PREPARATION OF ENGINEERING AND TECHNOLOGY GRADUATES FOR MANUFACTURING CAREERS

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Abstract

Faculty in programs other than manufacturing engineering need to teach manufacturing content in order to enhance student success in their careers. Whether designing special machines, solutions for transportation, agriculture, structures, energy, or consumer products, employers require that the designs go beyond function and style to consider economic manufacturability in a globally competitive environment. Regarding the need for manufacturing-oriented education, an argument was made for the need for manufacturing content in all technical degrees, including Mechanical Engineering. Examples of manufacturing considerations in design are presented here.

Introduction and History

Education is an inexact process. The design and delivery of content is a careful balance of objectives, constraints, and limited resources. Teachers strive to prepare graduates who will have successful careers and contribute to society. This process would be easier if the curriculum could be tailored to the students and their careers. In practice, though, the curriculum must try to stretch resources to serve the most students in the best way possible. After graduation, students enter the workforce or sometimes return for more education. Where and how the graduates are employed varies widely; however, there is no question that a majority will be directly or indirectly working in the manufacturing fields. Consider the following statement from a Department of Labor report [1];

> About 36 percent of engineering jobs were found in manufacturing industries, and another 30 percent were in the professional, scientific, and technical services industries, primarily in architectural, engineering, and related services. Many engineers also worked in the construction, telecommunications, and wholesale trade industries. Federal, State, and local governments employed about 12 percent of engineers in 2008. About 6 percent were in the Federal Government, mainly in the U.S. Departments of Defense, Transportation, Agriculture, Interior, and Energy, and in the National Aeronautics and Space Administration. Many engineers in State and local government agencies worked in highway and public works departments. In 2008, about 3 percent of engineers were self-employed, many as consultants. (5-6)

The most common engineering titles in industry are Design Engineer and Manufacturing Engineer. Ironically, the number of graduates with manufacturing degrees is very small compared to the number of employees with the title Manufacturing Engineer and there are no Design Engineering degrees. Many mechanical engineers are hired to work as manufacturing engineers without having had so much as a manufacturing processes course. Likewise, many designers are hired without any knowledge of how their designs will be produced. The simple fact is that if any engineering program is to effectively serve its graduates, it must include manufacturing content. Some of the gaps between the higher education outcome and industry needs have been identified in the Manufacturing Education Plan (MEP) from the Society of Manufacturing Engineers Education Foundation (SMEEF) [2].

General Competency Gaps:
- Business Knowledge Skills
- Project Management, International Perspective
- Written and Oral Communication
- Problem Solving
- Teamwork
- Personal Attributes

Manufacturing Competency Gaps:
- Supply Chain Management
- Materials
- Manufacturing Process Control
- Product/Process Design
- Quality
- Specific Manufacturing Processes
- Manufacturing Systems
- Engineering Fundamentals

Manufacturing-specific programs have been making progress in addressing these needs [3], to the shared benefit of graduates and industry alike. Other disciplines, such as Mechanical Engineering, are making progress on the general gaps but there are some excellent opportunities to address the manufacturing gaps. The extent of these curricular modifications and redesigns varies in scope and the addition of manufacturing curricula can occur many ways. Consider a

Mechanical Engineering program or instructor who chooses to address more manufacturing content. A very-low-impact approach is to add a few manufacturing-oriented problems and examples to an existing course by adopting a textbook in machine design that includes manufacturing considerations [4]. Another positive change might be the addition of manufacturing design techniques to a machine design or similar course. A subsequent section of this paper outlines the Design For Manufacturing (DFM) technique that can be applied to many design courses in many disciplines. More elaborate efforts include the addition of new electives or new emphasis areas in a program.

The Manufacturing Body of Knowledge

Manufacturing is a very old discipline that was exclusively housed in non-manufacturing-titled technical programs until 1955 when Hartford State Technical College (now Capital Community College) accredited their Manufacturing Engineering Technology Associate degree program. Since then the count of manufacturing-named programs in the U.S. has increased to over one hundred. Regardless, manufacturing education remains a vital part of many other technical degrees. How these other programs define manufacturing knowledge is a function of the program type and focus. For example, a mechanical program would tend to focus on machines, while an electrical program might put more focus on assembly.

