



Promoting Safety Throughout the Design-Build-Test Curriculum

Mr. Michael M. Umbriac, University of Michigan

Michael Umbriac is a lecturer in the Mechanical Engineering department at the University of Michigan, where he teaches the sophomore and junior design-build-test classes.

Mrs. Amy Hortop, University of Michigan

WORK IN PROGRESS:

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Abstract

The undergraduate mechanical engineering curriculum at the University of Michigan has a unique team-based, Design-Build-Test spine of required classes. In each of these design courses, students are tasked with solving an open-ended problem using the appropriate engineering skills and tools. Laboratories and equipment are made available to students for fabrication and testing of their design concept, giving them real-world exposure to engineering. In an effort to continue to keep our students safe, we have implemented several safety procedures for all undergraduate students working on projects. In this paper we present the procedures that are currently used for promoting the safety of our undergraduate students while they are building and testing their projects for these classes. We aim to provide students with appropriate guidance regarding the use of the tools, equipment, and laboratories which they use to build their projects. After describing the structure of the courses and the facilities available, we detail the procedures that are used, in context relative to the current literature and similar programs at other institutions. Specific aspects presented here include machine shop training, exercises on the mill and lathe, procedures for checkout of tools, safety plans, and approvals of both engineering drawings and manufacturing plans. We offer suggestions for procedures that could be adopted by other academic institutions.

Introduction

Yearly, about one thousand students are at some point in our Design-Build-Test curriculum as they work towards their Bachelor's degree in Mechanical Engineering. As an institution, we have a responsibility not only to keep these students safe while giving them hands-on, real-world engineering experiences required for industry, but to teach them to consider safety as part of future design and fabrication. Student outcomes prescribed by ABET state that students should graduate with an ability to design a system, component, or process to meet desired needs within realistic constraints, including health and safety and manufacturability. In addition, graduating students should demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET, 2015). To this end, our department provides state-of-the art facilities for design and fabrication, and we aim to provide students with appropriate guidance regarding the use of the tools, equipment, and laboratories which they use to build their projects.

A review of the websites of our six closest-ranked peer institutions indicates that while they all require students to complete machine shop training before they can use the machines, and some institutions also require the students to sign a safety agreement after completing the training, there is barely any mention of the level of planning (beyond a standard engineering drawing) that students may be required to complete before making individual parts as part of project-based courses. An exception is noted by Kemsley (2011), who indicates that Yale University has now implemented a safety review of all machine shop projects before students can begin work.

The purpose of this paper is to describe the safety procedures that we have put in place and to offer some suggestions for procedures that could be adopted by other academic institutions.

Design-Build-Test Spine

Our undergraduate mechanical engineering curriculum has a unique team-based, Design-Build-Test spine of required classes, one in each of the four years. Students are first exposed to technical problem-solving, teamwork, and real-world engineering in ENG 100, a course offered by the College of Engineering. Engineering 100 is a project-based class in which students work in teams on a somewhat open-ended design project and work individually to understand first-year level technical content and professional communication.

This teamwork is continued in ME250, *Design and Manufacturing I*. This is the sophomore level course, in which students work in teams of four to design and build a remote-controlled machine that must compete to perform specific tasks in an arena. The teams apply what they learn in lecture about engineering drawing, CAD and solid modeling, use of mechanical elements (such as bearings, gears, and springs), engineering analysis, and manufacturing processes. Working from a kit of materials to manufacture the components using the student machine shop, they get hands-on experience using machine tools such as a milling machine, lathe, laser cutter, and water jet cutting machine, as well as a 3D printer. The students learn to choose a strategy, generate concepts for the design, perform analysis on their concept, and then design and assemble the individual components. These designs are tested and verified before a competition at the undergraduate symposium every semester.

A similar competition-type project is given in ME350, *Design and Manufacturing II*. This is the junior level course, where the emphasis is on the model-based design of mechanical and mechatronic systems. The students learn the design of mechanisms, the design of mechanical elements for strength, and mechatronics. Mechatronics is the synergistic integration of mechanics, electronics, control theory, and computer science within product design and manufacturing, in order to improve and/or optimize its functionality. (French standard NF E 01-010)

The concluding course in this sequence, ME450, *Design and Manufacturing III*, is the senior level course. This course gives students an opportunity to collaborate in teams to apply a design process from eliciting user needs through to prototype validation on an open-ended design challenge as part of a capstone design experience.

Complementing these Design and Manufacturing courses are two Laboratory experiences. *Laboratory I* introduces the student to the basics of experimentation, instrumentation, data collection and analysis, error analysis, and reporting within the context of fluid mechanics, thermodynamics, mechanics, materials, and dynamical systems, while *Laboratory II* projects are designed to demonstrate experimental and analytical methods as applied to complex mechanical systems, with an emphasis on laboratory report writing, oral presentations, team-building skills, and the design of experiments.

Unfortunately, in giving students these real-world experiences and work environments, accidents at universities do happen and have happened. (Benderly, 2016) It is the goal of the mechanical engineering department, instructors, and staff to ensure that students have the tools, environment, and education to design an artifact that is safe and to fabricate and test it safely.

