Hands-on Manufacturing Concepts Taught to Sophomore Level Students During a Unique Field Session Experience

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Introduction to The Field Session Experience

Over 240 Mechanical Engineering (ME) students at Colorado School of Mines (Golden, CO) are required to take a three-week long, intensive hands-on Field Session course (MEGN201, 3-credit hours) at the beginning of the summer, directly after finals. This course has been designed to improve students’ ability to work with hands-on, open-ended design problems and challenges, specifically related to manufacturing topics found throughout the ME curriculum. Field Session is a designated time set-aside for students to learn about topics that they would not necessarily see in the classroom during their regular semester long courses, especially if lab time associated with the course is limited. As stated by Ssemakula et al., it is critical that manufacturing curricula includes hands-on activities in order for students to successfully learn and understand basic manufacturing topics in the classroom. For this reason, it is essential for ME undergraduates to understand how parts and components are manufactured, with the goal of developing better engineers and designers.

With the incorporation of several open-ended design challenges and hands-on projects throughout Field Session, specifically related to manufacturing topics, students begin to learn the following concepts early on in the undergraduate curriculum: 1) proper dimensioning and tolerancing, 2) manufacturing tolerances, 3) material selection 4) automated manufacturing techniques, 5) manual manufacturing techniques, 6) CAD-CAM processes, and 7) quality control. These topics are critical concepts for students to learn and are concepts that can easily be lost in manufacturing engineering curricula if students are not provided with appropriate hands-on experiences. Additionally, these skills provide an important link between academia and industry.

For the Mechanical Engineering Department at Colorado School of Mines, Field Session is not only a manufacturing and design focused, hands-on experience for students, but also a time for key concepts (listed above) to be taught to students early on in their degree program. With the current revamping of the Mechanical Engineering degree, both manufacturing and design concepts have been added throughout the ME curriculum. During this three-week period, students are taught basic and fundamental engineering skills such as design for manufacturability, engineering design process, modeling, CAD-CAM, manual and automated machining, prototyping, testing, quality control and GD&T all while working on open-ended design problems. Many of these subjects are taught through tutorials created in-house, after which, students apply the learned concepts to open-ended problems and challenges provided.
Throughout Field Session, students are required to complete three open-ended design challenges, which are split up into four phases; 1) SolidWorks and GD&T, 2) Data Acquisition-DAQ, 3) Machining (manual and automated) and 4) a Final Design Project (design process, prototyping with 3D printers, vacuum formers, laser cutters). All four of these phases assist students in completing a final team project, which is set-up as a competition between student groups. Throughout this four-phase process and long working days, students become more comfortable with course content learned in Field Session since they are learning the information and directly applying it to their projects.

Manufacturing Engineering Education Background

The work from Ssemakula et al. published a questionnaire where 25 universities responded about their manufacturing processes courses at respective universities. The survey states that 88% of the Manufacturing Process courses taught at universities had a lab component associated with the course.¹ The Learning Factory is an example of long standing research, providing data on the importance of hands-on learning in manufacturing engineering education. The Learning Factory is a practice-based curriculum with a goal to provide an improved educational experience that emphasized the interdependency of manufacturing and design with a focus in business development.²⁻³ The Learning Factory was originally developed jointly by Pennsylvania State University (PSU), University of Washington (UW), and University of Puerto Rice-Mayaguez (UPR-M) in collaboration with Sandia National Laboratories through the Manufacturing Engineering Education Partnership (MEEP) funded from the ARPA TRP. This approach to manufacturing engineering education provides balance between engineering science, engineering practice and hands-on experiences. Furthermore, the National Academy of Engineering published their attempts to answer the question, “What will or should engineering be like in 2020?”.⁴⁻⁵ The panel convened to discuss globalization and its impact on undergraduate manufacturing engineering curricula, outlining the importance of graduating not only engineers with fundamental skills, but highlighting the importance of technically skilled graduates capable of understanding and operation in global networks.

Recent publications on changes in manufacturing engineering curricula have mostly been limited to changes to outcomes and assessment along with a general attitude of how manufacturing based courses should be taught to students.⁶⁻⁹ Recent changes to curriculum with respect to the layout and format of manufacturing courses are limited to date. This paper attempts to provide general information on the importance of implementing hands-on manufacturing concepts along with design challenges to students during a 3 week intensive Field Session experience where students focus on completing several complex, open-ended projects, while having limited distractions such as homework or exams.

