Encouraging an Engineering Mindset amid Skill Practice In the Freshman Manufacturing Processes Lab

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Abstract

At Kansas State University's Salina Campus, Mechanical Engineering Technology students are introduced to Manufacturing Processes as part of the freshman experience, leading up to a design-to-build project in the end of the second semester.[1] Although the classroom content and lab discussion topics attempted to address engineering problem-solving and design decisions, student course evaluations revealed that for many, their focus in the lab was on basic machine operation procedure. Students complained that additional lab discussion on the machine, tooling, material, and inspection issues that affect part quality were irrelevant and thus a waste of time.

After recognizing that the existing lab deliverables overly-emphasized part production tasks of a machinist or operator, lab assignments were modified to be framed as engineering team scenarios which required the production of a part, but for the purpose of testing, development of engineering recommendations, and other reporting. Additional modifications to the course included two new lab part designs that were real and useful take-home items, the reduction of initial course time spent on measurement instruments, and shifting of some lab demonstration content to pre-existing video demonstrations available on the Internet.

Students in the newly-modified course returned significantly improved end-of-course evaluation scores and no negative comments. Overall student attitude demonstrated significant improvement. The success demonstrates possible techniques for achieving the fine balance between lab learning objectives that straddle machining skills and engineering design and problem-solving.

Introduction

A hands-on design-to-build experience is frequently applied in the freshman year of engineering and engineering technology programs as a means of engaging students early in the curriculum. Some freshman project programs rely on previous student backgrounds and their ability to jump in and apply more approachable tools and technologies. Occasionally an engineering program may skip the student-build portion of the project, allowing the student designers to contract with lab technicians to create prototypes (a practice similar to most engineering situations). Increasingly, however, programs and employers see hands-on process experience as a beneficial foundation for the designer and thus it is becoming common for engineering programs, as well as engineering technology, to provide some level of introduction to prepare students to execute their own design prototype build in the freshman year.

Bernardoni et. al at the University of Wisconsin – Madison (2008)[2] studied the skills freshmen students typically needed for their design projects and developed a training program supplemental to the curriculum to meet this need. More commonly, programs attempt to meet the training need within the required curriculum.

Dillon et. al. at the United States Military Academy (2010)[3] describe a freshman-level manufacturing processes course which culminates in design-to-build project. They have attempted to address typical challenges of basic machining exercises such as (1) providing adequate instruction and practice for students on key processes prior to their design build, (2) distributing a class of students among a limited number of pieces of equipment, and (3) providing meaningful and engaging practice exercises. Their work demonstrates the application of a carefully crafted part design that incorporated key learning opportunities at various pieces of equipment in the laboratory, and resulting in a useful product (a bottle-opener) that could be kept and enjoyed by each student builder. Having implemented some of these changes, they found that students were much more prepared for the design-and-build project.

Kansas State University's Salina Campus program in Mechanical Engineering Technology employs a similar approach of a freshman manufacturing processes course that gives students some hands-on experience with machine tools, forming, and basic welding operations, followed by a design-to-build experience the second semester. The K-State Salina approach differs from USMA's by opting for a more in-depth introduction, spreading processing and design across the two semesters of the freshman year and incorporating CAD modeling and technical drawing along the way (Figure 1).[1]

The two-semester approach culminating in the air-motor project has been applied for over fifteen years, consistently demonstrating the following positive results:

- Machining and fabrication skills sufficient for students to carry out basic mechanical design prototyping needs (with some technician assistance) for the remainder of their design courses.
- Increased appreciation in the importance of a carefully specified part drawing.
- Increased awareness of the costs of tight tolerances (or reckless tolerancing).
- Increased appreciation in the importance of designer attention to manufacturing tooling issues and standard available stock materials.
- Increased appreciation of team communication and management issues.