For each course within the Design-Build-Test sequence, students are responsible for submitting information that is specific to that course. Consistent across all classes in the sequence is the requirement of having a manufacturing plan for parts fabricated in the undergraduate machine shop. We feel that a manufacturing plan, written by the student, is an important tool for promoting students' safety because it requires the students to consider all aspects of fabrication before coming into the machine shop. This includes finding the correct tool speeds and method of fixturing the workpiece. We require the students to write a manufacturing plan for each part they intend to make, and then have the graduate student instructors and machine shop personnel review that plan along with the engineering drawing, before the students come to the shop. This process is described in more detail in a later section. In this way, we aim to greatly reduce the occurrence of "rushing to get a job done", knowing that mistakes and accidents could occur as a result. (Jiminez et al, 2014)

Similarly, for a capstone design class in which each student team is building a unique project, we believe that requiring the students to write a safety plan and to get it approved by the instructors before construction will ensure that they will consider the safety risks that could occur during the build and test phases of their project, and to take corrective actions to eliminate or minimize these risks. Some peer institutions also have a similar requirement (Kemsley, 2011.)

Design-Build-Test [Work space]

Upon completion of renovation work currently underway, our students will have over 9,000 square feet of collaboration and fabrication space available to them throughout the Design-Build-Test sequence of classes: An undergraduate machine shop, and assembly room, and a mechatronics laboratory.

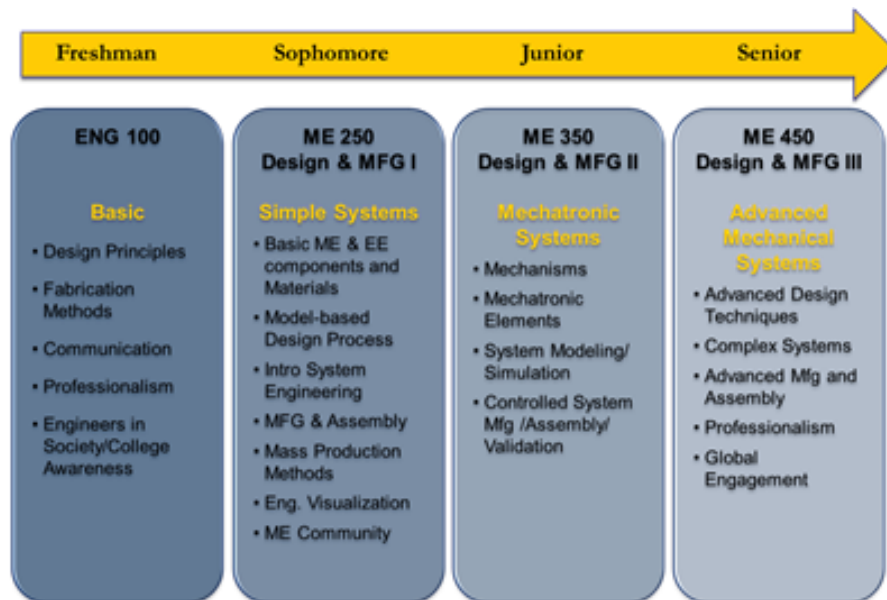


Figure 1: Sequence of Courses in the Design and Manufacturing Spine (Source: Professor Diann Brei, University of Michigan)

Staffing of and access to instructional labs

The staffing of the instructional labs is in line with models followed by universities. Barrett et al. (2015) discovered that the most common model identified for staffing of maker spaces utilized a combination of student support and specialized staff personnel. Forest et al. (2014) noted that in Georgia Tech's Invention Studio, training on the most complex equipment is handled by a university staff machine shop professional.

At the University of Michigan, the mechanical engineering machine shop is staffed by two full-time machine shop technicians who have significant prior experience working in machine shops. There are additional part-time employees (work-study students) who are the attendants for the tool crib in which the machine shop tools (milling cutters, measurement tools, etc.) are housed. The mechatronics lab, described below, is staffed by one full-time employee who is also the team leader of the machine shop technicians. He can fill in when one of the machine shop employees is on vacation. Students in the junior year use the mechatronics lab only under the supervision of a Graduate Student Instructor or the mechatronics lab supervisor. Students in the

senior year have access to the mechatronics lab outside of the regularly staffed hours. The assembly room (see below) is not staffed, but access is restricted to students who are taking the junior and senior level design classes. Access to the mechatronics lab and assembly room is controlled with an automated card reader which is keyed to the student ID cards of eligible students. The sophomore level shop is open only during lab sessions, which are taught by a graduate student instructor.

A summary of the safety controls and levels of access is shown in Figure 2.

