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# A Hands-On, Active Learning Approach to Increasing Manufacturing Knowledge in Engineering Students

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# A Hands-On, Active Learning Approach to Increasing Manufacturing Knowledge in Engineering Students

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David has more than 28 years in the workforce with 19 of those working for Harley-Davidson, Inc.. The majority of his Harley-Davidson® experience was as their Softail® Platform Director, developing and caring for that family of motorcycles with his management team. Over the years, he has participated in international assembly bench-marking studies, manufacturing capability assessments and strategic product development methods development. David holds a Bachelor of Science in Mechanical Engineering (BSME, PE) and a Master of Science in New Product Management (MSNP).

# A Hands-On, Active Learning Approach to Increasing Manufacturing Knowledge in Engineering Students

Abstract

This paper describes a new learning module implemented as part of the senior capstone design course at Marquette University to teach engineering students about basic manufacturing processes, lean manufacturing principles, and design for manufacturability. The module includes several examples of active and student centered learning as part of an in-class assembly line simulation exercise. Students reflected on this experience, and suggested process improvements to save time, reduce cost and waste, and improve the assembly line process. They learned of the importance of manufacturing documentation, process design, and design for assembly. At the end of the module, students understood the importance of designing a product not only for the end user, but also for the assemblers and inspectors. Details of the module design and implementation will be presented along with comments from students.

## Introduction

ISO 9001:1994, *Quality Systems–Model for Quality Assurance in Design, Development, Production, Installation, and Servicing*, requires a company's product design and development process to include specific components.[1] These include design and development planning, design input, design output, design review, design verification and validation, and design transfer. The more our students become familiar with each of these components, the better prepared they will be for careers in industry. Ideally, capstone design projects would involve each of these components. In situations where this is not feasible, lectures regarding the details of each design control component can be included in the capstone course.

A recent survey of capstone design instructors indicates that the duration of capstone design courses varies in length.[2] As a result, some courses only require paper designs while others require construction and testing of prototypes as the final deliverable. Due to time, cost, resource constraints, and a lack of large scale manufacturing facilities available to students, it is beyond the scope of most capstone design courses to include the design transfer phase, which involves the transfer of all design information such as drawings, assembly instructions, bills of material, and test procedures to the designated production facility in preparation for production. According to a 2005 study, less than 30% of respondents indicated that their capstone design courses included lectures on manufacturing processes or other related topics.[3] This lack of familiarity with the design transfer phase and manufacturing related topics results in a knowledge gap among many engineering students in the areas of manufacturing operations, lean manufacturing principles, and design for manufacturability.

An understanding of manufacturing operations allows engineers to modify designs to ensure that the product can be produced at a reasonable cost. The ability to apply lean manufacturing and design for manufacturability principles can help speed assembly operations, avoid repetitive motion injuries among production workers, and reduce waste and scrap, resulting in time and cost savings. Students need to understand that their role on a project team in industry will not end after design validation and verification and that they will often be responsible for tasks included in the design transfer phase. To expose them to the entire design process and improve their understanding of the requirements of professional practice, capstone design courses should include design transfer as part of the course curriculum.

The lack of experience with or knowledge of manufacturing processes is not limited to graduates of any one engineering discipline. Since 1997, surveys and interviews with leaders from all manufacturing industries were conducted by the Society of Manufacturing Engineers.[4] As a result, competency gaps among new engineering graduates were identified. These include process design and control, and manufacturing processes and systems.[5]

To address this lack of manufacturing literacy, students could take courses on these topics. However, due to the lack of credits available for additional courses in many engineering programs, students may not be able to fit another course into their schedules. A viable alternative would be to create a module on design transfer as part of the capstone design course. This module could cover basic manufacturing processes (cutting, molding, etc.), lean manufacturing principles (just-in-time, 6-sigma, 5S, reduced waste of materials, motions, and time, etc.), and design for manufacturability. Lectures, video presentations, in-class activities, and other active and student centered learning methods could be employed to help students learn about these topics.