The Field Session Experience
With over 240 ME students graduating each semester in the Mechanical Engineering program, it can be difficult to find the space and credit hours in the curriculum for students to experience hands-on learning. Additionally, with large class numbers, it can be difficult to teach students how to solve open-ended design challenges throughout the curriculum. Field Session is a course that focuses on getting sophomore students involved in both hands-on learning as well as experience with solving open-ended design challenges. At most universities, students will not experience these concepts until Senior Design.

For the past several decades, each undergraduate student enrolled at Colorado School of Mines, completes a Field Session experience with their designated department. This is a graduation requirement at the university. The Field Session experience is designed, campus-wide, to ensure that students are able to apply fundamental knowledge and skills while becoming familiar with solving open-ended design problems. The prerequisite for the Mechanical Engineering Field Session is an Introduction to Mechanical Engineering course (MEGN200), taken sophomore year by undergraduate ME students. This course provides students a semester long opportunity to work on open-ended design problems and is the first time students learn how to solve open-ended problems. Students are taken step-by-step through an engineering design process and shown how to solve complex and open-ended design problems starting with brainstorming and research. Additionally, MEGIN200 teaches students about prototyping and integrating software (MatLAB) to control hardware (Arduinos and sensors) along with testing prototypes and data interpretation and analysis. After students’ Field Session experience, Manufacturing Processes (MEGN381) is taken and expands the concepts and knowledge which students learn over their summer experience into a more advanced manufacturing course that all ME undergrads are required to take.

For the ME Field Session experience, students are expected to treat the course as a forty-hour per week job for three weeks. During this time, students learn key concepts to solving open-ended challenges, are able to apply fundamental knowledge to complex problems, are able to work in teams, communicate, implement time management skills, and think independently. Additionally, students learn about basic manufacturing skills and how to select materials for based on design and manufacturability. These skills are then further developed in the Manufacturing Processes course taken students’ junior years.

The unique traits of this program, which are generally not found in a typical classroom or classroom/lab setting, are as follows:

- Students are able to dive into the Field Session experience without worrying about other courses, homework or exams.
- Students work 40+ hours/week on a designated project, similar to an industrial experience.
• Students are guided through a rotating schedule for completing the various phases of their projects, expecting students to keep a strict time management schedule.
• Students learn how to communicate and manage a project in a team setting.

Additionally, learning outcomes for the course are tied into several modules and tasks that students complete and are analyzed through submission of various phases of the project. The following are the learning outcomes that are used for assessing the course along with their designated Field Session section:

1. Students understand how to approach an engineering design process (Final Project)
2. Students are capable of designing and drawing a part in SolidWorks (SolidWorks)
3. Students understand how to set-up and machine a simple part using the lathe and mill (Machining)
4. Students are capable of setting up the CNC mill and understand how to use MasterCAM and G/M code as well as calculate feeds and speeds (Final Project)
5. Students are capable of using MatLAB and/or LabView for setting-up a design of experiments for analyzing the speed of their race cars using various sensors provided to them. (DAQ)
6. Students are capable of design quality control tests for parts designed (Machining)
7. Student know when and when not to use GD&T (Machining and SolidWorks)

Each of these learning outcomes are assessed based on a portion of the project submission (in parenthesis) which is due for each of the phases. These consist of reports along with the final competition.

The Space

Several spaces have been created for students to work during their Field Session experience. Training on all equipment is provided to students during Field Session through tutorials and instructor/TA support. Through Field Session students can become familiar and comfortable with the equipment and technology provided to them in these spaces early on in the curriculum. This way, students are more willing to work in these spaces throughout their degree program. Through this experience, students will see the benefit of becoming both good designers and at least have a familiarity with building and assembling processes. The overall goal of these three weeks is to get students working, building and comfortable with designing, manufacturing and assembling.

The space that students take-over during Field Session is typically the Senior Design space. Since this course is taken after the spring semester during the summer, there
are no students occupying the Senior Design space during this time. Two additional spaces are open for students; a general Machine Shop for ME students including manual and automated machinery and ‘The Garage’ which is a design and prototyping space where students can use 3D printers, laser cutters, a vacuum former, material testing equipment and quality control gauge pins to build working prototypes and final products. This space was created in May 2013 for several courses including Field Session. ‘The Garage’ is run by student workers and managed by faculty in the Mechanical Engineering Department along with a general shop manager.