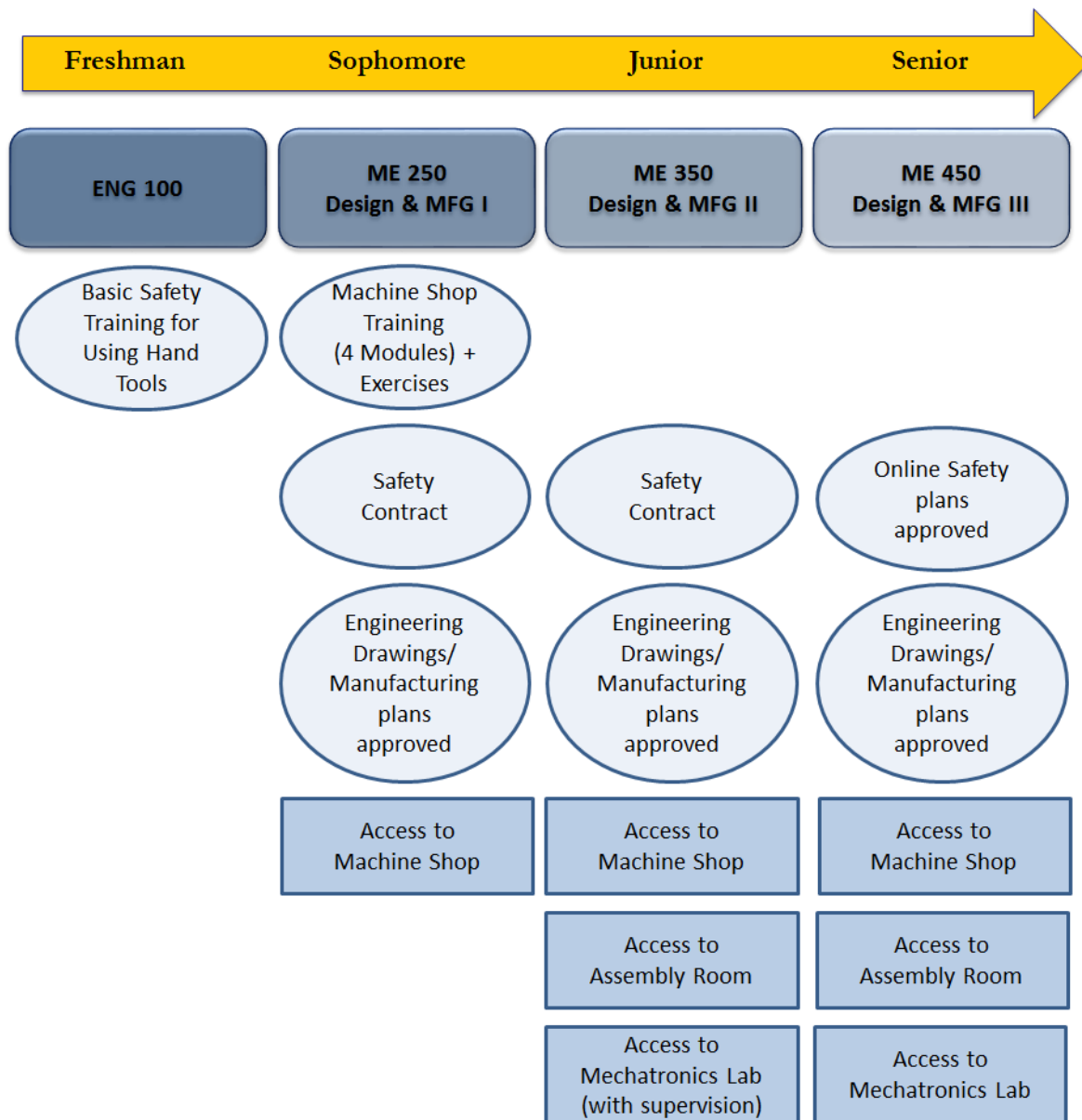


Figure 2: Safety Controls and Levels of Access to Facilities

Assembly Room and Mechatronics Laboratory

In the assembly room, students have access to non-powered hand tools, mockup materials, and collaboration space. Since power tools are housed in the machine shop, students in their junior and senior years are able to use the assembly room without supervision.

The mechatronics laboratory houses Arduino microcontroller boards, power supplies, motors, and other mechatronic components available for use by junior and senior mechanical engineering students, and has limited supervision. Students are expected to submit a safety plan for any prototype testing beyond the common junior-level project in this laboratory.

Rules

In the mechatronics lab, students are not allowed to work alone. At least two individuals must physically be present in the lab. Teams are responsible for leaving the the work benches clean for the next team to use the spaces. Equipment in the mechatronics lab poses the risk of high voltage or current, which can be deadly, and carries the extra rule of having projects inspected by an Instructor, a Graduate Student Instructor, or the lab supervisor, prior to powering it up.

Machine Shop

Rules

Machine shop rules and protocols have to be followed at all times while accessing and working in the machine shop. Every student is required to read and understand these rules described in the document “Machine Shop Rules.” This document is distributed as a paper handout, posted on the course website, and posted on the wall of the machine shop. Failure to follow machine shop rules will result in temporary or permanent loss of shop privileges.

These rules include the use of safety glasses and proper attire without exception. Students showing up in, for example, open toed shoes or loose flowing garments or muscle shirts will be turned away from the shop. An authorized supervisor must be present in the same lab, at all times, but students are responsible for working safely and keeping both their work area and the shop, in general, clean.

Machine Shop Training

Training is mandatory for all undergraduate mechanical engineering students before they are allowed to use the machine shop. This training is first offered during the sophomore year, but also made available to all transfer students. This training consists of four machine shop training modules that must be completed in the department undergraduate machine shop: cutting/drilling, lathe, mill, and precision measurement. The instruction is comprehensive, as recommended by

Backes and Nawolksi (2013), including general topics related to safety in the machine shop as well as specific topics for particular machines. These instruction modules are taught in small groups. Following these four modules, students must individually complete a separate Lathe exercise or Mill exercise, the details of which are described below.

Process for checkout of machine shop tools

When students use the machine shop, we must ensure that they have first completed the machine shop training. The training is recorded in an online database. When a student goes to the tool crib to check out tools such as milling cutters and measurement tools, the crib attendant takes the student's ID card and uses the database to verify that the training was completed. The crib attendant then keeps the student's ID card and gives the student a set of 10 tool tags which can be exchanged, at the same crib, for tools.

Mill and Lathe exercises

A few years ago, we recognized that the sophomore students needed hands-on experience with the mill and lathe machines before they could use these machines to build their projects. (The mills and lathes have controls which are much more complicated than those of the drill presses or bandsaws.) Two issues were identified. Firstly, although the machine shop technicians demonstrated safe practices during the training, this was not hands-on training for the students. Secondly, there were two months between the end of the training and the start of the project work. During this time, students could forget some of the procedures. Other researchers have reported similar findings (Haynie, 2009.)

