufacturing industry is still a significant and viable career opportunity for industrial engineers in the United States of America (USA). In 2013, the manufacturing industry accounted for 12% of the Gross Domestic Product (GDP) for within the United States [9]. Furthermore, for every $1.00 spent in manufacturing, another $1.37 is added to the economy, which is the highest multiplier effect of any industry [10]. In 2013, there were approximately 17.6 million jobs in the USA that the manufacturing industry directly supported [11]. Also in 2013, the average manufacturing worker earned $77,506 in salary and benefits, which is an increase of 24% over the average worker in all industries ($62,546) [12]. By itself, the manufacturing industry sector in the USA would be the 9th largest economy in the world [13].

Unfortunately, a number of future engineers have learned or developed incorrect assumptions and stereotypes regarding the manufacturing industry. Students are under the impression that manufacturing is a floundering industry in the USA and there are limited jobs and limited job growth potential. However, this is an incorrect, and perhaps devastating, misconception. To further compound the problem, there is a skills gap with the baby boomer generation retiring and a shortage of available workers. For example, in a 2011 survey of 1,123 manufacturing executives 67% of respondents reported a moderate to severe shortage of available and qualified workers, which included 60% stating they were experiencing a moderate to severe shortage of industrial engineers, manufacturing engineers, and/or planners. The survey indicated that within the manufacturing sector there are approximately 600,000 open jobs due to a lack of a qualified and available workforce [14].

The manufacturing industry is looking for ways to shrink the skills gap by partnering with universities, community colleges, and certification providers. In a report co-authored by Deloitte and the Manufacturing Institute entitled "Boiling Point? The Skills Gap in U.S. Manufacturing," it was noted that the lacking skills in college graduates to the manufacturing workforce are those that have the most impact on operations and require the most technical training [15]. The manufacturing industry (which relates to many other industries) is very heavily impacted by students moving away from STEM fields, as the companies and manufacturers are unable to fill technical positions. This manufacturing issue must be fixed within the engineering classrooms across the United States by offering more manufacturing exposure to students in the classroom. A paper in the *Journal of Engineering Education* notes that a movement to move to higher course content on manufacturing in both industrial and mechanical engineering is needed [16]. Many current engineering programs do not emphasize the marriage of design and manufacturing in a modern industrial technical workforce.

Many research studies have assessed the quality of exposure to manufacturing through the senior "Capstone" design project course. McMasters and Lang believe that too few in industry have an understanding of how the current engineering education is set-up. Therefore, if industry partners are brought into the education process through design projects, the education provided to students can be better adapted to reflect the expectations of industry. It is important to define what the industry wants and needs for the current engineering programs [17]. Many universities are exposing students to manufacturing through senior capstone design courses to offer students with a realistic perspective of industry needs.

Manufacturing work has become increasingly more technical to the point where engineers and very highly skilled technicians are needed to fill these positions. However, even the students coming out of strong industrial and manufacturing engineering programs are being seen as lacking important manufacturing skill sets. Industry leaders have brought this to the attention of ABET, the accreditation body that sets the global standard for these engineering programs. Going forward, engineering programs in the U.S. will be forced to implement curriculum changes to address the growing need to develop skills in design for manufacturing.

II. Introduction

An innovative approach is being taken within the industrial engineering program at Penn State Behrend. University leaders, along with business and industry leaders collaborated to create a brand new, state of the art Advanced Manufacturing and Innovation Center. Half of the space will be occupied by industrial tenants, where shared research space will encourage manufacturing research collaboration between industry professionals, faculty, and students. At Penn State Behrend, an approach is being taken by industrial engineering faculty members to integrate product design and manufacturing processes topics across two required industrial engineering courses for students to be able to see a product through the design, design for manufacturing, and manufacturing stages. The first course covers topics in product design, specification, and measurement while the second course specializes in design for manufacturing and manufacturing processes. The two courses are integrated through comprehensive course projects that cover both product design and manufacturing, allowing students to enhance their design and design for manufacturing skill sets. Students first design specific products assigned by the course instructors and then have an opportunity to model and carry out manufacturing within the school's additive manufacturing and traditional manufacturing lab. In the future, students will be able to carry out their work in the Advanced Manufacturing and Innovation Center.