Industry widely recognizes the need for reeducating new employees for manufacturing careers. Larger companies such as Caterpillar [5] develop and offer academic courses to cover the education gaps of new employees. When possible, companies try to use external educational sources including private training and relationships with local schools [6]. A vivid example is the recent corporate focus on Lean Manufacturing that has resulted in tremendous investments in continuing education and training. Even a minimal understanding of Lean Manufacturing gives new graduates a tremendous advantage in job seeking.

An academic degree indicates, at minimum, exposure to and, oftentimes, mastery of a certain body of knowledge. Given that few professional job applicants have degrees in design engineering or manufacturing engineering, employers must use a résumé to determine qualifications. In the absence of an appropriate degree, many manufacturers use certification as an alternative qualification. From an employee perspective, certification proves that their knowledge meets certain standards. Unlike degrees, certifications come in many forms, often endorsed by a professional group. At the entry level, these can include skills such as safety. At the upper professional level, these can include advanced design and manufacturing skills such as Lean Manufacturing or systems design management.

One of many groups involved in manufacturing education and certification is the Society of Manufacturing Engineers (SME). Of interest to this discussion are the Certified Manufacturing Technologist (CfMT) and the Certified Manufacturing Engineer (CfME) certifications. These certifications have a number of requirements including years of service and standardized tests. The standardized tests are based on a formal Body of Knowledge that is parallel to many undergraduate programs [7]. The major categories are summarized with content percentages used for certification testing. The exhaustive SME body-of-knowledge document breaks these headings out into finer details such as liability, algebra, communications, and tool design.

1. Mathematics, Applied and Eng. Sciences (10-12%)
2. Product/Process Design and Development (10-12%)
3. Manufact. Process Applications and Operation (14-15%)
4. Prod. Systems and Equip. Design/Develop. (20-21%)
5. Automated Systems and Control (7-9%)
6. Quality and Continuous Improvement (10-13%)
7. Manufacturing Management (14-15%)
8. Personal Effectiveness (8-10%)

A step above certification is accreditation. Accredited programs have been reviewed against formal standards and are endorsed with some legal standing. For manufacturing programs, there are two main accrediting groups, ATMAE and ABET. Technology programs from two-year, four-year, and graduate levels are accredited by ATMAE (Association for Technology, Management, and Applied Engineering), formerly known as NAIT. ABET, Inc. (Accreditation Board for Engineering and Technology) has historically focused on four-year, entry-level degrees in Engineering and Technology. The criteria for ABET manufacturing programs are provided below. These accreditation criteria have been developed by volunteer groups in SME.

ABET-TAC Manufacturing Engineering Technology
2012-13 [8]

Objective: An accreditable baccalaureate degree program in manufacturing engineering technology will prepare graduates with technical and leadership skills necessary to enter careers in process and systems design, manufacturing operations, maintenance, technical sales or service functions in a manufacturing enterprise. Graduates of associate degree programs typically have strengths in manufacturing operations, maintenance and service functions.

Outcomes: Programs must demonstrate that graduates are prepared for careers centered on the manufacture of goods. In this context, 'manufacturing' is a process or procedure through which plans, materials, personnel, and equipment are transformed in some way that adds value. Graduates must demonstrate the ability to apply the technologies of materials, manufacturing processes, tooling, automation, production operations, maintenance, quality, industrial organization and management, and statistics to the solution of manufacturing problems. Graduates must demonstrate the ability to successfully complete a comprehensive design project related to the field of manufacturing.