Active learning is an instructional method that engages students in the learning process. In active learning students conduct meaningful learning activities and think about and are connected to what they are doing. While this definition could include traditional activities such as homework, in the education literature active learning most commonly refers to activities that are introduced in the classroom. The core elements of active learning are activities that engage students. Active learning is often contrasted to the traditional lecture format where students passively receive information from an instructor.[6, 7] The benefits of active and student centered learning methods reported in the literature suggest to us that a hands-on classroom activity could be more effective in teaching manufacturing related topics to capstone design students than reading assignments and lectures alone.[6, 7]

## Senior Capstone Design at Marquette University

The senior capstone design course at Marquette University includes biomedical, electrical, computer, and mechanical engineering students. Three faculty members representing each of the disciplines involved teach the course over two semesters. Course enrollment is typically around 180 students in two sections. The course meets twice a week for lectures on various topics important to student projects and professional engineering practice such as:

- Problem identification
- Identifying customer needs
- Project management
- Teamwork
- Concept generation and selection
- Risk management
- User centered design

- Prototyping methods
- Industrial design
- Standards
- Design for the environment
- Design validation and verification
- Constraints of design
- Cost-benefit analysis
- Entrepreneurship

The focus of the course is on the design project of which there are typically thirty-five project teams consisting of three to six students from the mix of disciplines enrolled in the course. Approximately half of the projects are industry sponsored, with some proposed by students, some by faculty, and others requested on behalf of clients with disabilities.

The course schedule and required team deliverables are based on the design control requirements of ISO 9001 and reflect the design process used in industry. Required team deliverables include the Project Definition, Customer Needs/Target Specifications Document, Generated/Final Concepts Document, Formal Proposal, Prototype/Mock-Up, Project Notebook, Oral Proposal, and Peer Review in the fall semester. A Project Schedule/Risk Analysis, Experimental Verification Document, Prototype, Project Notebook, Peer Review, Oral Report, and Final Report are required during the spring semester.

The course deliverables provide students with experience with almost all requirements of the design process including design and development planning, design input, design output, design review, and design validation and verification. However, students do not learn much about or gain experience with the design transfer phase. Recognizing the importance of manufacturing processes and related issues to design, it was decided to incorporate lectures and in-class activities related to this important phase of the design process into the capstone design course through the development of a learning module on design transfer.

## Module Design and Implementation

In August 2011, a *Shaping Entrepreneurial Engineers* (SEE) workshop sponsored by the Kern Entrepreneurship Education Network (KEEN) was presented in Eagle, WI. The workshop included several hands-on activities designed to teach faculty about design for manufacturability, design for serviceability, and design of experiments, and emphasized what new engineers should know about manufacturing when they graduate. One of these hands-on activities involved a simulated assembly line that if adapted to a single class period, would be an excellent in-class active learning exercise to teach students about lean manufacturing and design for manufacturability.

In spring 2012, a module on design transfer was presented to the capstone design students at around the time they were building and testing their prototypes. David Rank of Root Cause Consortium, the designer of the SEE workshop activities, developed a customized module consisting of one 50-minute lecture and one 50-minute hands-on in-class activity. The lecture was presented to students in all engineering disciplines in the course and included the following information:

- Overview of predominant manufacturing processes used for medical devices
    - Material removal (cutting, drilling, boring, grinding, etc.)
    - Surface finishing (polishing, etc.)
    - Melting, flowing (molding, extrusion)
    - Bending, forming (casting, forging, etc.)
- Principles of lean thinking
    - Efficiency (time, energy, motion, steps, etc.)
- Selection of appropriate manufacturing processes
- Design modifications to reduce cost
    - Reducing the number of parts
    - Changing draft angles, etc., to allow for easier molding and assembly
    - Using standard hole sizes
- Tips for talking with manufacturing personnel
    - Concurrent engineering to involve manufacturing and manufacturing engineering personnel early in the project
    - Design engineers working with production personnel to demonstrate assembly of product, explain importance/criticality of certain dimensions and tolerances

Although most of the lecture topics listed above are applicable to any type of manufactured product, the emphasis is more on mechanical products. To ensure that issues relevant to electronics manufacturing were included to address the needs and interests of our electrical engineering students, two speakers from a local electronics manufacturer presented a second lecture that covered topics such as printed circuit board design, testing, and cost issues in electronics design.