The bottom line in today's business environment is that manufacturers need engineers and technicians to be able to step into the manufacturing facility and add value from day one. For this reason, the manufacturing training cannot stop in the classroom and laboratory. The course instructors are very active with the local manufacturing community. The local manufacturers are an integral part of providing manufacturing co-op and internship experiences for the students. The instructor of the manufacturing processes course worked in Industrial Engineering at Penn State University Park prior to transitioning to Penn State Behrend for the 2015-2016 school year. This is the reason data is reported from Penn State University Park from 2014 and 2015 and Penn State Behrend from 2016. In 2014, out of the 50 industrial engineering students at Penn State University Park that responded saying they looked for a summer internship or co-op opportunity, 48 of the students were successful in securing such an experience. 66.67% of the students (32 out of 48) said that the experience was with a manufacturing company. In 2015, out of the 50 industrial engineering students at University Park that responded saying they looked for a summer internship or co-op opportunity, 41 of the students were successful in securing such an experience. 43.9% (18 out of 41) said that the experience was with a manufacturing company. At the time of the writing of this paper in Spring 2016, out of the 21 industrial engineering students at Penn State Behrend that responded saying they looked for a summer internship or co-op opportunity, 15 of the students were successful in securing such an experience. 93.3% (14 out of 15) said that the experience was with a manufacturing company.

III. Related Literature

As manufacturing employers cut back workforces and outsourced manufacturing jobs to lower cost nations in an effort to improve financial statements and stock price, a United States manufacturing "brain drain" was being made increasingly worse. As a result of this new way of doing business, manufacturing skills were not being passed down through apprenticeship programs to the next generation of manufacturing employees. As the current workforce in manufacturing approaches retirement, the skills gap is becoming increasingly wider. Today, manufacturing companies rely on technical institutions and universities to produce manufacturing employees that can contribute on day one. One of the only ways of getting young industrial engineers real life experience is through internships and co-op experiences while they are completing their degree programs. There are a number of articles in the engineering education literature that are supportive of internships, cooperative (co-op) education programs, and manufacturing education. The University of Cincinnati has been operating a cooperative education program since 1906. A course at the University of Cincinnati is offered to students to introduce students to the co-op experience. Course topics include professional development skills, job search skills, interview preparation, workforce representation, and preparation. Results have shown that this specific course has had a positive impact for students as they entered the cooperative education workforce [18]. At Texas A&M University, a similar study found that internships can be a positive experience for both the student and the employer, but it is extremely important for the internship experience to be structured with clear communication of expectations at the beginning of the internship between the student and the sponsoring organization [19].

More recently, the "four pillars" of manufacturing have been a focal point of researchers looking for ways to educate the next generation of manufacturing engineers. The "four pillars of manufacturing knowledge" was developed and is maintained by the Society for Manufacturing Engineers [20, 21]. The four pillars of manufacturing knowledge consist of: Materials and Manufacturing Processes; Product, Tooling and Assembly Engineering; Manufacturing Systems and Operations; and Manufacturing Competitiveness. Since the four pillars of manufacturing knowledge was only rolled out in the past few years, there has only been limited used to date to evaluate the existing curricula of university courses. The four pillars of manufacturing have been used to identify various engineering programs in Michigan with mechanical engineering degrees or concentrations in an effort to align course outcomes with those of a manufacturing processes course. Furthermore, the literature shows how these various programs are meeting or not meeting the recommendations of the four pillars, with recommendations to align the university program with the four pillars by recommending different course content for addition and subtraction to the manufacturing processes course (e.g., additional lecture for nanotechnology, subtraction of a lecture for costing and finishing) [20]. The Society of Manufacturing Engineers recommends promoting the wide availability of "creative, high-tech" jobs that can be found in manufacturing careers [15]. Students can be motivated to pursue a certain career path if they see the value and need for skilled engineers. Internships are often useful for students to experience a facet of industry and learn the skills needed to be a manufacturing engineer