ABET-EAC Manufacturing Engineering 2012-13 [8]

Content: The program must prepare graduates to have proficiency in (a) materials and manufacturing processes: ability to design manufacturing processes that result in products that meet specific material and other requirements; (b) process, assembly and product engineering: ability to design products and the equipment, tooling, and environment necessary for their manufacture; (c) manufacturing competitiveness: ability to create competitive advantage through manufacturing planning, strategy, quality, and control; (d) manufacturing systems design: ability to analyze, synthesize, and control manufacturing operations using statistical methods; and (e) manufacturing laboratory or facility experience: ability to measure manufacturing process variables and develop technical inferences about the process.

A parallel set of standards is offered by ATMAE. However, ATMAE has a much broader mission than SME and ABET including accreditation and certification of both technical and technical management programs. Despite the different approaches of these groups, they are complementary and are coupled by overlapping membership, interests, and objectives. As an illustration of the similarities, the ATMAE Certified Manufacturing Specialist (CMS) Certifications are listed here [9]. Although stated differently, they are parallel to the expectations of SME and ABET.

1. Manufacturing Joining Processes
2. Manufacturing Forming Processes
3. Manufacturing Casting Processes
4. Nontraditional Machining
5. Machining
6. Manufacturing Philosophies
7. Polymers
8. Industrial Materials
9. Computer Integrated Manufacturing
10. Quality
11. Production Planning
12. Wood Technology
13. Metrology
14. Supervision/Management
15. Technical Drafting
16. Electronics

Another partner is the U.S. Department of Labor (DOL), which has a mission "To foster, promote, and develop the welfare of the wage earners, job seekers, and retirees of the United States; improve working conditions; advance opportunities for profitable employment; and assure work-related benefits and rights." The DOL plays a major role in defining and supporting manufacturing, including Engineering and Technology professions. In terms of standards, they define various career paths in manufacturing and provide education and training support. One ongoing and relevant development is the DOL Skills Pyramid model [10] shown in Figure 1. The certification and accreditation models discussed previously focus heavily on knowledge, while the DOL model focuses on skills and competencies.

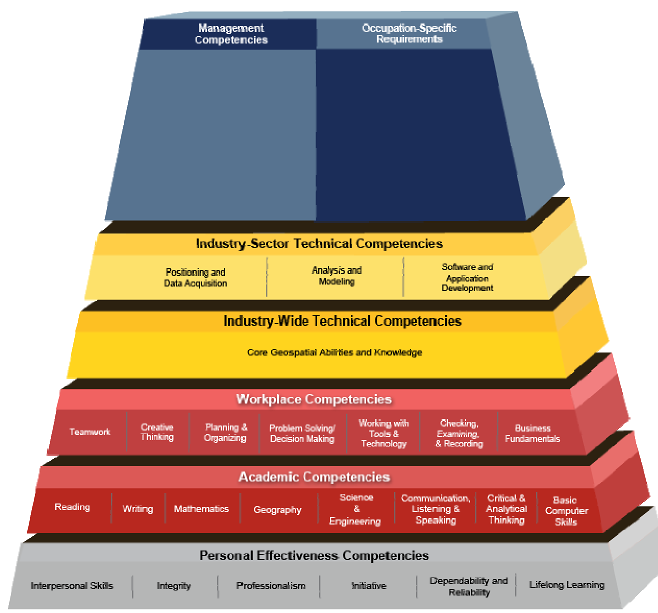

Figure 1. The DOL Skills Pyramid

The Four Pillars of Manufacturing Engineering

In 2010, a discussion arose between academics and professionals with an interest in better defining Manufacturing Engineering. Similar efforts had been undertaken previously [11-13] but changes in technology, competition, globalism, and methods required an update. After numerous rounds of discussion, the Four Pillars of Manufacturing Engineering model emerged, as shown in Figure 2 [14]. The model was meant to be descriptive (not prescriptive) and integrate the various models discussed in the previous section including ABET, ATMAE, DOL, and SME standards. An extensive description and application examples for this are available in the Curricula 2015 Report [3].