Due to the large number of students in the capstone design course, the in-class activity was tried with biomedical engineering students during a breakout session while students of the other disciplines each met separately to discuss discipline specific topics. This resulted in a smaller group that allowed all students to participate in two parallel assembly lines. The in-class activity consisted of an assembly line simulation to produce a water battery consisting of a wooden base, copper wires and coils, paper towels, galvanized screws, alligator clips, and an LED as shown in Figure 1. Wet paper towels placed between copper coils and zinc-coated screws provide a path for current flow between these two components in each single cell. This produces a voltage across each single cell which when connected in series, results in a battery that is capable of lighting an LED bulb. The battery design was intended to meet the customer's requirement of powering a light bulb. Through this in-class activity, students experienced first-hand the impact of process flow, line balance, work design, product and process documentation, repetitive motion, lean principles, quality control, production variation, and design trouble-shooting on the resulting product. They developed an appreciation for why product designers need to know how their products will eventually be made, and how this knowledge can be used to improve a product's design.

Before class, tables and chairs were moved to create two parallel assembly lines made up of four tables in each line aligned lengthwise, with the ends of the tables touching. Each table accommodated two students and all students in the same assembly line faced the same direction. Each student was assigned a specific job to perform in the assembly line and was provided with written work instructions on how to perform their assigned assembly, test, or inspection operation. Work instructions, assembly materials, and tools were placed at each workstation during classroom setup. An example of a work instruction is shown in Figure 2. Students were assigned the following jobs in the following order:

1. Coiler – wraps precut lengths of copper wire around a mandrel to form copper coils
2. Electrolysis Strip Maker – cuts strips of paper towels
3. Core Roller – rolls paper towel strips around galvanized screws
4. Cell Assembler – assembles copper coil over cores
5. Cell Installer – screws each cell into wooden base board
6. Battery Activator – pours water over cells mounted in base board
7. Wiring Installer – using alligator clips, connects cells in series (copper to zinc)
8. Electrical Checker – measures voltage produced by connected cells; confirms battery's ability to light a light emitting diode (LED).

The student assembly workers were asked to note opportunities for design or process improvements. Students who were not part of either assembly line were asked to serve as Quality workers and observe one of the lines, make notes of problems and bottlenecks they saw, and develop a list of recommended improvements to the assembly line. Quality workers were asked to pay particular attention to the various forms of waste (based on lean principles) such as:

- *Transport* – moving products when not actually required to perform a process
- *Inventory* – all components, work-in-process, and finished product not being fully processed
- *Motion* – people or equipment moving or walking more than is required to complete an operation
- *Waiting* – waiting for the next production step
- *Overproduction* – production ahead of demand that can lead to one-piece flow
- *Over processing* – additional steps in a process resulting from poor process, tool, or product design
- *Defects* – effort involved in inspecting for and fixing defects
- *Unused human talent or equipment capacity*

Two students volunteered to serve as supervisors who were responsible for ensuring that assembly workers had what they needed to perform their jobs, keeping the lines moving, and answering questions regarding work instructions. They were also provided with a set of rules governing the assembly line including:

- Workers must follow work instructions provided at each workstation
- Defects must not be passed downstream
- Defects received from a previous workstation should not be corrected; they should be sent back upstream to the station that did the work. Once corrected, the product should be sent back downstream.
- Workers must not reach into another workstation

- When work is complete at each workstation, workers are to place the finished product on the border of workstations.

At the end of the assembly line, the completed water battery assembly was inspected and tested for correct wiring. Voltages produced by the water battery were measured, polarities were checked, and its ability to light an LED was confirmed.

Results

Unknown to the students, some information was intentionally excluded from the written instructions. Similarly, some simple tools that would make specific assembly operations easier were intentionally withheld. Soon after the assembly line began students discovered ambiguous, confusing, and missing parts of work instructions. They also realized that they needed better tools to complete specific operations. Some students created their own tools to make a specific job easier. For example, to aid in cutting paper towels to the correct width, one student rolled up a dollar bill to the correct width for use as a template for cutting paper towels. Immediately after each line assembled and tested their water battery, students reflected on the process, and proposed process improvements to save time, reduce cost and waste, and make assembly easier.