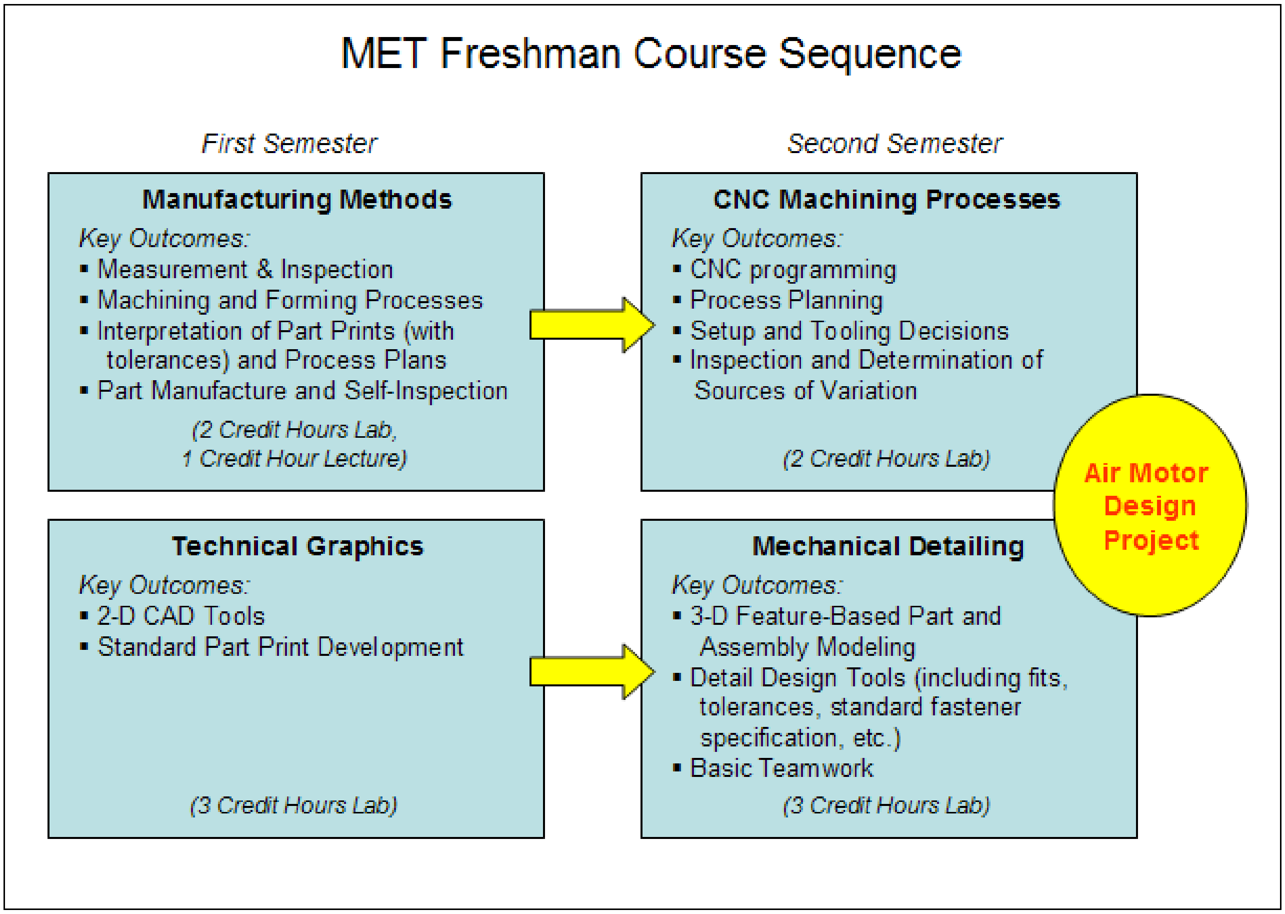


Figure 1. MET Freshman Course Sequence.

Problems to be Addressed

While the end of the two-semester sequence has consistently produced positive results, we have experienced difficulty in getting students to buy into the engineering objectives of the earlier manufacturing processes course.

Our freshman manufacturing processes course straddles both the machining skill world and the engineering problem-solving world: The labs take the opportunity to introduce students to hands-on machining and fabrication techniques, while the classroom and text material introduces a more general view of industrial manufacturing processes, emphasizing foundational technologies, science, and simple math applications relevant to mechanical designers and manufacturing engineers. The text is a standard materials and processes text often used in the sophomore or junior year of industrial or mechanical engineering programs.[4] The course has one credit hour of "lecture" credit meeting in the classroom, in addition to the two credit hours of laboratory (four actual hours per week in the lab, meeting two hours, two days a week). The classroom meeting builds on text homework and applications. Lab time includes introduction of lab-based topics, lab demonstrations, and some discussion attempting to bridge broader, engineering content from the text and classroom.

The course at K-State Salina emphasizes that the lab objective is not to create skilled machinists (though machining skills are valued), but to prepare students to be better engineering designers by increasing their knowledge about the process of building their designs. Discussion of machine functionality, tooling choices, process parameters, sources of variation, measurement options, and other process options seem an integral part of an engineering or engineering technology student's introduction.