The model is based on the four fundamental pillars of i) Materials and Manufacturing Processes, ii) Product, Tooling and Assembly Engineering, iii) Manufacturing Systems and Operations, and iv) Manufacturing Competitiveness. The divisions for the pillars are aligned with the ABET manufacturing program criteria. Each of the pillar areas can be broken into sub-topics such as Metrology, under Quality and Continuous Improvement, under Manufacturing Competitiveness. The sub-topics in the pillars are drawn from various Body of Knowledge documents. These divisions of

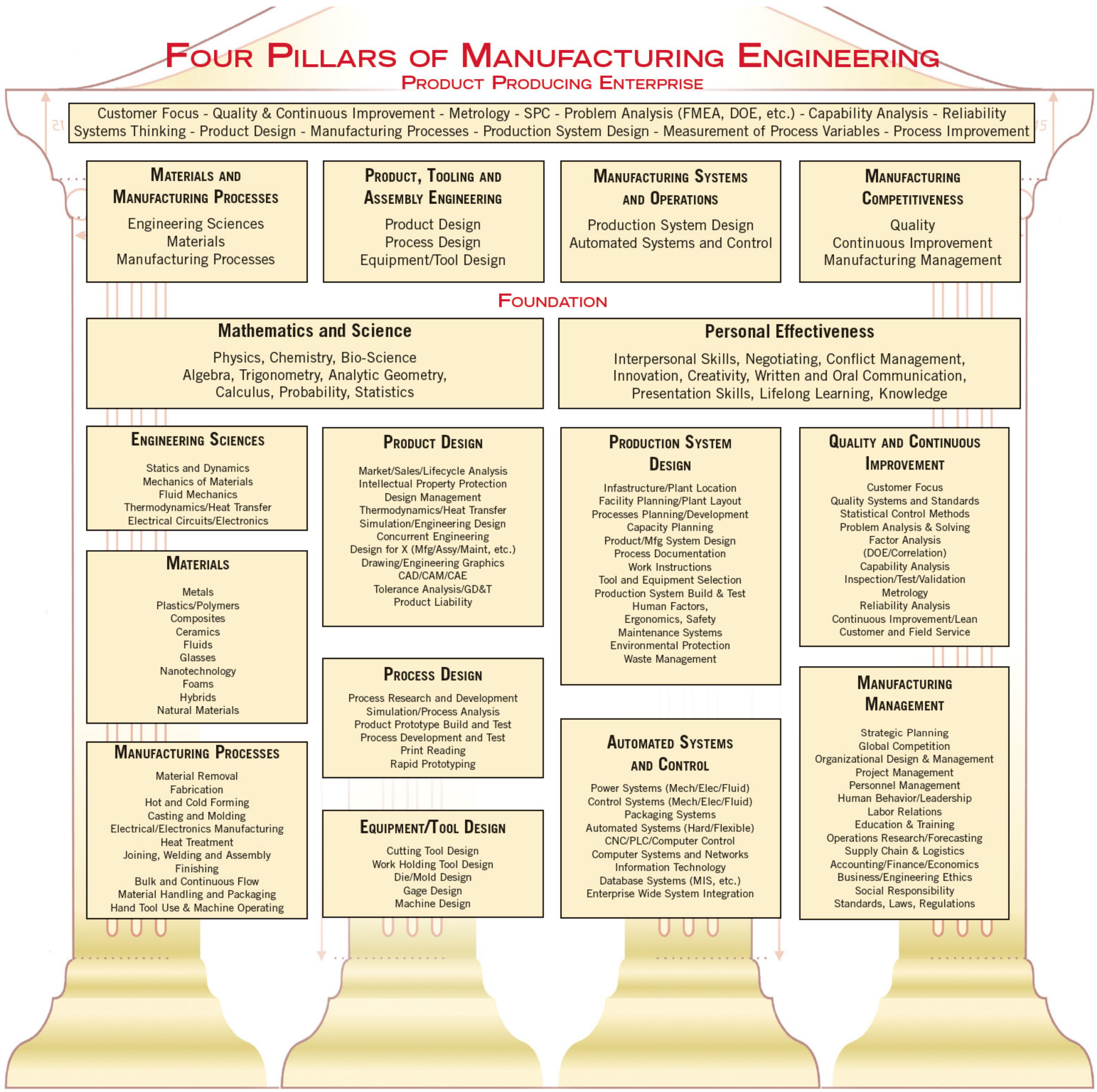

Figure 2. The Four Pillars of Manufacturing Engineering

the pillars and topic areas were based on current standards and practices with no intent to redefine. Beneath the four pillars are the foundations of i) Mathematics and Sciences and ii) Personal Effectiveness. The roof of the structure includes those professional skills recognized by multiple sources including the SME competency gaps, the DOL pyramid, and all accreditation standards.

With respect to a curriculum, a manufacturing-titled program will contain extensive coverage of all four of the pillars. On the other hand, non-manufacturing-titled programs, like Mechanical Engineering, will cover some of the four-pillar subjects such as Materials but may exclude others such as Manufacturing Management. It is worth noting that a topic like Materials can be taught multiple ways, including some that do not include the manufacturing aspects of materials. While this may ”check a box” in a column, it does not benefit the manufacturing body of knowledge. It is understood that the clean boxes in the columns will not always align with particular courses and curriculum threads, but the whole of the curriculum is what defines a manufacturing engineer.

The model is still being refined and reviewed, but it has been receiving wide acceptance and it could be used in the accreditation process to illustrate program coverage and emphasis. For programs with other emphases, like Mechanical Engineering, the four-pillars diagram can be used as a visual tool for assessing manufacturing coverage and opportunities in the curriculum. The Four Pillars can also be used as a medium when discussing program focus with companies and advisory boards so as to set a common language for discussion. At present, the model is not as well suited for describing associate and graduate degree programs but can certainly set a context for selecting content and courses. The content of the Four Pillars will continue to evolve with the field of manufacturing and with contributions from topic experts. Examples of topics that may see greater individual prominence include energy, the environment, product lifecycle, sustainability, agility, and simulation.