Students observed and cited several examples of bottlenecks and waste:

- Wire coiling was difficult and created an early bottleneck; one hand was needed to hold mandrel and the other used to wrap copper wire around the mandrel to form the coil. *(Over processing, Waiting)*
- Some core assemblies were assembled as described in the work instructions, but were not usable during installation at a later workstation. This resulted in several core assemblies being returned back to the core assembly workstation for rework that held up the line for a short time. *(Defects)*
- Some work instructions did not include enough specific details; too much was left up to the interpretation of the workers which often resulted in additional steps. *(Over processing)*
- Students at downstream workstations were idle while waiting for product from upstream workstations to arrive. *(Waiting)*
- Screws were difficult to screw into wood base; created a bottleneck in the assembly line. *(Waiting, overproduction)*
- Too much consulting between supervisor and assembler due to incomplete work instructions. *(Over processing)*
- An (intentional) error in the wiring diagram was not discovered until the end of the assembly process after significant time was spent in testing. *(Defects)*
- Some tasks were faster and easier than others resulting in bottlenecks and inventory pile-ups. *(Waiting, overproduction)*

Students proposed several improvements to the assembly process:

- Mount the mandrel in a fixed base to make both hands available for wire coiling.
- Consider using smaller diameter copper wire to make coiling easier.
- Provide a ruler to allow cutting of the paper towels to the required 1.5 inch width.
- Use double ply towels to allow use of shorter strips of paper towels.

- Increase diameter of predrilled mounting holes in wood base or add a workstation to drill larger holes to make screw attachment easier.
- Provide socket wrenches to assist in attaching screws to the wood base
- Assign more people to or rebalance the work of the labor-intensive operations such as coiling and screw attachment.
- To reduce waiting and idle time, allow students at downstream stations to help with upstream tasks until product begins to flow into downstream stations.
- To reduce idle time, students at test stations can arrange leads for cell connections ahead of time while waiting for product to arrive.
- Improve communication between workstations.
- Spend time prior to beginning assembly explaining what needs to be done.
- Test each cell subassembly prior to wiring or attaching to wood base.

Discussion

These observations and recommendations involve process and product design changes and clearly demonstrate the students' understanding of lean principles and the impact of product design on manufacturability. The results of the in-class exercise indicate that students 1) understood the various forms of waste as presented in the lecture on lean principles, 2) recognized problems, bottlenecks, and forms of waste that occurred during the in-class exercise, and 3) were able to propose solutions to improve the process.

Participation in this active exercise allowed students to apply what they learned from previous lectures. Witnessing problems first-hand during this activity helped create an awareness of the impact of product design on the ease and cost of assembly and helped students recognize that the assembly worker is another customer whose needs must also be met through good design. Students realized that good product and process design helps speed assembly operations, avoid repetitive motion injuries, and reduce waste and scrap, resulting in time and cost savings. This appreciation of design for manufacturability will better prepare them for professional practice and careers in engineering. We feel that students learned more from this active learning exercise than they would have from reading and/or lectures alone.

<u>Student Feedback</u>
To determine the value of the in-class activity to students and if the activity should be repeated for future classes, students were asked to provide feedback on their experiences. Responses were received from four students and are shown below, along with the questions they were asked via email:

1. **What did you learn about manufacturing and assembly processes as a result of this activity?**

   *#1: I learned that manufacturing and assembly processes all rely on previous steps. If the first step takes too long, then the second step is waiting to do its job. However, if the first step is too fast, then the product can pile up on the second step possibly causing a back up. Both of these things happening in different parts of a manufacturing process can cost time and money for the company. Therefore each step needs to be looked at to see*

*how it could function better and would it be better to make that step and possibly implement two machines/people to complete this step.*

*#2: The fabrication activity taught students several key aspects about manufacturing and assembly process: the stigma/relationship between workers and boss, privacy about intermediate steps/final design of line works, and the monotony of assembly line tasks. By placing students in particular "jobs" within the line, the attitudes of students changed depending on the assigned jobs. Students working on the line took more of a "listen and follow through" attitude while the manager/boss took the leadership position with a "what I say goes" position. Student line workers even came to call the manager/boss with a title of disrespect if something was not going well during the assembly process. Within the assembly line processes, workers did not know the final product design. By being given one task, the student workers were forced to perform the same tasks without the ability to help others if slack was created along the process. This pigeonholed student workers to become an expert in one aspect of the assembly process through the monotony of a single job. Stepping back after this exercise and talking about what occurred during the activity opened up my eyes to the roles and relations we assume based on what our job is within the manufacturing and assembly process.*