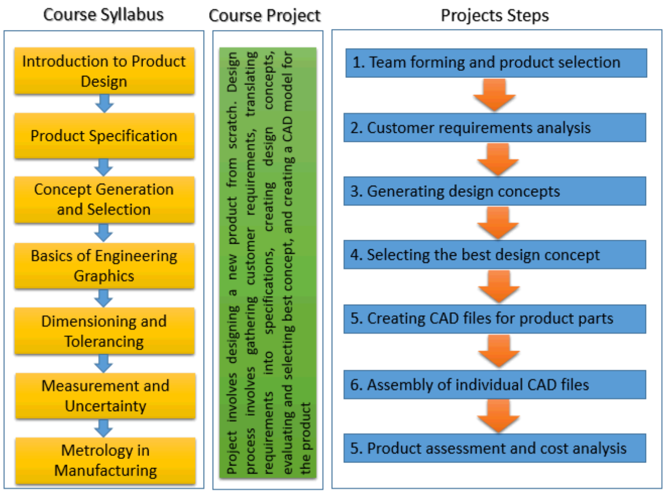
For the educational institutions, aligning product design and manufacturing education with market needs is very important to overcome these skill gaps and the challenges faced by students when they graduate and start working in industry. Several examples can be found in the literature where approaches were used by researchers to integrate teaching and practicing to improve student knowledge. For example, the contents of different Industrial Engineering areas (such as materials, manufacturing, design, etc.) were integrated to allow students to enhance their transversal skills [22]. The integration and analysis included all aspects regarding technical and economic feasibility, and manufacturing optimization of the product. The effects of product design projects on student's innovation and entrepreneurial skills was discussed [23]. Teaching initiative and entrepreneurial skills is as essential as design skills for design students to survive in today's business world [24]. A review of some existing frameworks on Engineering Education was conducted by [25] in order to identify improvement opportunities. Including the product design process and inviting principles into the engineering curriculum can improve the economy and technology growth [25]. Applying the 'designing with users' notion instead of 'designing for users' into a practice in the education field was introduced by [26] to benefit experts and satisfy user expectations. Two design projects were conducted where groups, each consisting of students and users, were formed to design products according to project briefs. Teaching sustainability to students by considering school building design as an example was discussed in [27]. In order to leverage the manufacturing learning and training, an integrated module using a Teaching Factory concept was proposed [28]. An evaluation of the simulation games used in teaching engineering and manufacturing was discussed in [29]. Two simulation games are considered: Cosiga, a new product development simulation game and Beware, a risk management simulation game. Evaluation results of the two games showed that effective learning outcomes can be delivered as a result of the simulation games. In [30], a proposed scheme for teaching creative design by incorporating augmented reality (AR) technology was presented. Teaching model design and manufacturing based on a running united college-enterprise was introduced in [31].

This study presents a unique paradigm for integrating design and manufacturing skills. Two industrial engineering courses are integrated through practical course projects. The study also discusses initiatives for collaboration between academia and industry at Penn State Behrend. Furthermore, the study presents the active Industrial Engineering faculty involvement in developing the design and manufacturing skills of IE students both inside and out of the classroom and manufacturing laboratory.

IV. LEARNING MODULES

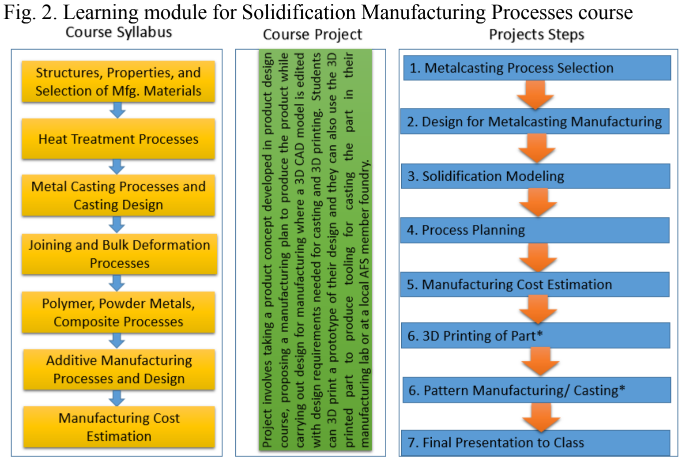
Individual and integrated learning modules were designed to assess the student's learning of design and manufacturing skills. Figure 1 shows the learning module for IE 305: Product Design, Specification and Measurement which includes the course syllabus, course project, and detailed steps for the course project. The 15-week course aims to provide an introduction to product design with an emphasis on the tools, standards and methods used for product and part representation, specifications and measurements. It involves hands on learning and exercises in CAD and metrology laboratories. The class involves lectures, quizzes, laboratory reports and assignments, a CAD modeling project, exams, and in-class participation. The course content covers three main parts: product design and specification, dimensioning and tolerancing, and metrology. Product design and specification focuses on the product design process and basics of engineering graphics including CAD modeling. The dimensioning and tolerancing module covers details related to dimensioning basics and tolerance models as well as Geometric Dimensioning and Tolerancing (GD&T). The metrology part covers all aspects of measuring the product and calculating uncertainties. The course also includes two internal labs, a CAD lab and metrology lab. Each week, the students are subject to (2) 50-minute classroom lectures and (1) 115-minute laboratory experience. There are 15 lab meetings, 10 for CAD lab and 5 for metrology lab.