Design for Manufacturability and Assembly: A Classroom Application Example for Mechanical Engineering Faculty

As stated earlier, the critical nature of product design activities must go far beyond ensuring functional performance and durability. Commercial products of all types and volumes must be designed so that they will be economically successful in the face of global competition. It is estimated that as much as 80% of the cost of a product’s development and manufacture is determined by the various decisions made in the initial design stages [15]. Students must be made to realize that a critical cost element is time. Reiterations of a design through review and rework sessions—so that the product can be produced and sold—is not only costly in terms of money and engineering resources, but especially time in the sense that the end product is delayed in becoming available to potential customers. New products that come on the market earlier than others typically earn a greater portion of sales volume and revenue.

After an initial design is adopted and produced, product engineering often evolves to include re-engineering effort addressing changes to style, next-generation materials, increased demand, performance or cost reduction goals, or governmental regulations. Creative, effective problem solving demands a broad awareness of potential material/process solutions and related issues. The process of designing a product, whether a single component or a complex final assembly, requires a professional knowledge set that involves aspects from each of the four pillars of Manufacturing. With rare exceptions, product designers must be future-oriented. Therefore, it is essential for design professionals to not only have a foundation in existing technologies and methods of utilizing them, but to also maintain and grow their knowledge by proactively pursuing opportunities to learn about new and emerging materials, processes, advances in equipment and tooling, automation, and aspects that improve waste-reduction and competitiveness. Curricula must evolve to keep pace with associated technologies.

Engineering faculty must, in course content and delivery, include the above factual content issues, but also emphasize concepts, facts, and examples of what are commonly referred to as producibility or manufacturability considerations and solutions in product design. There are many directly related print and electronic reference materials available under the heading of DMFA (Design for Manufacturing and Assembly) or Product Life Cycle Design, which looks beyond production to include factors such as serviceability and “cradle to grave” environmental impact [16].

