The Integration of Hands-On Manufacturing Processes and Applications within Engineering Disciplines

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Abstract

Current engineering graduates are highly knowledgeable within their specific academic disciplines regarding the application of finite element analysis and parametric solid modeling software in pursuit of prototyping and simulating theoretical product designs. However, it would appear that many engineering students are not receiving adequate exposure to the actual fundamental hands-on manufacturing processes, concepts and practices, thus resulting in the continuation of a knowledge gap between entry level engineering graduates and the production, fabrication and manufacturing processes being practiced by their industry employers. This gap ultimately leads to a greater learning curve for the newly hired engineers and a longer time span before their company can begin to see economic benefits from their productivity. By incorporating a more practiced based course related to actual manufacturing processes and applications, engineering students will recognize a direct link between their course work and the on-the-job tasks being performed within the engineering and manufacturing work environment. These processes will also enhance the student's abilities to truly participate in the current "design for manufacturability" (DFM) processes that are currently in practice in today's competitive global marketplace.

Employers are not the only group interested in seeing more hands-on manufacturing processes being developed; students are also voicing their concerns. An increasing number of students are indicating a desire to have a stronger connection between what is being discussed in the classroom as theory and the actual application of those production/shop practices within a manufacturing environment. Today's engineering graduates should possess a basic manufacturing knowledge base that would include fundamental practices associated with precision measurements, metalworking, machining, welding, and composites. This paper will attempt to define the need, outline specific methods for implementation and give examples of current successful university programs.

Justification

During the past decade the United States has seen its share of global production and manufacturing significantly reduced due to increased competition from overseas. As a result, there is a seemingly endless cry for more engineering graduates resonating within

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our domestically owned and operated manufacturing companies as they try to compete within the highly competitive global marketplace. Along with the demand is also a concern from both prospective employers and students that graduating engineering students are not receiving enough hands-on applications oriented coursework. Students seem to be overwhelmed with theoretical concepts that have little to no real application value. Bernard Gordon, founder of NeuroLogica Corp. writes in the New England Journal of Higher Education last summer, "Moreover, a growing emphasis on science and research rather than on, say a hands-on familiarity with machine tools or the ability to rapidly and intuitively compute, with reasonable accuracy, the impedance of an electronic circuit (without the help of a machine), has in most engineering programs led to the production of cadres of young engineers whose skills are fatally limited[1]." A practicing engineer from Bell Helicopter emphasized his requirements for newly hired engineering graduates to have some applied hands-on skills and the willingness to get their hands dirty by using hand tools to build and modify a variety of production test stands for various aero structure components[2]. Employers truly value students that have both product design theories along with a working, hands-on knowledge of manufacturing processes and applications. Matthew McGoff, a recent Georgia Tech mechanical engineering graduate now working at Procter & Gamble states, "I think what I've learned outside of Georgia Tech, here at Procter & Gamble, is that the hands-on is critical. The schoolwork is a foundation and a fundamental you have to have. But if you don't physically get the hands-on, and understand how components go together and understand how processes go together, I think it's all for naught. You've got to have both parts of the equation[3]." Rick Graff, a senior drilling engineer with Chevron whose undergraduate degree is in petroleum engineering is responsible for certifying and validating various outside vendor oil tool products from a materials and manufacturing processes standpoint. He definitely sees the benefits of having undergraduate engineering majors exposed to basic hands-on manufacturing skills even if it's outside their own chosen field of engineering[4].

Students too are voicing their desire to put their hands on real world equipment and projects during their university education experience. At Wichita State University, students participate in a recently implemented program that provides hands-on manufacturing skills to mechanical engineering students. The students revealed some very positive feedback on their course evaluation documents after completing the course:

- "provides an awareness to the practical areas of my career."
- "the practical application was by far the best part."
- "really enjoyed the welding, machining was also very useful and interesting."
- "the more focus on practical manufacturing methods, the better. ME courses already provide plenty of theory. Good practical knowledge is important for engineers."
- "I only wish we had more time."

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These hands-on manufacturing activities can also be very valuable as recruiting and retention tools within the engineering disciplines, as students seem to relate better and stay focused within their chosen engineering fields when they are actively engaged in hands-on projects early on in their curricula. The hands-on lab in a supportive learning environment helps to develop a sense of involvement and fun for the new students. These type of activities also help to support and validate many theories presented within a lecture environment which ultimately help in the overall understanding of the subject matter. In addition to their effectiveness as a retention tool, these hands-on lab experience courses also attract new students as the word spreads.