Fig. 1. Learning module for Product Design course



After successful completion of the IE 305 course, students must take IE 311: Solidification Manufacturing Processes to satisfy their manufacturing processes course requirement. Figure 2 shows the learning module for the IE 311 course. Each week, the students are subject to (2) 50-minute classroom lectures and (1) 115-minute laboratory experience in the manufacturing laboratory at Penn State. The objectives of the course are to introduce industrial engineering students to the theory, principles, mechanisms, and concepts of solidification / additive manufacturing processes for materials, emphasizing process selection and the effects of process capabilities and limitations on design, costs, and quality. The course includes lectures, laboratories, manufacturing plant tours, demonstrations, videos, extension readings, and homework problems. The main course topics covered in the course are material structures, mechanical testing and properties, metal casting processes, joining processes, polymer processes, solid state deformation processes, advanced / additive manufacturing processes, and manufacturing process cost estimation. The course manufacturing project is a culmination of the knowledge gained in IE 305 and IE 311.

Fig. 2. Learning module for Solidification Manufacturing Processes course



V. CASE STUDY

The case study presented in this section represents a course project that was considered in both courses, IE 305 and IE 311. In IE 305, the course project required students to design the CAD model of the product. In IE 311, students used the CAD model to design the product for manufacturing by casting processes. The following two subsections discuss in detail the two steps for product design and manufacturing.

A. *Phase I: Product Design*

One sample course project is presented in this section. The project involved designing a mirror for motorcycles (see Figures 3 and 4). The product design processes involved gathering and analyzing customer mirror requirements, generating and prioritizing design concepts, and building final CAD models for the best concept. The idea behind the new design concept is to provide a new adjustable motorcycle mirror that more closely mimics the design and function of an adjustable mirror on an a car. Like an automobile mirror, this motorcycle mirror design may be adjusted inside the case itself, meaning that the case is stationary while the mirror glass itself is adjusted to provide an optimal view for the driver. The mirror glass is glued onto a thermoplastic adjustment piece with a large flat circular piece a little larger than the diameter of the mirror glass. On the back of this cylinder is a rod that has a sphere on the end of it. The rod with the sphere is placed in a threaded cast on the inside of the mirror case that also acts as the hole where the case is screwed onto the bolt on the base. When the mirror is tightened, it pushes against the sphere on the adjustment piece, holding it in place. This acts as an effective and easy tightening mechanism on the mirror. Having the mirror inside the case and not keeping the motorcycle mirror as a single piece allows the case to protect the mirror from the wind loading it will see. Since the case is screwed onto the mirror, this created a problem with the wind force on the case possibly loosening the case and therefore allowing the mirror to move, even possibly letting the entire case fall off altogether. This was solved by creating a slope, opposite sloping on either side, that allows the wind force to help tighten the case, eliminating the potential of the mirror moving or the case falling off. The base is a cylindrical shape that is curved so the end is parallel with the handlebar of the bike. At the bottom is a bolt that screws into the hole already in the handlebar. The overall design creates a solid mirror that won't move when in motion and can be easily tightened by the user. The only downside to the design is that the adjustment design forced the mirror case to be slightly longer than wanted, leading to a slightly bulky look. The adjustment piece is made out of a thermoplastic, the same material that car bumpers are made of, so that it doesn't break easily. The case and base are both made of steel with a chrome finish for added aesthetics. This design is a little costly, but solid and durable. The description of main components of the mirror is shown in Table 1. The designs of the components are shown in Figure 3. The final mirror assembly is shown in Figure 4.

TABLE I. MAIN COMPONENTS OF MOTORCYCLE MIRROR

Part #	Part Name	Material	Description
1	Base	Steel (chrome finish)	Connects case to bike and holds it in place
2	Case	Steel (chrome finish)	Holds mirror glass in place
3	Adjustment	Steel (chrome finish)	Allows rider to move, adjust mirror
4	Mirror Glass	Steel (chrome finish)	Allow rider to see behind