- One key concern is designing within the scope of the processes and limitations used by the manufacturer’s own factory, and/or their suppliers. An example is the case of a major U.S. aerospace firm’s engineering project manager trying to keep proposal costs down by excluding a producibility engineer from the initial design team. After six months of costly design work on a titanium substructure, a manufacturing producibility engineer was allowed to review the design. He informed the designers that while the design solution was elegant, there was only one forging press in the world capable of producing the large critical central forging, and it was in Russia.

- Another concern is the reduction of processing and assembly costs. A case example is found in the redesign of the blower housing (air-cooling engine shroud) assembly of a small gasoline engine. Converting from a metal design to plastic eliminated metal drawing and stamping, VOC solvent cleaning and painting, while greatly reducing the number of parts and thus the related production floor space, equipment, materials, and assembly labor. In this case, the combined cost savings more than offset the fact that the now integrated assembly would need to be purchased from a supplier since the parent firm was not in the business of molding plastics. Further benefits involved end-product weight and noise reduction.
- A classic case involving Product Life Cycle Design is the instance of an office copy machine manufacturer focusing on the reduction of assembly costs through desirable features such as using snap-fit rather than screws or other fasteners. The product was a success in terms of selling price, but a failure because the component most often needing service replacement was buried within the machine. Users were faced with major service-call costs because of the time required to get at the component and then reassemble the machine.

Importantly today, DFMA and Product Life Cycle Design, as umbrella terms, must include Lean concepts and requirements in addition to the traditional focuses illustrated above. Lean methods involve identification and elimination or minimization of eight categories of waste. For example, parts and assemblies may need to be designed in consideration of the Group Technology approach so that they fit into product families that are used to define the workflow and capabilities of work cells in the modern focused factory.

Mini case studies such as those described above can be effective tools when briefly included in materials science, engineering economy, or design classes. One goal of the SME Manufacturing & Research Community is to develop and disseminate such case studies to engineering faculty. Beyond this sprinkling of producibility content, faculty members may find it difficult to include ever greater amounts of additional content within the lecture time allotted to existing courses; and adding a dedicated new manufacturing course within the constraints of the undergraduate curriculum simply may not be possible. It should be noted, however, that processes and producibility-focused and/or Lean methods courses could be value-adding components of graduate program offerings, serving to fill the manufacturing knowledge gap that is typical of recent graduates of B.S. degree programs and of significant concern to industry.

An excellent way to convey an understanding of the issues and importance of manufacturability knowledge is to provide the students with real-world case studies in the form of study assignments outside of class. Case studies may involve good, effective examples of producibility in design, as well as examples of real-world failures and successful redesign solutions. The literature contains a great amount of related supporting information, and real-world case examples may also be contributed through interviews with local companies, submissions from academic program industry advisory board members, or external sources such as SME. These cases can be very motivating to the students when assigned as small-group analysis projects, and today's online research and communications capabilities make these much more practical than in the past.

One example of design for manufacturing would be a case involving the transition from initial prototyping and small-volume production to higher volumes as a product gains popularity. For plastics parts, a distinct advantage of rotational molding is that there is no pressure involved, thus the equipment and tooling can be fairly low cost. But to produce similar hollow components in the high volume required by a major automotive firm, a faster, more automated/less labor-intensive method is needed, so the product might transition to injection blow molding. A meaningful assignment for students might be to be exposed to the basics of rotational molding, then be challenged to research and propose alternatives for mid- or high-volume production.

Modern design and production steps and procedures are intimately linked through the practice of Computer Integrated Manufacturing (CIM). The 3D CAD database created by the product designer is passed along, to be utilized in various simulations for form, fit, function, and processing. The data may be used to produce a rapid-prototype model, to simulate the cutter path for CNC machining of a mold and/or the component, for programming of automated inspection procedures, or for assessment of accessibility for product final assembly and maintenance. The designer must have insight into how the product can be/will be created, including processes, tooling and equipment.