Introduction and discussion of engineering concerns *at the equipment* is meant to link the process operation to the deeper learning objectives. However, we found that students are increasingly impatient with demonstration discussion on engineering considerations and tend to disregard as irrelevant topics beyond what they think they need immediately to operate that equipment.

Certainly those of us instructing in the lab (instructor and lab technician) were also frustrated at the time it seemed to take to introduce important processes, tooling, and the process considerations. We were already examining ways to use videos of some of the demonstration content so that students could view it as part of their homework outside of class. Complaints about the length of demonstrations and explanations came as no surprise, but since we had already spent some time struggling with what content we could leave out or defer, student assertions of the *irrelevance* of the material we chose to include in lab demonstrations was disconcerting:

- "Most of the class time is wasted listening to [the instructor] talk about things not relevant to the topic at hand."
- ". . . most of the students have some type of shop history and they know how to do most of the task at hand."
- "The main problem is, it takes [an instructor] 45 minutes to show a person how to do a 15 minute job. After 5 minutes the class is bored and doesn't care."

In short, many students believed the purpose of the demonstration was only what they needed to know to make this one immediate part. In spite of continual reminders that "our purpose is to make you better engineering designers, not machinists," students concluded that the discussion material which we had worked hard to include in the demonstrations was irrelevant and a waste of their time.

Strategy Applied

One of our first thoughts was reduce demonstration time in the lab by creating videos demonstrations and put those online so that students could watch them outside of class (a "flipped classroom" technique). However, this would not completely solve the problem of perceived irrelevance, but rather, just push it into a different timeslot.

As we considered student comments, we had to admit that the emphasis on the lab assignments did, indeed, look a lot like "shop class" assignments, emphasizing the completion of a part within tolerances. We required students to interpret process plans, fill out dimension check sheets, and choose and record their feeds, speeds, and depths of cuts, but the emphasis was on the completed part. If the part was successfully made to specification, there was no need for the student to consider and report on possible sources of quality problems. We were being incongruous in expecting students to be mindful of engineering considerations, while mainly asking for operator-level deliverables in the lab portion of the course.

Of course, hands-on experience building mechanical designs is still needed. We required an approach to balance the need for students to practice both process skills and the application of engineering-level process knowledge.

The strategy we developed involved the modification of part-building assignments to present the building of the part as a step necessary in some engineering task. The engineering tasks were kept at an introductory-level, reasonable for first-year students, often presenting examples of engineering testing, decision-making, reporting, and documentation.

Example 1: Introductory Lathe Assignment

The previous "Shaft 1" assignment required students to practice basic longitudinal turning and micrometer skills in order to make a simple part with stepped-down diameters. Figure 2 shows the updated lab sheet which presents at the top of the assignment an "Engineering Team Problem." The new lab exercise requires the student part to be made as part of a team experiment to sample surface finish obtained by various feedrates.

Improvements achieved by this assignment include new emphasis on:

- The engineering team and engineering's involvement in process parameter specification for production parts.
- The effect of feedrate on surface finish.
- Experimental investigation.
- Surface finish as a specification.
- The importance of reporting results and engineering team decisions.

Lab 2 – Surface Finish of Lathe Part
Part Name: SHAFT 1

Engineering Team Problem:

The "Shaft 1" component has a surface finish specification of Ra 63. The original process plan proposed by a team member specified a finishing pass with a feed of 0.0056 ipr, but some members of the team believe that the faster (roughing) feed rates of 0.0072 or 0.0092 ipr would still meet the surface finish specification. Since this ultimately will be a high-production part, it would be more economical to specify the faster feed rate, if possible.

Testing is needed to **determine if the faster feed rates would be sufficient** to obtain the specified surface finish.

The Team Approach:

☐ A series of sample prototype parts will be built, such that there will be at least one sample part made at each of the following feed rates for the finish pass. (**Each team member will build one sample part**.):
  - 0.0056 ipr
  - 0.0072 ipr
  - 0.0092 ipr

☐ Each team member will inspect his/her part for its as-built surface finish, as well as dimensional values. Please record these on the provided **Dimension Check Sheet**.

☐ After each team member has produced and inspected his/her sample part, **the team will meet to compare results and determine the recommended feedrate for the finish pass**.

Individual Deliverables:

☐ **Finished sample part**, labeled with the operator name and finish pass feedrate used (on masking tape applied to the non-machined surface).

☐ **Dimension check sheet** reporting dimensional and surface finish results.

☐ **Copy of the team memo** recording the team's decision on the feedrate to specify for the finish pass.