Many colleges and universities have successfully developed a first year engineering program aimed at improving student success and retention, and these programs very often include hands-on, collaborative, laboratory-based courses in the first semester. The University of Colorado School of Engineering has developed a first year engineering projects course where students are afforded various hands-on lab activities and working in teams to design, build and test new products and inventions. The program has been ongoing since 1994 and the results have been overwhelmingly positive towards increasing new student retention rates. Students involved in this hands-on projects course have experienced a 10% increase in student retention compared to those students not taking the projects course[5].

Another example is Polytechnic University in Brooklyn where the *EG101: An Introduction to Engineering* class is a requirement for all entering engineering students in the first semester of their freshman year. Working in teams, students complete weekly lab projects. In just the first year of this program, freshman retention rates in engineering improved by 50%[6].

Michigan Technological University implemented their First Year Engineering Program in 2000. This program utilizes a common first year approach, and includes an engineering course where "students work on teams to apply the engineering problem-solving method to real-world problems." The students in this course work in teams and participate in activities that include a semester design project. The program has produced consistently higher retention rates among engineering students beginning with the second year after implementation. "Swail states that over 70% of the students studied in eight different colleges indicated they learn better through hands-on projects and real-world application than through classroom or textbook instruction[7]."

Successful Programs

With so many positive reasons and justifications for adding hands-on manufacturing skills to an engineering discipline, the question becomes a matter of how to incorporate these skill level labs into existing engineering curricula. In the last 30 years most of the hands-on application oriented courses/labs have been delegated to engineering technology programs at the various universities. Engineering technology majors are known for being more on the applications side of the engineering educational spectrum

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and employers have utilized their skills within a variety of engineering related tasks. Now however, more and more engineering disciplines are seeing the benefits of providing their students with applied hands-on manufacturing skill development labs. Most engineering programs have some type of undergraduate fabrication facilities/labs available that could or are being used to develop these courses. The “Learning Factory” at Penn State University’s mechanical engineering department is one facility with established comprehensive opportunities and facilities for practiced-based learning of design, manufacturing, and product realization[8]. This particular model has been replicated at other institutions over the past decade, with the help of the National Science Foundation and other supplemental outside agency funding[9]. New mechanical engineering students at Harvard University are introduced to the field of engineering through an applied product design development project[10]. In order for the students to finish the projects they are introduced to a variety of applications oriented design concepts and the use of both manual and Computer Numerical Controlled (CNC) machine tools. At Purdue, ME students learn about both product design and manufacturing processes by pursuing a series of projects involving conventional fabrication processes including drilling, milling, turning, grinding, polishing and assembly methods[11]. At Christian Brothers University in Memphis, Tennessee, Dr. Yeu-Sheng Shiue teaches a junior-level class to mechanical engineering majors that applies kinematic principles to the dynamics and dimensional structure of machine parts and mechanisms. Dr. Shiue has implemented a new practical orientation to actual kinematic mechanisms by involving the students in a real world project involving both design and fabrication skills. The students must be able to manufacture the device using available equipment found in their engineering development shop. “Building the project in the Development Shop is the most exciting part of the process,” Shiue says. “There are a lot of frustrations because of the manufacturing skills of the students. They learn from their mistakes and realize the importance of the manufacturing process in product design[12].” Wichita State University (WSU) recently implemented a new course called Creative Design and Practice where ME students are afforded hands-on manufacturing applications in the areas of welding, machining (both conventional and CNC) and composites fabrication. However, unlike the other successful institutions mentioned in this paper, WSU lacked enough available lab space and manufacturing equipment to adequately support these hands-on activities. Despite these restrictions and with the continued strong demand by both students and employers to add these basic manufacturing skills they pursued an alternative solution. They enlisted the assistance of the local technical college that had both the lab space and equipment necessary to provide the WSU students with hands-on manufacturing skills and applications. This scenario proved to be extremely beneficial for both the students and institutions. Details of this program will be discussed in more detail later in the paper.

Implementation

Implementing any kind of actual student performed hands-on activities within a university curriculum can be both monumental and frightening if there isn’t a true spirit of collaboration and cooperation between faculty and staff members, department chairs,

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industrial advisory boards as well as industrial support. Two significant physical issues that must be resolved initially are space and equipment needs to support hands-on real world manufacturing activities. Qualified and experienced faculty is also vital for this program to be totally successful and worthwhile for the students.