To resolve both of these issues, the machine shop technicians developed mill and lathe exercises, shown in Appendices A and B. The students have one month to complete the mill and lathe exercises after they have completed the machine shop training. Each student must complete either the mill exercise or the lathe exercise, and students have the option of doing both exercises if they wish. Each team of four students must have one or more students competent in the mill and lathe exercises. The mill and lathe exercises effectively bridge the gap between the machine shop training and the project work.

Safety contract

After completing the machine shop training, each student must read and sign a safety contract, a use agreement which is shown in Appendix A. This sheet was adapted from one used by the junior and senior level lab classes. The safety contract is not a waiver of liability; rather, it reinforces the students' awareness of the risks and the safety practices associated with working in a machine shop or laboratory environment. Some other academic institutions have reported using a similar agreement. (Ssemakula, 2015, and Haynie, 2009)

Process for approvals of Engineering Drawings and Manufacturing Plans

Before the students can fabricate any part in the machine shop, we require that the student have an approved engineering drawing and manufacturing plan for the part. While engineering drawings are standard practice in industry, manufacturing plans in industry usually take the form of process sheets, used in mass-production operations. The manufacturing plan (a sample is shown in Appendix D) lists each operation to be performed, the machine tool and other tools to be used, and the machine tool settings such as speeds. In writing these plans, students can refer to the online course management system for reference material such as speed charts and the drill and tap chart. While process sheets have the function of communicating and documenting a procedure, the manufacturing plans have the additional function of requiring the students to consider all the details of the procedure before coming into the machine shop. It helps them to use their shop time most efficiently.

In order to create an engineering drawing, students must have training in both engineering drawings and CAD. The instruction in engineering drawings, dimensioning, and tolerancing is given in lecture, while the instruction in CAD is given in the lab section of the course. In the lab, each student works at their own pace through a set of 5 CAD modules, with assistance from the graduate student instructor as needed.

To get their drawings and manufacturing plans approved, the students must submit them to their graduate student instructor (GSI.) For each part that is to be fabricated or altered, the student creates a drawing approval package. The package consists of a drawing approval sheet (Appendix E), the engineering drawing, and the manufacturing plan.

For each approval package that the students submit, the GSI reviews the design and the use of proper drafting standards. The GSI may approve the design as drawn, approve it with notes, or reject it. The GSI would reject the design only if the practices are unsafe (insufficient fixturing, or tool speeds that are too high, etc.) The GSI then leaves the approval package in a box for review by the machine shop technicians. The technicians review it for safe manufacturing practices. Again, the machine shop technicians may approve the design as drawn, approve it with notes, or reject it. The machine shop technicians are not overly burdened by having to do the drawing approvals, because the approval package has already been pre-screened by the GSI.

The approval package is then returned to the student. Depending on the status, the student may have to correct the mistakes and resubmit it for approval.

The entire approval procedure usually takes a couple of days from the time the student submits the approval packages to the time they are approved.

Safety Plan for Build / Safety Plan for Test in the capstone design course

Experience has shown that students cannot be reminded enough times about the need to keep safety considerations paramount.

Throughout our design sequence, students are introduced to the process of documenting, assessing, and eliminating safety risks in the design process. At the sophomore and junior level, the principles of safety by design are introduced and the principles of machine shop safety and safe product testing are reiterated throughout the semester. At the senior level, even more emphasis is put on designing safe products and safely building and testing prototypes.

By the time students have reached their capstone design course, the onus is on the students to develop and demonstrate their own safe working habits. Students are expected to be responsible first and foremost for their own safety. With sometimes more than 30 unique projects being offered each semester, it is a challenge for instructors to teach general safety procedures that would be applicable to each and every team's manufacturing and testing plans.

For this reason, each capstone team must appoint a safety officer: a student within the team tasked with watching the team for safe practices and communicating with course instructors about any upcoming build or test activities via a safety plan. An online safety plan is required to be filed by each capstone team and approved before the initiation of any physical testing, prototyping, or laboratory experimentation. The safety officer logs onto the safety plan submission website (developed within the mechanical engineering department), fills out the safety form for prototype development and the form for testing, and submits the plans to instructors. This document records the details of any planned fabrication and validation and must show that not only the proposed activities are reasonably safe to the team and broader stakeholders, but it also must clearly communicate that potential hazards have been designed out of the system or minimized to acceptable levels. Safety Plans are reviewed by the section instructor, the course GSI, and department staff. If necessary, reviews may involve further discussion with each team to address any concerns. The results of these reviews/discussions will be shared with the capstone course coordinator, with appropriate action taken to assure that all senior level projects are incident-free. Aspects of projects featuring questionable safety characteristics will not move from paper to physical realization.

Simultaneously, students submit a manufacturing plan inclusive of engineering drawings for any prototype fabrication work being planned. For a capstone design team to be able to go forward with their intended prototype development or testing plans, both the safety plan and the manufacturing plan have to be approved. Once approved, students may reserve equipment and/or laboratory space to proceed with their plan. If it is not approved, instructors or staff will request edits to either plan, which will then need to be re-submitted. This communication has helped to avoid potential hazards, with more than one set of eyes looking out for likely trouble. Moreover, it has helped to improve the safety content delivered in lecture, and written feedback has helped students recognize and follow safer practices.

If any activity proposed in a safety plan is deemed sufficiently dangerous, the team will be required to conduct some/all of it under supervision from their section instructor. If the section instructor cannot make it to the only available testing time, the course GSI may be present instead.