Figure 2. New lab instruction sheet highlighting the engineering task associated with an introductory hands-on exercise on the lathe (Example 1).

Lab 4 – Tool Grinding

Engineering Team Problem:

Your engineering team is planning the standard procedure for measurement of custom-ground single-point lathe tools.

Traditionally, machinists in your facility have measured ground tools using a **bevel protractor**, which can be located right at the grinder. However, your facility now provides access to an **optical comparator**, and the engineering team wishes to consider whether final measurement of the tool angles can be better inspected at the optical comparator.

Your Task:

Prepare two different cutting tool geometries and experiment with measurement with both the bevel protractor and the optical comparator.

Note advantages and disadvantages of each of the two measurement processes and report your recommendations to the engineering team.

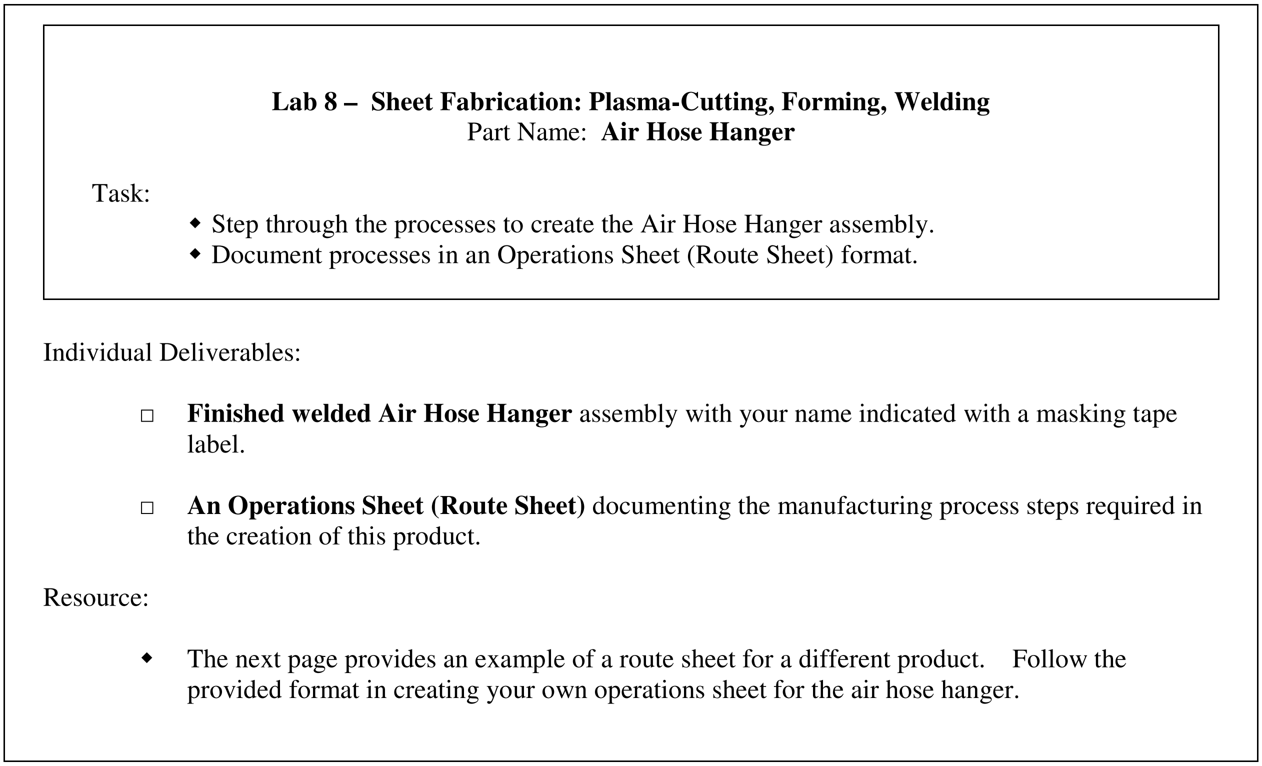
Figure 3. New engineering problem task presented with a project practicing bench grinding and measurement of angles (Example 2).

Example 2: Investigating and Recommending Measurement Procedure

The part for Lab 4 originally required students to safely practice manual control of bench grinding, interpret surfaces at complex angles (as specified on part drawings), and measure the angles using a standard bevel protractor.