Fig. 3. Main componentes of the motorcycle mirror

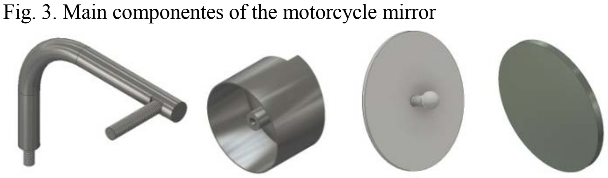


Fig. 4. Final assembly of the motorcycle mirror

B. *Phase II: Product Manufacturing*

The IE 311 Solidification Manufacturing processes course goes in depth into metal casting processes, process capability, and critical metal casting design requirements. The main metal casting design concepts that students need to understand to be able to take the 3D model produced in IE 305 and design for manufacturing in IE 311 are the concepts of draft/ taper and design for minimizing solidification shrinkage. Students first need to add draft and taper to their IE 305 solid model, and later, they are required to carry out solidification modeling in an effort to design the casting configuration to minimize hot spots and microporosity. Figures 5 and 6 show the output of the Critical Fraction Solid point for casting part 1 and part 2 using a metal casting process. The Critical Fraction solid point is the point at which hot liquid metal can no longer be fed in the casting.

Fig. 5. SolidCast Solidification Model of Base.

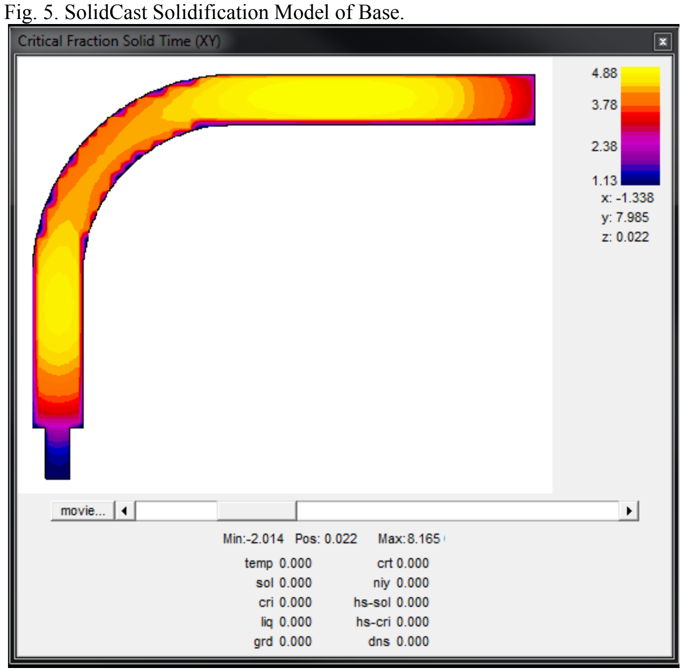
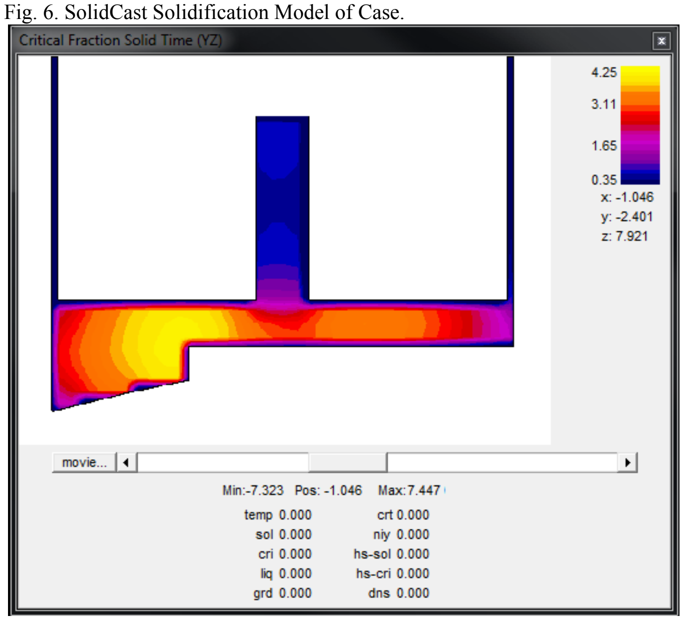


Fig. 6. SolidCast Solidification Model of Case.



In addition to the curriculum modifications mentioned to give students real life design and manufacturing training in the classroom, the manufacturing faculty members are working closely with the manufacturing community around this campus and across the state of Pennsylvania to bring industry leaders, faculty, and students together. The first step in the process of filling the manufacturing skills gap is informing students about the promising manufacturing careers in their own backyard.

VI. Perception of Manufacturing

In a Spring 2014 survey of industrial engineering students at Penn State University Park, students were asked an open ended question about what their perception of manufacturing was before taking the solidification manufacturing processes course. One half of the students (28 out of 56) responded to this question and the responses are found in Table 2 below [32].