*#3: My contribution happened at the end of the assembly line, where I connected the batteries with wired cables. I was unsure most of the time, especially since there was no guarantee the product would be consistent with the diagram on my instruction sheet once it got to me. I remember seeing a team member hammering in a screw into the wooden board. Since I heard this was not the prescribed approach, I was wondering if my connections would need to change as well. To be honest, I'm not sure what I learned from this exercise exactly. I was too worried about doing my part to beat the other team.*

*#4: The in-class activity was a live illustration of how product parts are assembled in the manufacturing process. I could have also learned about this process through a lecture, but nothing is more comprehensible than being able to do it yourself.*

2. **Which would you prefer: participating in this activity or listening to a lecture on the same topic?**

*#1: Definitely participating in the activity. You just don't get the same experience listening to someone talk about manufacturing as you do actually making something. I am also a hands-on type of learner. I had a lot of fun doing this activity last year!*

#2: *If given a choice, I would prefer participating in an activity. Engaging students facilitates learning (at least for me) through action rather than throwing information at students. This activity even allows students without prior workplace experience to understand the purpose/goal of the activity.*

*#3: I prefer participating in this. Even though I worried about my contribution, it was nice to see the interaction between each station.*

*#4: Participating in this activity.*

3. **Did what you learned from this activity impact how you will design products in the future?**

   *#1: What I learned will definitely have an impact on the way I look at design. For instance, you can't make a product too detailed because the manufacturing cost would skyrocket for the product. This is an important thing to keep in mind when designing something.*

   *#2: Besides what I have learned from the points made above, I would attempt to design the manufacturing processes a bit differently if given an opportunity. For starters, I would be more than happy to show employees the final product, so as to give workers an understanding and fulfillment in what they build. Further, I would attempt to have workers change jobs and roles on a consistent basis to break up the monotony of the routine. Finally, I would attempt to eliminate or reduce the employee and boss level distinction by enforcing equality in the workplace. From what I know, some companies apply this concept by having line workers and bosses dress in the same clothing.*

   *#3: Yes. I would focus on making multiple instruction sets, which account for all approaches the previous stations could take.*

   *#4: Definitely. This was a quick, but very apt activity to demonstrate the assembly line process, and how it can prove to be an efficient way for designing products.*

As a result of student feedback and our observations of the in-class activity, we plan to expand this module to five 50-minute class periods:

- Class period #1: Previously described lecture on manufacturing processes, lean principles, design for manufacturing and assembly, and cost issues.
- Class period #2: Previously described lecture on design for electronics manufacturing, assembly, and testing.
- Class period #3: Previously described in-class assembly line simulation activity.
- Class period #4: In-class meetings of each assembly line team (two per class) to discuss their observations and propose improvements to the assembly line and process.
- Class period #5: Repeat of the in-class assembly line activity (class period #3) with the implementation of the proposed improvements developed by the students during class period #4.

One unanticipated consequence of the structure of the in-class activity occurred in both class sections. The assembly line simulation involved two parallel assembly lines with two production "supervisors". Both lines were told to start at the same time after receiving similar instructions. Once the activity began, we noticed that the two supervisors were competing with each other to see whose line could complete the water battery assembly first. During one section, this competitive attitude resulted in some negative interactions between one supervisor and a few workers. This supervisor appeared to take on a different personality as he behaved in a manner that he perceived to be how a production supervisor should behave. Students did not appreciate this behavior. To prevent this from occurring again, we will spend more time emphasizing the learning goals of the activity and making it clear that it is not a competition between assembly lines.

Another unanticipated consequence occurred when workers were assigned to stations involving tasks requiring greater hand strength. When the supervisor noticed that a female worker was not able to coil wires as quickly as her male counterpart in the "competing" assembly line, he told her to switch with a male student at a station involving a task that did not require as much hand strength. As a result of this event, a Quality observer reported "offensive, sexist remarks".