Resource Coordination

The machine shop, mechatronics lab, and assembly room are resources that are shared between multiple courses taught by different instructors, some of whom rotate from year to year. Before the start of each semester, a meeting is held to ensure that all instructors who are using the labs understand the safety practices and communicate them to the students. In this meeting, the timelines of the courses are also compared and adjusted to minimize the number of bottlenecks in the shops. In particular, the project for the junior course is structured so that the students finish most of their work in the machine shop by the middle of the semester, then take their project to the mechatronics lab for the second half of the semester. In this way, the machine shop is more available for the sophomore and senior courses, and shop supervisors are able to more closely monitor safety.

Improvements to the Current Process, and Future Work

Even with the training and exercises detailed above, it has been observed that multiple teams would submit drawings as part of our approval process, each with the same mistakes. Students were disappointed in having to fix these mistakes under the time pressure of building their project, and instructors realized that the students needed more practice creating engineering drawings and manufacturing plans before having to create drawings specific to their projects. A homework assignment has been added in which students must make an engineering drawing and manufacturing plan of a standard part. This assignment is graded and returned to the students with feedback before they have to make drawings for their projects.

After seeing common errors made by the students, a checklist of items to check in their drawings before submission of their approval packages has also been provided to the students. In addition to ensuring safe and efficient fabrication of parts, this approval process prepares the students for drawing approval procedures that they will encounter in industry.

To assess the level of safety awareness and learning across the entire Design-Build-Test sequence, this same assignment will be given in the future to students in all four years of the undergraduate curriculum. Safety plans and manufacturing plans will be assessed to find differences in skill and learning levels between students in each year level. It is hoped that those students in their senior year will touch on many more aspects of safety to consider than those in earlier years, but this assessment may also point to aspects of our current procedures that would benefit from instructional improvement.

Conclusions

Academic institutions that wish to improve their culture of safety for student design/build/test projects might consider adopting the requirement for signoff of engineering drawings and manufacturing plans for introductory design courses, and add the requirement for review and signoff of safety plans for capstone design courses, as these activities prepare the students for the procedures that they will face in industry after graduation.

Some academic institutions find that students forget the procedures that they learned in the machine shop training for operation of complicated machines such as the mill and lathe. In these cases, it might be beneficial for the institution to require the students to complete simple mill and lathe exercises, similar to the ones given in the appendices, before working on their projects.

Acknowledgements

We would like to acknowledge the contributions of our colleagues and thank them for their efforts. Toby Donajkowski, Mark Stock, John Hall, and Charlie Bradley provided valuable feedback on the guidelines for approval of engineering drawings and manufacturing plans. Bob Coury developed the mill and lathe exercises, as well as the process for checkout of machine shop tools. Toby Donajkowski continued to develop the safety procedures in the machine shop. Professor John Hart oversaw the development of the original signoff procedure for the engineering drawings and manufacturing plans. Professor Shorya Awtar developed the procedures for resource coordination between classes. Professor Volker Sick provided the safety contract from the lab classes, which was used as the model for the safety sheet used in the design and manufacturing classes.

References:

1. Haynie, W. J. III, "Safety and Liability in the New Technology Laboratory" *Technology Teacher*, v69 n3 p31-36 Nov 2009.
2. "Safety and Health in the Technical Classroom and Laboratory: Part 1," 2013, *Techniques: Connecting Education & Careers*, 88:2 pp.44-47.
3. Jimenez, M., Romero, L., Dominguez, M., Espinosa, M.D.M., (5S Methodology Implementation in the Laboratories of an Industrial Engineering University School), *Safety Science* 78, pp. 163-172, 2015.
4. Forest, C.R., Moore, R.A., Jariwala, A.S., Ngo, P., Quintero, C., "The invention studio: A university maker space and culture" *Advances in Engineering Education* 4 (2), 2014.
5. Barrett, T.W., Pizzico, M.C., Levy, B., Nagel, R.L., Linsey, J.S., Talley, K.G., Forest, C.R., Newstetter, W.C. "A review of university maker spaces", Paper presented at 122nd ASEE Annual Conference and Exposition, 2015.
6. Ssemakula, Mukasa E., "Ensuring Safe Use of the Machine Shop by Students", Paper presented at 122nd ASEE Annual Conference and Exposition, 2015.
7. Kemsley, J.N., "Improving shop safety", *Chemical and Engineering News*, Volume 89, Issue 42, 17 October 2011, Pages 56-57.
8. *Criteria for Accrediting Engineering Programs* - ABET, <http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf>
9. Benderly, Beryl L., "No Accident", *ASEE Prism*, January 2016.
10. "Mechatronics - Vocabulary", French standard NF E 01-010

[This page is to be signed and turned in to your instructor.]

Phone Numbers: **EMERGENCY: 911**
 Department of Public Safety: _____
 ME Facilities Office: _____

As in many engineering environments, students in the ME X50 classes will be working with equipment, materials, and power sources which, if used improperly, can present a serious safety hazard. While the laboratory equipment and procedures have been designed with your safety in mind, negligent use of the equipment can result in unsafe situations and possibly serious injury. We remind you to be especially aware of your own personal safety and that of your classmates as you work on your projects.

Potential Safety Hazards include, but are not limited to, the following:

Rotating machinery	Flying debris
Electrical power	Loud noises
Powered mechanical equipment	Chemicals such as solvents and adhesives

None of the items listed above will present a serious risk if proper attention is paid to the written laboratory instructions and the guidance of your section supervisor (GSI, staff, technician). If, at any time, a situation develops which you deem to be unsafe, do not proceed, and immediately report it to your section supervisor. Also be aware that if you are taking certain medications, this may affect your ability to operate machinery.