TABLE II. RESPONSES FOR STUDENT PERCEPTION OF MANUFACTURING

(4) Manufacturing is for making or producing goods through processes
(3) No Idea
(3) Worked in Manufacturing Company on Internship
(3) High production factories or on the floor at a facility
(2) Making products in a high volume, efficient or cheap manner
(2) Lots of machines, dirty work
(1) Manufacturing is an important branch in industry
(1) Manufacturing "was" an important part of today's world
(1) Manufacturing is a good field to pursue
(1) Production lines such as Ford's assembly lines
(1) Operations that occur after a piece is made
(1) The scope and design of manufacturing processes
(1) Production when materials are already supplied
(1) Making some stuff with different machines
(1) Mainly a hands-on field that requires working with many different machines and people
(1) Materials and Processes
(1) There are different types of manufacturing

37.5% of the students (21 out of 56) said they had no knowledge or very little knowledge of manufacturing processes before taking the solidification processes course. 60.7% of the students (34 out of 56) said they had some basic knowledge while only 1.8% of the students (1 out of 56) said they had a strong knowledge base of manufacturing processes prior to taking the solidification processes course. Prior to taking the solidification processes course, over 41% of the students (23 out of 56) said they would not have ever considered a career in manufacturing. The remaining 59% of the students (33 out of 56) said they would have considered a career in manufacturing prior to taking the course. After taking the course, only 12.5% of the students (7 out of 56) said they would not consider a career in manufacturing. The remaining 87.5% of the students (49 out of 56) said they would consider a career in manufacturing after taking the solidification processes course. By taking the solidification processes course, the number of students that would consider a career in manufacturing increased by 28.5%. All 56 of the students (100%) said that after taking the solidification processes course, they feel as though it is important for industrial engineering students to have a strong working understanding of manufacturing processes. A positive learning experience in a manufacturing course can be an effective means of getting students interested in manufacturing. Getting students exposure to manufacturing leaders and manufacturing tours along with internship and co-op experience in manufacturing is the focus of the manufacturing instructors to get young, talented engineers into the U.S. manufacturing workforce.

VII. Faculty and Industry Involvement

The instructor of IE 311: Solidification Manufacturing Processes is the Materials and Manufacturing Group (M.M.G.) faculty adviser at Penn State Behrend. The Materials and Manufacturing Group encompasses the student chapter of the American Foundry Society (AFS) and the Association for Iron and Steel Technology (AIST). The instructor of the IE 305: Product Design, Specification and Measurement is the Institute of Industrial and Systems Engineers (IISE) faculty adviser. This past school year was the first year for both student groups at Penn State Behrend. M.M.G. and IISE collaborate on manufacturing tours, and students attend monthly local Northwestern PA AFS meetings with manufacturing leaders. Both faculty members have undergraduate researchers working with them on manufacturing and design related projects. In addition, the industrial engineering faculty members at Penn State Behrend have been working closely with both local manufacturing companies and also the Northwest Industrial Resource Center (NWIRC) in Erie. The NWIRC offers an Advanced Manufacturing Apprentice Program that is designed to meet the technology development and implementation needs of small-and medium-sized manufacturers in northwest Pennsylvania. The program is designed to help match qualified STEM majors from colleges and universities along with students from technical trade school with manufacturers in the northwest Pennsylvania region [33]. This program has helped the local manufacturers make it affordable to hire engineering interns because the Advanced Manufacturing Apprentice Program subsidizes the manufacturing engineering intern's wages up to 40%. Prior to this school year, NWIRC and local industry leaders were working independent from the industrial engineering faculty. After connections were made this past school year, NWIRC, local industry, and the industrial engineering faculty members are now all working together to help place engineering students in manufacturing internships in the Erie region. It is critical for the small and medium size manufacturers to attract talented engineers and it is important for engineering students to gain on the job internship experience prior to searching for full time positions. The industrial engineering students at Penn State University Park and now at Penn State Behrend have been very successful in obtaining summer internship and co-op opportunities.

VIII. Internship and Co-op Job Placement

In 2014, out of the 50 industrial engineering students at Penn State University Park that responded saying they looked for a summer internship or co-op opportunity, 48 of the students were successful in securing such an experience. 66.67% of the students (32 out of 48) said that the experience was with a manufacturing company. In 2015, out of the 50 Penn State University Park industrial engineering students that responded saying they looked for a summer internship or co-op opportunity, 41 of the students were successful in securing such an experience. 43.9% (18 out of 41) said that the experience was with a manufacturing company. At the time of the writing of this paper in Spring 2016, out of the 21 Penn

State Behrend industrial engineering students that responded saying they looked for a summer internship or co-op opportunity, 15 of the students were successful in securing such an experience. 93.3% (14 out of 15) said that the experience was with a manufacturing company. Additional industrial engineering students were interviewing with local manufacturing companies at the time this paper was written.