A simple example of a student exercise in redesign for cost reduction is shown in Figure 3. A simple metal plate must have an attachment point for a tension spring. Based on students being exposed to basic process lab experiences, their initial solution might be to drill and tap a hole so that a threaded pin could be installed. The pin might be custom made by machining, but could be a purchased part in the form of a machine screw. Research might lead them to discover that a projection resistance-welded pin would eliminate all the drilling and threading operations. They might eventually realize that the separate pin could be eliminated by simply punching, shearing and bending a small tab on the edge of the plate as it is stamped, all in one quick step (bottom). A greater depth of study could be pursued by designing the process tooling for the press.

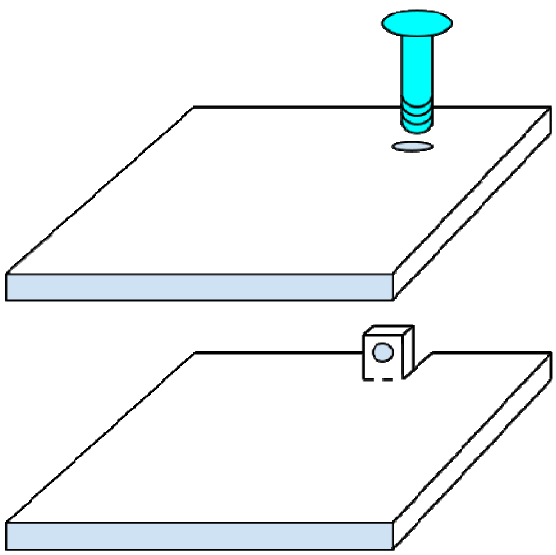

Figure 3. Simple DFMA Exercise Example

The merits of such a simple, basic exercise may be considered in relation to several of the competencies and content elements described in Figures 1 and 2. Among others, from the DOL model (Figure 1) these would include Critical and Analytical Thinking, Creative Thinking, Teamwork, Problem Solving/Decision Making. From the four-pillars model (Figure 2), students could delve into, and gain insights into the interdependence of a wide range of subtopics from within at least three of the key pillars: Materials and Manufacturing Processes, Product, Tooling and Assembly Engineering, and Manufacturing Competitiveness.

Conclusions and Recommendations

Given that manufacturing is critical to the viability of any national economy and the largest identifiable employer for engineering and technology graduates, educators have an obligation to prepare their students for these careers. The present financial situation in higher education may dictate that, while perhaps ideal, it is not feasible to add courses or to establish a new curriculum. However, modifying the delivery of traditional content within existing courses can do much to support all of the educational prerequisites, while imparting valuable career knowledge. Faculty members in a non-manufacturing-named program may consider some of the following strategies:

- Use the models of manufacturing education, including the Four Pillars, to identify curriculum opportunities.
- Identify courses where manufacturing problems and examples could enhance current content[17]
- Identify courses where manufacturing could replace less-relevant topics. The DFMA section illustrates one approach while others include prototyping [18] and bevel gear design [19].
- Consider offering a manufacturing-engineering-focused elective or emphasis.
- Allow students to take a manufacturing elective from another program.
- Enhance a graduate program by offering a course that is tailored to address the aforementioned gaps typical of undergraduate programs.
- Approach local manufacturers to find examples of applications of theory.

Manufacturing program faculty can help by promoting and supporting manufacturing education in other programs, acting as emissaries and support resources for those teaching faculty who have an interest in manufacturing.

- Approach faculty in other disciplines teaching traditional topics such as Machine Design, Computer Aided Design, Thermo-Fluids, Electronics Design, etc.
- Offer to help support new materials, identify textbooks that include manufacturing examples, help develop laboratory experiences and projects, etc. DFMA is an excellent bridge between other disciplines and manufacturing.
- Introduce other faculty to manufacturing techniques such as Six Sigma [20].
- Consider developing elective courses that introduce product design and manufacturing to other technical disciplines.
- Help other faculty engage local industry.
- Help other faculty apply for grants and resources from internal and external resources.

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