The Field Session Project

The overall goal of the Field Session Project is to have students’ design, manufacture and assemble a small, hand-sized, car that will be raced through an automated system, which students design and develop. Throughout this experience there are four phases of the Field Session experience that students must step through:

1) SolidWorks and GD&T
   - Dimensioning, tolerancing and GD&T
   - Open-ended design project (drawing)
   - When and when-not to use GD&T

2) Manual and automated machining (Machining)
   - Safety Training
   - Use of the lathe and mill
   - Speed and feed calculations
   - Quality control measurements
   - Basic understanding of G/M code

3) MatLAB and SimuLink /LabView (DAQ)
   - Overview and use of Arduinos, breadboards and MatLAB
   - Overview and use of LabView
   - Design a system to wirelessly control race-car
   - Design a system to take accurate track time readings
   - Using LabVIEW to control interface

4) Design, manufacture and assemble a mini car (Project)
   - Drawing and designing car chasis and bearings
   - Design for manufacturability
   - Material Selection
   - Use of The Garage and the Machine Shop
   - Assembling processes materials
   - Understanding of a simple motor and soldering battery pack
Each of these four phases that make-up Field Session are taken separately with appropriate faculty and TA support. These sections are taught with the use of tutorials related to the projects, which have been created for students to go through step-by-step. The students are then able to use that knowledge to guide them through their open-ended projects. Each phase of Field Session can be taken at any given time, allowing students to spread out in an organized and structured format.

Throughout Field Session, students work with SolidWorks and are taught GD&T, G/M code, MasterCAM and begin gaining familiarity with what CAD-CAM means (Figure 1 and 2). Additionally, students build the car chassis using the CNC Mill, design and build bearings, couplings and axels as well as assemble a motor which has several set-ups for changing gear ratios (Figure 3). The final step is to use their DAQ stills to set-up a track with sensors to take accurate track time readings.

**Figure 1:** Design of a car chassis using SolidWorks and MasterCAM  
**Figure 2:** Running G/M code on the simulator before using the actual CNC mill  
**Figure 3:** Final assembled car
Field Session Curriculum Overview

- **Machining:** Manual and automated machining
  - Safety overview of space and equipment
  - How to use the manual mill and lathe (1 day)
  - How to use the CNC mill
  - Quality control
  - Speed and feed calculations
  - Material selection and the difference between machining plastics and metalics
  - Analysis of chip formation during cutting processes

- **Project:** Design and build the chassis of a race car
  - Students design their race car in SolidWorks using 3” x 6” x ½” HDPE (high density poly(ethylene))
  - Students must work with the following design constraints:
    - Positioning the motor and axels so there is bottom clearance
    - Design bearings for the axels with equipment that is currently available to them (3D printers, laser cutter, general machine shop)
    - Making sure they have enough clearance in final assembly
  - MasterCAM is taught to students through various tutorials created specifically for the project
  - Basics behind G/M code are shown through a worksheet/tutorials
  - Students are asked to use MasterCAM to create the machine path for machining their car chassis (machine times must be less than 30min)
  - Students test their MasterCAM codes on a simulator before actually machining their parts
  - If there are errors in their code, they must go through the G/M code to change the errors in the simulator
  - Students set-up and machine their chassis on the CNC mill
  - Students machine or use laser cutter to create pillow-block bearings
  - Students solder their battery packs
  - Analysis of gears and motors and how they work
  - Final inspection and de-burring of the part
  - Quality control testing
  - Assembly of the car with proper gearbox set-up
  - Race cars on a flat track and also a hill climb
  - Soldering overview and actual soldering of their battery packs

- **DAQ:** Data Acquisition using MatLAB and Labview to set-up track times and turn on/off their cars wirelessly
  - Students are given an overview of LabView/Simulink through the use of tutorials
  - Students go through a MatLAB overview
Students go through several tutorials that guide them through similar examples to those that they will design for their projects.

- Students will work on designing a program and building a track to take times and record the times of their race cars.
- Students will program their Arduinos to turn on/off their cars wirelessly.
- Test car to make sure it travels in a straight path.
- Add Arduino to car

**SW & GD&T**

- Students go through a four-day intensive SolidWorks review with tutorials.
  - Students are required to get certified in SolidWorks through a program at the university before coming into Field Session.
- Students learn how to properly dimension and tolerance parts.
- Students are taught GD&T basics and learn when and when not to use it.
- Students are asked to design their car chassis in SolidWorks and do several FEA’s on the car chassis.

**Field Session Schedule**

Two sections of the three-week long Field Session experience are run, capping both sections at 160 students (Field Session II does not fill). Due to space constraints, this is the maximum number of students who can take Field Session at once. Generally Field Session I is larger than Field Session II since many students have internships starting the first week in June.

For Field Session, students are put into cohorts of 20 students, having 8 cohorts total. Each of the cohorts go through each of the Field Session sections a different order, once again due to space constraints. The curriculum has been designed so any student can go through any of the Field Session sections at any time, leading to ease of scheduling. Figure 4 below is an example of two cohorts schedules from Summer 2014. Students are given this schedule at an introduction meeting the first day or Field Session.