Students will be expected to behave in a responsible manner while using the machine shop, _____ shop, X50 Mechatronics Lab, and X50 Assembly area. The lab section supervisor (GSI, staff, technician) is responsible for maintaining a safe laboratory environment. If at any time the section supervisor feels that a student is disregarding this warning and willfully acting in an unsafe manner, the section supervisor has been instructed to expel the student from the lab and report this action to the course instructor.

Safety glasses and proper clothing must be worn at all times while in the laboratory. Safety glasses with a Z87 rating must be provided by the student. (Ordinary eyeglasses do not satisfy safety requirements). Open-toed shoes, high-heeled shoes, dangling hair, ties, long necklaces, and scarves should not be worn. Food and beverages are not allowed in the labs.

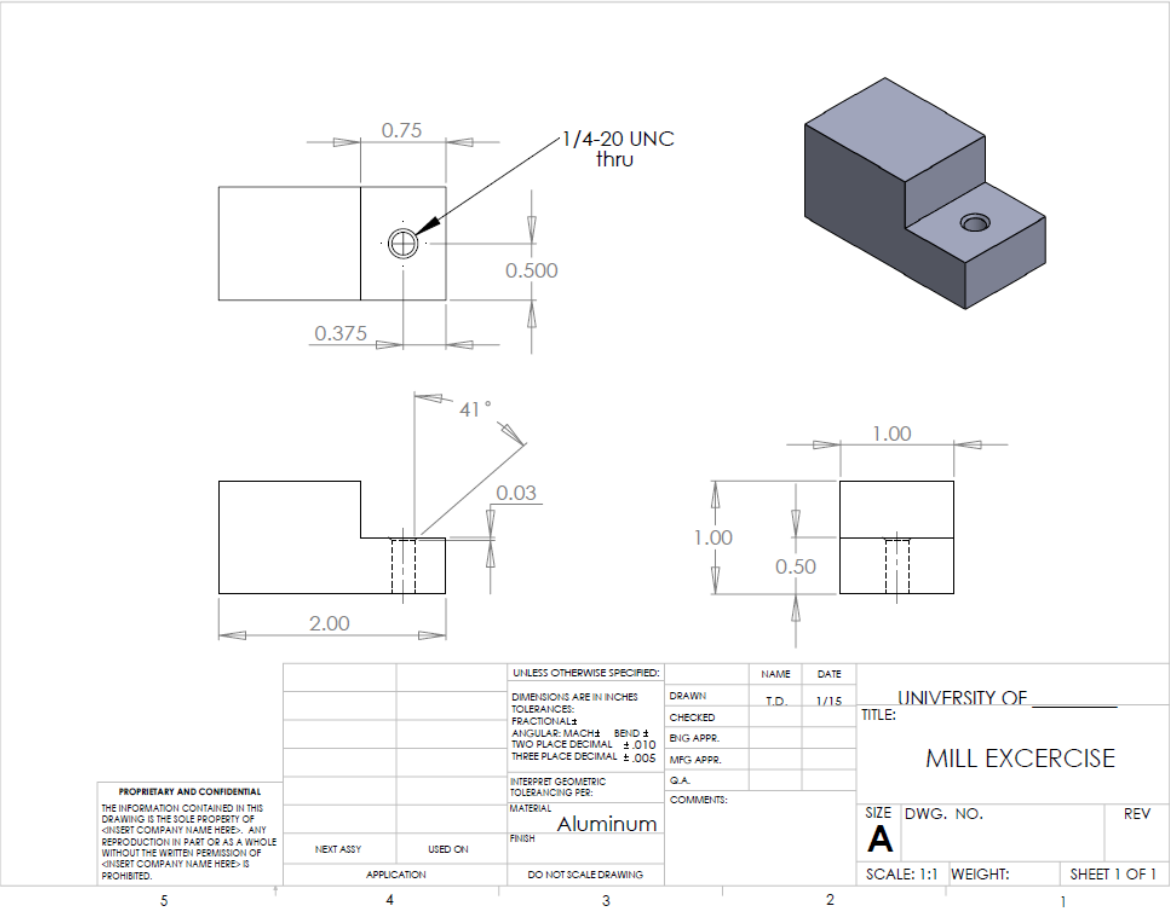
As practicing engineers you will be often be working around potentially hazardous machinery. Always think about the consequences of your actions before proceeding, and if you are unsure, do not continue until your questions or concerns are dealt with.

I have read the above safety information and the X50 machine shop rules, attended machine shop training, and agree to abide by the safety rules of the X50 classes.