Collective cooperation is vital when trying to initiate the development of a comprehensive manufacturing skills lab. Often, there are several labs scattered across the engineering programs that potentially could be utilized. However, the best case scenario would incorporate all of the resources into one fully functional lab that would be accessible to all engineering disciplines through a specific course structure. Pooling resources from both a facilities and equipment standpoint ultimately will lend itself to better space and time management of the lab along with an increased leveraging factor for outside equipment suppliers to lend their support through donations and or entrustments. Equipment manufacturers are more apt to help with equipment and material needs when they see a collaborative and comprehensive lab that is truly focused on manufacturing applications and processes that can showcase their particular machines to such a wide variety of students.

Most entering engineering students have not experienced actual hands-on manufacturing processes and definitely will rely heavily upon the experiences and knowledge base of their professors. Faculty who are engaged at this level of instruction must have industrial experience in the areas that they will be teaching. Students need to learn from those who have the background and expertise to fully explain and physically demonstrate the proper methods and techniques associated with the processes being taught in the manufacturing skills lab. Safety in the lab is of extreme importance, and someone with an industrial background fully understands the significance of 100% compliance by all students of all prescribed safety rules. Students are anxious to get their hands on the manufacturing processing equipment and it’s the experience and enthusiasm of the teaching faculty that will provide a total learning experience for them while inspiring the student’s inherent creativity to seek alternative methods and procedures.

With so many different and specific manufacturing methods and applications currently being used in industry and so little actual time available within allocated lab schedules, you must choose the processes that are basic to any general understanding of current manufacturing practices. Local and statewide manufacturing companies along with Industrial Advisory Boards are good resources for input into which processes are more applicable for potential graduates. Armed with these inputs and knowledge of currently available space and equipment, the task as hand is to develop a comprehensive manufacturing processes course with intensive student performed hands-on lab experiences.

At Texas Tech University we are in the process of developing just such a course for the engineering technology and mechanical engineering programs. However, the course will also be promoted to the entire college of engineering as a possible elective course for any of the engineering disciplines. The course description is as follows:

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ENGR 2312: Manufacturing Processes

Introduction to the fundamental manufacturing processes currently being used to produce a variety of discrete products within statewide and national industrial market sectors. A hands-on approach will be utilized to develop an applications oriented understanding of basic manufacturing and production methods using engineering materials, including precision measuring instrumentation, conventional and CNC machining, welding, metal working and fabrication, plastics and composites processing and manufacturing assembly methods.

The overall course objectives will be to introduce students to the basic manufacturing processes used in producing a variety of engineered components and assemblies. Both traditional and non-traditional methods will be covered along with an understanding of the specific materials associated with each process. Individual student performed projects will be emphasized in the lab. The specific course content areas are listed below.

- Manufacturing philosophy and its importance to America
- Product and process design, including design for manufacturability
- Precision tools and measurement
- Conventional machining and auxiliary processes
- Computer Numerical Control machine tool operations
- Metal casting methods, including sand and permanent mold casting
- Forging and hot working processes for metals
- Cold working processes for metals, including punching, shearing and bending
- Welding processes, including gas metal arc, tungsten inert gas and oxy-fuel cutting
- Powder metallurgy
- Nontraditional manufacturing processes, including electrical discharge machining
- Processing methods for thermoplastic and composite materials

The labs will cover a wide variety of manufacturing related skill areas to include the following:

- Orientation to general shop safety and procedures, equipment, and tooling
- Precision tools and measurements
- Conventional machining
- Computer Numerical Control (CNC) machining
- Metal casting

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- Hot working – Forging
- Oxy-fuel cutting and welding
- Gas metal arc welding
- Thermoplastic processing – Injection molding
- Composites fabrication – Vacuum bag molding and resin transfer molding

The emphasis within these labs will be that the students will be doing the actual processes themselves and not merely seeing a demonstration of the process. This also warrants a series of student projects that can be stand alone or integrated with other processes to complete a multiple component type project. Specific projects will be assigned to the students with applicable and compatible dimensional tolerances specified for successful completion. The projects should be designed to warrant an interest in the student wanting to do their best because of either the projects overall functionality or aesthetics. (Several student projects will be presented during the paper presentation, with appropriate process completion sheets.) Understanding the student's potential frustration level in the beginning phases of the learning process, it is imperative that the equipment being used is fully functional within the degree of tolerances that are specified. Students will also learn valuable lessons associated with all the hands-on details that must be worked through prior to completing and finishing a manufactured part. They will also gain insight into how much time is involved in performing these various manufacturing processes.