IX. ADVANCED MANUFACTURING AND INNOVATION CENTER

The Fall 2016 semester at Penn State Behrend will mark the first semester of education and research collaboration between faculty, staff, students, and corporate tenants under one roof. The $15.6 million Advanced Manufacturing and Innovation Center (AMIC) covers 60,000 square feet of space and house eight classrooms and twenty-five faculty offices, Figure 7. Half of the building will be occupied by students, faculty, and staff while the other half of the building will be home to corporate tenants that will have access to the school of engineering's labs and equipment. The intention of this "open lab" initiative is to bring together students, faculty members, and business leaders to support the training and growth of manufacturing in the Erie region. Students taking the IE 305 and IE 311 classes discussed earlier will have the opportunity to work directly with corporate employees to solve real world problems under the same roof as part of the open lab concept. Students will also have access to these manufacturing companies for internship, co-op, and full time job placements.

Fig. 7. Advanced Manufacturing and Innovation Center (AMIC)

X. CONCLUSIONS AND RECOMMENDATIONS

In order to develop design and manufacturing knowledge and enhance the creative and practical skills of IE students, the course material and delivery need to be reviewed and continuously improved. Design and manufacturing courses should be integrated and enhanced to meet the requirements of the dynamically changing manufacturing industry. This study proposed a framework for integrating design and manufacturing knowledge to enhance students' skills. Survey data showed that most of the students who experience this integrated design-manufacturing learning framework were able to find internships and jobs in manufacturing. The faculty involvement in design and manufacturing applied research and collaboration with industry as well as advising students groups has contributed to the manufacturing skills development among IE students. The establishment of the Advanced Manufacturing and Innovation Center will provide more opportunities for incorporating industry projects into the courses.

ACKNOWLEDGMENTS

The authors would like to thank Adam Riddle, an undergraduate IE student at Penn State Behrend, who was involved in developing the CAD and casting models for the course project.

REFERENCES

[1] A.C. Baker, P.J. Jensen, D.A. Kolb, "Conversation Learning: An Experiential Approach to Knowledge Creation," Greenwood Publishing Group, Quorum Books, Westport, CT, p.52, 2002.

[2] J. Darrell Gibson, M. Patricia Brackin, "Techniques for the Implementation and Administration of Industrial Projects for Engineering Design Courses," *Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition.*

[3] James Noble, "An Approach for Engineering Curriculum Integration in Capstone Design Courses," *International Journal of Engineering Education*, 14(3), 197-203, 1998.

[4] Ana Vila-Parrish, Dianne Raubenheimer, "Integrating Project Management & Lean-Six Sigma Methodologies in an Industrial Engineering Capstone Course," *Proceedings of the 2012 American Society for Engineering Education Annual Conference & Exposition.*

[5] John Lamancusa, Jens Jorgensen, Jose Zayas-Castro, Julie Ratner, "THE LEARNING FACTORY – A new approach to integrating design and manufacturing into engineering curricula," *Proceedings of the 1995 American Society for Engineering Education Annual Conference & Exposition.*

[6] R.S. Sawhney, S. Maleki, J.H. Wilck, P. Hashemian, "Center for Productivity Innovation's Student Project with Industry Program at the University of Tennessee, Department of Industrial and Systems Engineering," *INFORMS Transactions on Education*, 13(2), 83-92, 2013.

[7] Alan Dutson, Robert Todd, Spencer Magleby, Carl Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses," *Journal of Engineering Education*, 86(1), 17-28, 1997.

[8] Paul Kauffman, Gene Dixon, "Vetting Industry Based Capstone Projects Considering Outcome Assessment Goals," *International Journal of Engineering Education*, 27(6), 1231-1237, 2011.

[9] Bureau of Economic Analysis, Industry Economic Accounts, http://www.bea.gov/iTable/index_industry_gdpIndy.cfm, (Accessed, 2015).

[10] Bureau of Economic Analysis, Industry Input-Output Tables, http://www.bea.gov/iTable/index_industry_io.cfm, (Accessed, 2015).

[11] Bureau of Labor Statistics, Current Employment Statistics, http://www.bls.gov/ces/, (Accessed, 2015).

[12] Bureau of Economic Analysis, National Economic Accounts by Industry, http://www.bea.gov/iTable/index_nipa.cfm, (Accessed, 2015).