A third unexpected outcome involved non-technical aspects of the assembly process. A few students described and commented on the supervisor/worker relationship that emerged during the activity. This in-class activity made these students more aware of the affect of the supervisor's behavior on assembly worker morale, motivation, and productivity. These are important characteristics for students to think about and become aware of as they prepare to move into any type of management position later in their careers.

Some of the reported problems and proposed improvements developed through student reflection (immediately after completion of the in-class activity) and feedback from students (after graduation) were related to how the activity was structured. Some students did not understand what they were supposed to do, why, and how they were to do it. To address these weaknesses, and prevent problems from occurring in the future, we will explain the purpose of the in-class exercise in greater detail, place more emphasis on learning goals, and allow more time for supervisors to "train" workers.

## Conclusions

At the end of the module, students understood the importance of designing a product not only for the end user, but also with the assembler and inspector in mind. The in-class activity was a fun, hands-on active learning exercise that helped students learn about design for manufacturability, lean principles, and design transfer. Experiential learning occurred in a relatively short timeframe. The exercise did not require access to a full-scale manufacturing facility, thereby making it feasible to implement at any school. Based on feedback from students, the authors feel that students learned more about these topics through this hands-on, active-learning exercise than they would have if they had only read about or listened to lectures on these topics. We feel that the planned expansion and proposed improvements to the module will enhance student learning and better prepare students for professional practice and careers in engineering.

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Figure 1. Assembled water battery consisting of a wooden base, copper wires and coils, paper towels, galvanized screws, alligator clips, and LED. Wet paper towels placed between copper coils and zinc-coated screws provide a path for current flow between these two components in each single cell. This produces a voltage across each single cell which when connected in series, results in a battery that is capable of lighting an LED bulb.

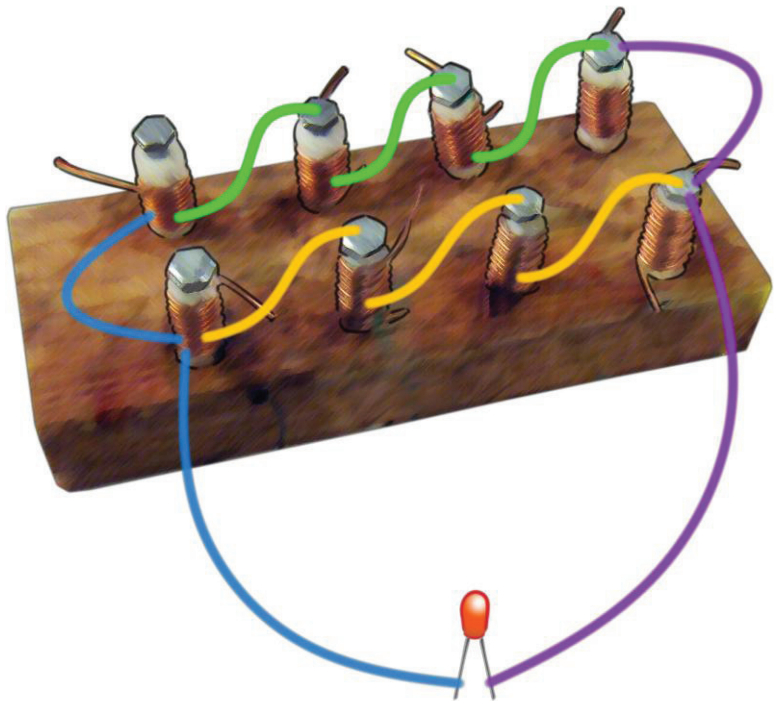

Figure 2:  Work instructions for cell assembler.

## Work Instructions - Cell Assembler

1) Receive a coil from the Coiler
2) Receive a paper towel and screw core from the Core Roller
3) If either part is defective, send back to appropriate station
4) If not, screw Core into Coil
    a) Leave even amounts of paper towel protruding from either end of coil
    b) At least three threads should be available at end of screw
    c) Paper towel should be just up against underside of screw head
    d) Paper towel should be a snug fit into the coil.  If not, ship Core back to Core Roller for more paper towel