Actual process equipment knowledge will also become a valuable tool for later engineering product designs. One case in point might involve specifying several different weldments on a particular fabricated part and without the actual knowledge of the welding process to be used; it is highly conceivable that a particular weldment could not be performed, simply because the GMAW or MIG welding gun would not fit into the area specified to be welded. Although an elementary example, this definitely would be classified as a "design for manufacturability" issue and one that could have been avoided had the design engineer had any previous welding experience. In no way are these educational activities an attempt to make machinists, welders or composites technicians out of the engineering students. But having their hands on some of these processes will definitely make them more acutely aware of how products are actually made and enhance their ability to improve their own product designs based upon manufacturability.

If the need and desire to offer such a course is warranted, however the university does not have or maintain sufficient space and equipment to provide for the actual student hands-on lab activities there does exist at least one alternative if appropriate. As mentioned earlier in the paper, this particular dilemma occurred at Wichita State University within their Mechanical Engineering program. They were able to solve the lab and equipment shortages by enlisting the help and support of Wichita Area Technical College (WATC) who had very strong hands-on and applications oriented manufacturing programs. Working with the WATC instructors, the WSU professors were able to formulate a plan to ensure their students would be provided with the mandated hands-on manufacturing experiences in the areas of machining, welding and composites. The course was submitted to and approved by the Kansas Board of Regents and last spring the course was

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offered as an elective for the first time and enrollment had to be limited due to both WSU student interest and the limitations on some to the lab facilities at the tech college. Both institutions benefited as the WSU students were receiving the hands-on manufacturing skills being taught by the highly qualified WATC instructors while the tech college received a lump sum of money from WSU to cover their expenses and overhead. As referenced earlier, the students comments were overwhelmingly positive and the word spread quickly throughout the ME department about the "hands-on manufacturing course" now being offered collaboratively with WATC. The course now enjoys a full enrollment each semester and the students are coming away with value added hands-on manufacturing skills that enhance their engineering educational repertoire.

Conclusion

To quote Johann Wolfgang von Goethe, "Knowing is not enough, we must apply", truly summarizes the intent of providing undergraduate engineering students the opportunity to learn by doing when it comes to truly understanding basic manufacturing skills from a hands-on perspective. These skills are paramount to the continued success of American manufacturers competing the global marketplace. Engineering graduates who have experienced first hand the actual manufacturing processing methods are contributing to their company's productivity through better product design and manufacturability of those products. No matter how many computer designs and or simulations are performed, the bottom line is that the product must be built, and for some of those designers the best way to learn the manufacturing processes is by hands-on. In the past a new product was designed with little or no input regarding the manufacturing processes and steps that would be involved. Consequently, production schedules were constantly being revised and extended due to engineering design changes as the product moved through the manufacturing facility. With the growing number of university programs that have successfully implemented hands-on manufacturing labs, the trend now has become "design for manufacturability" as industry seeks to streamline their production systems. The implementation of these labs will provide students with the hands-on knowledge of manufacturing processes and applications which industry values, while affording the university programs with a proven retention tool.

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The disciplines are self-reinforcing, and disciplinary specialization and fragmentation have intensified as the disciplines have strengthened and solidified. As historians of higher education and of integrative learning have long observed, the disciplines have their strengths, but they were always meant to be engines of human invention and discovery rather than cubicles to constrain academic endeavors (Klein, 2010). To return to Einsteinâ€™s analogy (see Chapter 1) that all disciplines of human knowledge are â€œbranches from the same tree,â€ the vitality of the whole depends on the strength of the ...Â manufacturing processes (National Academy of Engineering and National Research Council, 2009). Manufacturing process engineering came from the technological development and profound change of the steel industry. Ferrous metallurgy is a process of iron-coal chemical engineering at high temperature. The manufacturing process consists of many procedures and consumes plenty of resources and energy. In some countries with high steel capacities, the energy consumption of the steel industry usually occupies 10% of total consumption or even more. The supply and prices of the resources and energy therefore have a significant influence on the steel industry. Due to the oil crisis in the 1970s, th