Printed Name _____ Section _____

Signature _____ Date _____

Appendix B: Mill Exercise



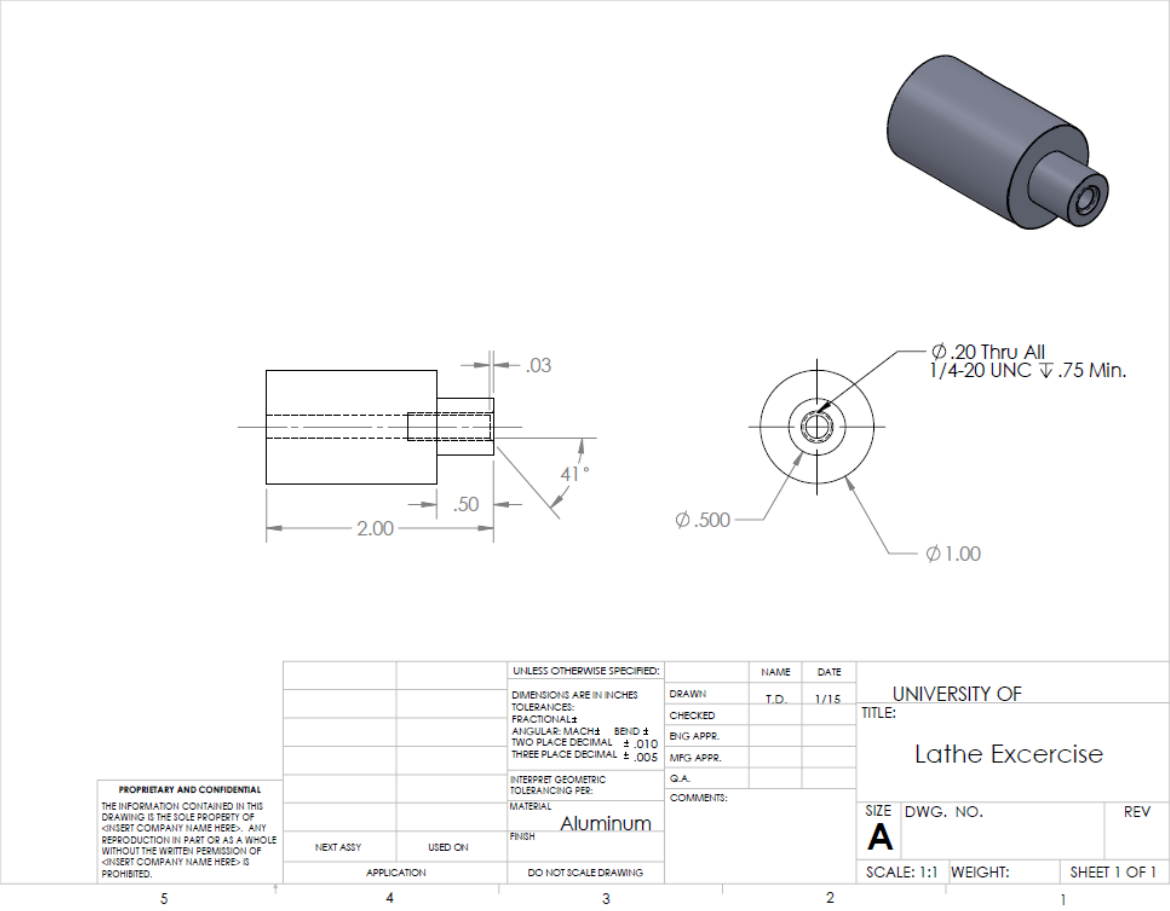
Mill Exercise

Tools you will need to check out from tool crib: 3/4 inch 2 flute endmill, 3/4 inch collet, 1.375 parallels, caliper, drill chuck, edgefinder, #3 center drill, #7 drill bit, chamfer.

Always ask the shop staff questions if you are in doubt about any manufacturing process for your safety and to ensure success with your task.

1. ☐ Take materials, tools and drawing to mill. Make sure vise is installed and work surface of vise is clean. Place part in vise on top of parallels with >.125" material sticking out the right side of vise to allow access with the left side of the endmill, tighten vise. Install stop on left side of material.
2. ☐ Install collet and endmill in spindle and tighten drawbar as instructed in training.
3. ☐ Ensure spindle range lever is in Hi position. Turn spindle switch to hi range and set speed to 840 rpm.
4. ☐ Lower spindle half of its travel and raise table as needed to engage the full side of material with the side of endmill.
5. ☐ While the spindle is turning, engage the material with the end mill by moving the table along the X axes. When you see the first chip, stop the table, zero X on the read out and mill .010" per pass until side is fully machined.
6. ☐ Remove part and file off all burrs.
7. ☐ Place part in vise to machine other end of part. Repeat step 5. Once you have 2 machined parallel surfaces, measure with calipers and bring to 2.000". Zero X axes on read out. Move X to -.375 and re-zero to compensate for the endmill radius.
8. ☐ Remove part break all edges with file and go to surface plate and use height gauge to mark part to remove .5 X .75 area of material.
9. ☐ Place part in vise and up against the stop. Move endmill to X-.730 and establish Z0. Mill to a depth of -.480 with passes no more than .050. Measure and bring to size.
10. ☐ Remove part from vise, break all edges with file.
11. ☐ Remove cutter and collet and install edgefinder and set velocity to 1,000 rpm or less.
13. ☐ Find datum lines for X and Y. Move to hole location. Install centerdrill set spindle speed to 1200 rpm.
14. ☐ Centerdrill and drill with #7 drill bit. Install chamfer, set spindle range lever to low. Start spindle in low and set velocity to 100 rpm. Establish Z0 and chamfer to a depth of .0325 in..
15. ☐ Remove part from vice and take to tapping machine. Install 1/4-20 tap and engage hole in part with clockwise rotation.
16. ☐ Reverse tap, remove and clean tap. Remove drill chuck from and part from machine.
17. ☐ Clean tools, machine and surrounding floor. Return tools to crib.
18. Write name/# on part and drawing. Place part and drawing in designated spot. Part will be available if you would like to keep it when the term ends.

Appendix C: Lathe Exercise



Lathe Exercise

Tooling needed from Tool Crib: #3 center drill, #7 drill bit, ¼"-20 (2) flute tap and tap handle, chamfering tool, 0-1" micrometer and a pair of calipers.

Always ask the shop staff questions if you are in doubt about any manufacturing process for your safety and to ensure success with your task.