The new engineering scenario developed for this lab (Figure 3) addresses the real issue of difficulty in the application of the angle measurement processes. The student engineering practitioner must test both the bevel protractor technique, as well as the optical comparator, to report on the relative advantages and disadvantages of each process for this application, and to recommend which instrument should be specified for final inspection of this part. The new scenario emphasizes:

- An application for the measurement system advantages and disadvantages.
- The role of engineering experimentation and testing.
- The role of the engineer in inspection procedure specification.



Lab 8 – Sheet Fabrication: Plasma-Cutting, Forming, Welding
Part Name: **Air Hose Hanger**

Task:

- ◆ Step through the processes to create the Air Hose Hanger assembly.
- ◆ Document processes in an Operations Sheet (Route Sheet) format.

Individual Deliverables:

- ☐ **Finished welded Air Hose Hanger** assembly with your name indicated with a masking tape label.
- ☐ **An Operations Sheet (Route Sheet)** documenting the manufacturing process steps required in the creation of this product.

Resource:

- ◆ The next page provides an example of a route sheet for a different product. Follow the provided format in creating your own operations sheet for the air hose hanger.

Figure 4. New lab instruction sheet requiring students to formulate and document a process plan (Example 3).

Example 3: Preparing Engineering Documentation

The engineering scenario for the sheet fabrication lab (Figure 4) requires the student engineering practitioner to observe existing processing steps and to communicate them in the format of an Operations Sheet. New elements to this assignment emphasize:

- The engineering role in development of process documentation.
- The importance of standard manufacturing terminology.

Additional Changes

In addition to the new emphasis on “engineering” assignments associated with the processing exercises, we implemented other changes designed to make the course more engaging and more palatable to students:

- Two lab projects were redesigned to result in a useful product that could be taken home and used by the student (similar to the concept practiced at USMA[3]).
- We reduced introductory time on measurement and inspection techniques in order to get students on the manufacturing equipment sooner. We accomplished this by starting at the beginning of the semester with only the basic micrometer and caliper techniques needed

for the first labs, and then introduced other equipment—usually as it was needed--throughout the semester.

- When practical, we reduced laboratory explanation time by assigning students to watch applicable videos as part of their homework. We incorporated these into take-home study guide assignments and backed them up with online quizzes. This small step toward the "flipped classroom" allowed us to skip some basic equipment introduction and focus within our laboratory on details of particular interest.

Results

Although not statistically significant given the small student class size from year-to-year (10 students in 2011, 16 in 2012), the numeric results of student-returned course teaching evaluations showed significant improvement over the previous year. The following response categories showed an improvement of at least one point on a five point scale:

Table 1. Increase in Student Response between 2011 and 2012 Classes on Semester-End Course Evaluation

Evaluation Category	*Change in student response average, 2011 to 2012 (on a rating scale from 1 to 5)*
Increased desire to learn about the subject	+ 1.6
Amount learned in course	+ 1.2
Stimulated thinking about the subject	+ 1.0

Although consideration should be given to differences in student groups, the same survey showed that the 2012 student group only rated themselves, on average, 0.2 points higher in "Interest in the course before enrolling." In "effort to learn," the 2011 group was the one that rated themselves higher, by a 0.4 point difference.

Overall, we hoped for a positive change in student attitude. By early spring, the laboratory technician, not having seen the course evaluations, voluntarily commented that he perceived a noticeable improvement in general student attitude and receptivity to the engineering problem-solving aspect of our curriculum.

Conclusions

Improved student course evaluation responses and overall improvement in student attitudes indicate that incorporating engineering tasks with the hands-on labs, along with other modifications, were successful in improving student receptivity to higher-level engineering concepts.

Some opportunities for continued improvement include:

- The new "engineering" activities developed for these labs were meant to be easily attainable, intending to introduce and encourage thought on the engineer's roles related to manufacturing. Certainly more challenging engineering tasks can be developed that use active learning to more deeply link and reinforce the text and possibly even replace lab discussion material.
- We would like to employ "flipped classroom" techniques to move more of the lab demonstration points to short videos or other teaching objects that students can experience outside of class and lab time.
- The USMA model[3] incorporates a design project into the end of their semester. The Kansas State University Salina Campus course seeks instead to give students more lab exposure and practice with processing technologies, tooling, and techniques the first semester, waiting until the spring semester for the design-to-build project. However, there could be benefit to incorporating a limited design-and-build project experience near the end of the first semester. This would provide a deeper, earlier application of principles learned in the course.

Although only an initial step, the significant positive change in student perspective suggests the usefulness of engineering task assignments to turn student attention to the engineering issues beyond immediate machine operation concerns.

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