[13] Bureau of Economic Analysis, via Industry Economic Accounts and International Monetary Fund, http://www.bea.gov/iTable/index_industry_gdpIndy.cfm, (Accessed, 2015).

[14] Roadmap for Manufacturing Education, The Manufacturing Institute, December 2012.

[15] "Workforce Imperative: A Manufacturing Education Strategy." Society of Manufacturing Engineering. N.p., n.d. Web. 30 Jan. 2015.<http://www.sme.org/WorkforceImperative/>.

[16] Todd, Robert H., W. Edward Red, Spencer P. Magleby, and Steven Coe. "Manufacturing: A Strategic Opportunity for Engineering Education."

[17] McMasters, James H., and James D. Long. "Enhancing Engineering and Manufacturing Education: Industry Needs, Industry Roles." Proc. of American Society for Engineering Education Annual Conference and Exposition, Anaheim, CA. N.p.: n.p., 1995. 177-86 Web. 30 Jan. 2015.

[18] Watson, J., Schomaker, M.G., “Introduction to Cooperative Education-The Course,” Proceedings of the 2014 American Society for Engineering Education Annual Conference & Exposition, 2014.

[19] Rangan, S., Natarajarathinam, M., “How to structure an internship that is great for the intern and the manager?,” *2014 American Society for Engineering Education Annual Conference & Exposition*, 2014.

[20] Ermer, G.E., “The Four Pillars of Manufacturing as a Tool for Evaluating Course Content in the Mechanical Concentration of a General Engineering Curriculum,” *2014 American Society for Engineering Education Annual Conference & Exposition*, 2014.

[21] Four Pillars of Manufacturing Knowledge, SME.ORG/FOURPILLARS, (Accessed, 2015).

[22] M. San-Juana, M. del P. de Tiedraa, O. Martína, F. J. Santosa, R. Lópeza, R. Suáreza, and R. Mahillo-Islaa, “An Experience in Integrated Knowledge about Manufacturing Technologies for Students of the Grades of Industrial Engineering,” Procedia Engineering, vol. 132, 221 – 227, 2015.

[23] R.J. Odora, “Integrating Product Design and Entrepreneurship Education: a stimulant for enterprising Design and Engineering students in South Africa,” Procedia Engineering, vol. 20, 276 – 283, 2015.

[24] S. Gunes, “Design Entrepreneurship in Product Design Education,” Procedia - Social and Behavioral Sciences, vo. 51, 64 – 68, 2012.

[25] J.O. Mahmud, M.S. Mohd Ismail, and J. Mohd Taib, “Engineering Education and Product Design: Nigeria’s Challenge,” Procedia - Social and Behavioral Sciences, vol. 56, 679 – 684, 2012.

[26] Z. Yalmana, and H. G. Yavuzcana, “Co-Design Practice in Industrial Design Education in Turkey A Participatory Design Project,” Procedia - Social and Behavioral Sciences, vol. 197, 2244 – 2250, 2015.

[27] B.G. Tascıa, ““Sustainability” Education by Sustainable School Design,” Procedia - Social and Behavioral Sciences, vol. 186, 868 – 873, 2015.

[28] L. Rentzos, M. Doukas, D. Mavrikios, D. Mourtzis, G. Chryssolouris, “Integrating Manufacturing Education with Industrial Practice using Teaching Factory Paradigm: A Construction Equipment Application,” Procedia CIRP, vol. 17, 189 – 194, 2014.

[29] J.B. Haugea, and J.C. Riedelb, “Evaluation of simulation games for teaching engineering and manufacturing,” Procedia Computer Science, vol. 15, 210 – 220, 2012.

[30] X. Wei, D. Weng, Y. Liu, and Y. Wang, “Teaching based on augmented reality for a technical creative design course,” Computers and Education, vol. 81, 221 – 234, 2015.

[31] W. Hong, “Teaching Reform and Practice of Mold Design and Manufacture Course Based College-Enterprise United Running,” Procedia Engineering, vol. 15, 132 – 136, 2011.

[32] Lynch, P.C., Bober, C.A., Wilck, J.H., “Educating and Training the Next Generation of Industrial Engineers to Work in Manufacturing,” *2015 American Society for Engineering Education Annual Conference & Exposition, 2015.*

[33] NWIRC Advanced Manufacturing Apprentice Program, http://www.nwirc.org/services/manufacturing-technology-acceleration/advanced-manufacturing-apprentice/, (Accessed April 2016).