**Student Surveys**
At the end of Field Session, anonymous surveys were given to students asking them about their Field Session experience. These were the questions given along with the results:

Students were given a likert scale from 1-7 (1 = strongly agree, 4 = neutral, 7 = strongly disagree)

1) After taking the Design Project portion of Field Session, I have more confidence in approaching and solving open-ended design problems where there is no correct answer.

2) After taking the Design Project portion of Field Session, I am more comfortable performing research on open-ended design problems and I am able to use this research to start solving an open-ended design problem.

3) After taking the Design Project portion of Field Session, I feel more comfortable designing a new product.

4) After taking the Design Project portion of Field Session, I feel more confident in my ability to manufacture a working prototype of a new product.

5) After taking the Design Project portion of Field Session, I feel more confident in performing an analysis and evaluating results.

Figure 5: Students survey responses to Questions 1-5
From the data shown in Figure 5, it is found that the highest student responds rate to ‘strongly agree’ was with respect to question 3, stating that after ME students had taken Field Session, they are more comfortable designing a new product. Students also responded positively to question 4, stating that ME students feel more confident in their ability to manufacture a working prototype of a new product. It was surprising that thee was not a higher percentage of students who ‘strongly agree’ to question 1, which stated that after taking Field Session, students had more confidence in approaching and solving open-ended design problems where there is no correct answer. Less than 50% of the students responded with ‘strongly agree’, however over half of the students responded to either ‘strongly agree’ or ‘agree’, still less than questions 3 or 4. One possibility might be due to their engagement in the new MEGN200 course, Introduction to Mechanical Engineering. It is possible that students who were introduced to solving open-ended design problems using an engineering design process had enough experience in which they felt as though Field Session did not improve these skills.

The response to question 5, was the lowest with over 50% of the students stating that they had a ‘neutral’ response or ‘disagreed’ with feeling more confident in performing an analysis and evaluating results. In order to address this, the Field Session committee got together at the end of last semester to discuss changes that should be made to the DAQ portion of Field Session. Field Session 2015 will include a section of DAQ where students are required to use various sensors for their track set-up and analyze the data and results of these differing systems. The goal is to get students feeling more confident in analyzing discriminating values and to start thinking about why these values may be different.

**Assessment and Future Work**

Field Session has been tracked and assessed using annual surveys, senior exit surveys, assessment of course learning outcomes and assessment of student learning outcomes (ABET a-k). For the annual and senior exit surveys, the goal is to track the five Student Survey questions. With changes to our recently accredited Mechanical Engineering degree, along with the addition of a required Manufacturing Processes (MEGN381) course it is thought that when students get to Senior Design, they will be more comfortable with open-ended design challenges, various manufacturing processes and design for manufacturability leading to stronger overall projects and eventually getting students better prepared for industry or graduate school.

ABET student learning outcome (k), an ability to use the techniques, skills and modern engineering tool necessary for engineering practice, is mapped using Field Session as a course. Field Session is used to assess a primary course for student learning outcome, (k). This outcome is analyzed through the use of a grading rubric for grading the final report. It was found that students were competent (80% of the students scored an 80% or better on the graded report based on the rubric) in their
ability to use techniques, skills and modern engineering tool necessary for engineering practice.

Course outcomes (#1-7), listed above are assessed annually and are based on specific grading rubrics specific to certain projects and sections of Field Session. These course outcomes are also evaluated annually. If there is ever a section where students do not perform at a competent level, the course is reevaluated based on that specific outcome. Field Session is run by 3-4 faculty members who analyze course outcome results annually and continuously make improvements to the Field Session experience.

Future work in this course includes enhancement of DAQ and continual assessment and improvement of the course. Additionally, we are planning to bring in other state-of-the-art equipment for student use including a water jet, new lathes and an upgraded quality control table and equipment.

Conclusions

This paper presents an overview of the Mechanical Engineering Field Session experience, specifically related to manufacturing and design. This open-ended experience for students is a unique opportunity for students to jump into several open-ended design problems and work on a team of fellow peer students. The 3-week, 40+ hour/week experience allows students to focus on several open-ended projects, without other course work ‘getting in the way’. Through surveying students who have taken Field Session, it was found that after this experience, the majority of the students felt:

• More confidence in approaching and solving open-ended design problems where there is no correct answer.
• More comfortable designing a new product.
• More confident in my ability to manufacture a working prototype of a new product.

Additionally, students are meeting the course learning outcomes along with student learning outcomes and improvements have been documented and planned for in the 2015 Field Session.

References