- ☐ 1. After collecting the tooling from tool crib, locate the 1.00" diameter aluminum round stock. Measure approximately .125" over the finish length of the part and cut off using the band saw.
- ☐ 2. Hand file off the burr left from the band saw and install the material into the collet on the Lathe. Remember the 3:1 ratio discussed during the training.
- ☐ 3. Rotate the potentiometer speed control all the way counterclockwise to zero then turn the power on to the lathe. Turn the spindle on by engaging the spindle lever downward to start the spindle rotating in the correct direction. Adjust the velocity to approximately 750 rpm by rotating the spindle speed control potentiometer clockwise.
- ☐ 4. With the spindle running touch the end of your part with the tip of the tool, then retract the tool in the X-axis and set Z to zero.
- ☐ 5. Move the Z-axis inward to cut approximately .020 off the end of part, continue this until the end of the part is cleaned up. Once you have a completely machined surfaced, remove the burr from end.
- ☐ 6. Remove the part and flip 180 degrees to repeat the process on the other end. If you have a "stop" installed, make sure the part is up against it.
- ☐ 7. Repeat steps 4 and 5 until the part is cleaned up. Once cleaned up, re-zero the Z-axis.
- ☐ 8. Remove the part and measure the length. Re-install the part and continuing cutting until the required length is met, then set a new Z-zero.
- ☐ 9. With the spindle running, touch the outside of the 1" diameter with the tool and retract in the Z-axis and set X to zero. Ensure that the digital readout is in diameter mode (icon in upper right of screen).
- ☐ 10. Move the tool to the end of the part and remove .100 of material off the diameter in the X-axis to a length of .480 in the Z-axis, repeat this four times. On the fifth pass, remove an additional .080 off the diameter. Now take a .005 deep cut (your readout should read .485 at this point). Re-zero the X-axis after this cut.
- ☐ 11. Stop the spindle and measure the diameter using the micrometer. Remove the difference to machine the diameter to print. On this final cut, traverse to the finish length in Z (.500") and retract the tool once you reached this final length. Remove all burrs at this point.
- ☐ 12. Install the drill chuck into the quill of the tailstock and then install the #3 center drill. Move the tailstock within range of the part and lock it into position. Apply cutting oil to the center drill and drill to a depth of approx. three quarters of the way up to the major diameter of the center drill.
- ☐ 13. Remove center drill and install #7 drill bit into the drill chuck. Peck drill through entire part, liberally applying cutting oil.
- ☐ 14. Install the chamfer tool, slow spindle speed to 100 rpm using the speed control potentiometer. Turn chamfer in until it comes into contact with the hole, turn quill in an additional .032 to create the proper chamfer depth.
- ☐ 15. Remove drill chuck and install a live or dead center into the quill of the tailstock.
- ☐ 16. Install the ¼-20 tap into the tap handle. Now place the tip of the tap into your thru hole and capture the back end of the tap handle using the live or dead center in the tail stock this keeps the tap in proper alignment. Turn the tap handle and quill forward simultaneously keeping the center in contact with the tap handle, until you reach the required thread depth.
- ☐ 17. Clean the lathe and return the tooling to the tool crib.
- ☐ 18. Write name/# on part and drawing. Place part and drawing in designated spot. Part will be available if you would like to keep it when the term ends.

Appendix D: Sample Manufacturing Plan (for the Mill Exercise)

Manufacturing Plan

Part Number: ME250-001

Revision Date: 9/26/2012

Part Name: Mill Exercise

Team Name: _____ Staff

Raw Material Stock: 6061-T6 Aluminum, 1 x 1 x 2-1/8

<i>Step #</i>	<i>Process Description</i>	<i>Machine</i>	<i>Fixtures</i>	<i>Tool(s)</i>	<i>Speed (RPM)</i>
1	Hold part in vise.	Mill	vise		
2	Mill one end of part, just enough to provide a fully machined surface.	Mill	vise	3/4 inch 2-flute endmill, collet	840
3	Remove part from vise. Break all edges by hand.			file	
4	Place part in vise to machine other end of part. Mill the part to 2.00 length, taking several passes at .05 inches per pass. Turn off the spindle, and measure part with calipers.	Mill	vise	3/4 inch 2-flute endmill, collet	840
5	Remove part from vise. Break all edges by hand.			file	
6	Mark the part to remove .5 x .75 of material.			Height Gauge, Surface Plate	
7	Place part in vise and use endmill to remove material. Turn off the spindle, and measure part with calipers.	Mill	vise	3/4 inch 2-flute endmill, collet	840
8	Remove part from vise. Break all edges by hand.			file	
9	Remove cutter and collet. Install drill chuck. Return part to vise.	Mill	vise	drill chuck	
10	Find datum lines for X and Y.	Mill	vise	edge finder, drill chuck	900
11	Centerdrill and drill the hole.	Mill	vise	Center drill, #8 drill bit, drill chuck	1600
12	Chamfer the hole.	Mill	vise	Chamfer, drill chuck	100
13	Tap the 1/4-20 hole by hand, using the center to align the other end of the tap.	Mill	vise	Center, drill chuck, 1/4-20 tap and handle	

Appendix E: Cover Sheet for Approval Package

Revised 1/30/2013

Approval Sheet for Drawings and Manufacturing Plans

Course Number: _____

Team Number or Name: _____

Name of GSI: _____

Email address of Team Captain: _____

For each part that you intend to make in the machine shop, this approval sheet, the engineering drawing, and the manufacturing plan must be stapled together, in that order. Do not staple drawings and manufacturing plans for multiple parts together.

The engineering drawing does not have to use the standard title block posted on CTools, but it must include general tolerances.

The manufacturing plan must use the standard format posted on CTools. The manufacturing plan is not required for parts made on the waterjet or laser cutter.

The course staff expects the students to make the changes that are listed here. After you make the changes, staple the revised sheets to the back of this package. There is no need to resubmit.

Approval from GSI: _____

Comments from GSI:

Approval from Machine Shop: _____

Comments from Machine Shop: