

# **A Manufacturing Systems Capstone Course**

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## **INTRODUCTION**

Capstone courses serve a valuable function in Engineering and Engineering Technology curricula. Typically these courses offer the student an opportunity to integrate the lessons learned in engineering science classes, as well as transition from the textbook problems with a limited scope to more open ended problems.

A capstone course also offers the opportunity to fill in some gaps in the student's academic background prior to entering the professional ranks.

The Society of Manufacturing Engineers (SME) [1] has developed a quantitative survey instrument to measure the technical and professional competency of newly hired manufacturing engineers and rate how well these new engineers met expectations. If the survey respondent rated a competency of a new engineer as "below" or "well below" expectations, they were asked to rate how important this competency was to the success of their company.

Using the results of this survey SME ranked the competencies in order by their importance to organizations and the frequency they were cited as falling short of expectations. The competencies are listed below in order.

1. Business knowledge/ skill
2. Project management
3. Written communications
4. Supply chain management
5. Specific manufacturing processes (hands-on experience in at least one process)
6. Oral communications/ listening
7. International perspective
8. Manufacturing process control
9. Quality
10. Problem solving
11. Teamwork/ working effectively w/ others
12. Materials
13. Product/ process design
14. Engineering fundamentals
15. Personal Attributes

This listing proves a good source of input for the design of a manufacturing oriented capstone course.

In addition, the thrust of the course should be determined. Manufacturing engineering encompasses a wide variety of topics. Several valid approaches are possible in a capstone course, including quality systems, process analysis, or a more general approach.

Many mechanical engineers are employed in the engineering and maintenance segment of manufacturing, where their machine design coursework is valuable.

A new course was devised at Purdue University Department of Mechanical Engineering Technology to hone and focus those machine design skills while also attacking the competency gaps identified in the SME survey.

### **COURSE ORGANIZATION**

The new course, MET 442, Plastic Manufacturing Systems is designed to integrate those courses that support design of machinery with a challenging project and with supporting lectures.

### **LECTURE SERIES**

The lecture series in this course is divided into the following areas.

- Safety
- Project management
- Process analysis
- Introduction to plastics
- Applications of heat transfer
- Industrial Controls
  - Basic relay circuits
  - Motor starters
  - Motor speed control
  - Programmable logic controllers
  - Wiring practice

The first lecture session and part of the first laboratory session is dedicated to safety. Since students will be expected to work with voltages as high as 220 volts and with pressurized, molten plastics, safety is an important issue. The OSHA “Lock Out/ Tag Out” process is covered.

During the first offering of this course approximately 20% of the available lecture time was used to present the basic elements of project management and the use of computerized systems, such as MS Project. This did not deliver the dividends in the execution of the project that one might have expected, so a more basic approach was adapted.

Project management is an area that may be, and indeed is, expanded into a complete course on its own, but there are some aspects that are common to small machine design projects. These are defining the scope of work, estimating effort and cost, and tracking progress. Rather than add the time and effort to learn a computer program to organize this data, some simple tools were incorporated and the concentration was on the basics. Students were encouraged to use software such as MS Project, but other approaches, such as using spreadsheets was also allowed.

Scope definition is a skill that is developed through practice. In lecture, the students were exposed to some examples of clearly defined scope of work, and some poorly defined. An exercise was presented in class in which the students jointly identified the elements of the scope of a simple and common project, painting a room. Student project groups were then challenged with preparing the scope of work for their class project and presenting it to the class and gaining approval from the instructor.

Estimating is part art and part data collection and begins with the development of a work breakdown, or a list of all the things necessary to produce the product described in the scope of work. Development of the work breakdown follows the pattern set for teaching the scope of work, and the same simple project was used as a class exercise. The students were then required to develop the work breakdown for their project. This is organized into lists of activities, which are grouped under milestones.

Students were taught to estimate the time necessary to accomplish their projects. In order to add some realism, the students were required to purchase the parts necessary through the University purchasing system, so they had to account for the ordering and shipping times. Students then prepared a simple Gantt chart (Figure 1) and use it to track and report on progress.

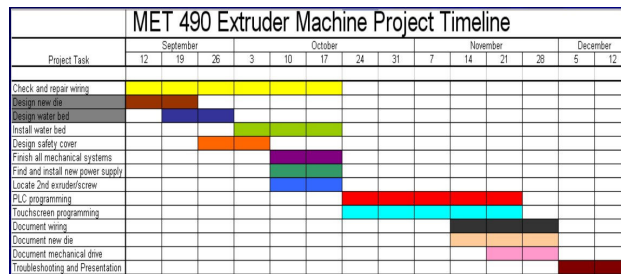


FIGURE 1- PROJECT GANTT CHART

Development of expertise at cost estimating is typically difficult in the academic setting, as prices of many components, such electrical parts are not readily available to students. This is addressed by focusing the project activity into a fairly narrow area so that price documentation may be maintained, and by using “e-enterprises” such as AutomationDirect [2]. AutomationDirect is an internet based company that supplies a full line of electrical automation needs. Since they are internet based, all of their technical and user manuals, as well as pricing are available to students on the internet.

Design of manufacturing machinery differs from product design in that instead of the design being driven by product attributes, it is instead driven by an understanding and analysis of the process which it facilitates. Thus some practice at process analysis should be included in the supporting lecture. In this course the processes are focused on the manufacturing of plastics, and primarily on thermoplastic processes. In thermoplastic processes the primary elements of the process are the issues of viscosity control and heat transfer into and out of the process.

Several lectures were used to develop the background knowledge to understand the basic characteristics of commodity thermoplastic materials, such as polyolefin’s. Internet based materials from plastic raw material vendors such as Equistar [3, 4] and GE Plastics [5] were used to supplement the lectures in lieu of a textbook.

A heat transfer module that was designed for use over a variety of courses [6] was used in this course. This module reviews the basic concepts of heat transfer, and then presents steady state and transient applications to practical systems. An emphasis is placed on methods for obtaining the information needed to solve practical problems.

It is very difficult to separate electrical, electrical controls, and machine design in modern machinery. For mechanical engineers understanding the concepts, terminology, and the time and cost associated with the electrical components in a project has traditionally been a problem. A significant portion of the lecture is given over to building on the survey courses in electrical engineering technology and on the controls and instrumentation course required in the MET curriculum to give students the ability to design and specify basic electrical motion control circuits, such as starting and stopping 3 phase electrical motors. In order to accomplish this it was necessary to review the operation of relays and basic input and output devices such as pushbuttons, pilot lights, and solenoids. The NEC criteria for across the line starting of 3 phase motors was covered as well as reversing and students were required to design a simple conveyor control circuit in class.

Low cost powerful Programmable Logic Controllers (PLC) with analog and discrete inputs and outputs have had a significant impact on how machinery is designed. These PLC's, with electrical and fluid power motion control, have replaced much of the cam and mechanism design traditionally done by mechanical engineers, and so today's manufacturing engineer must know how to apply these tools.

The use of PLC's to control a simple conveyor based process are covered and manufacturer's literature, available on the internet, was used to supplement the lecture [7, 8].

One issue in electrical and controls that is frequently over looked is the actual construction and part selection necessary to construct electrical systems. Students in this course are required to select, purchase, install, and wire the panels in the enclosure. This gives them an appreciation of the time and effort required to accomplish this part of a machine design project. Figure 2 below illustrates a student built electrical panel incorporated into a blow molder.

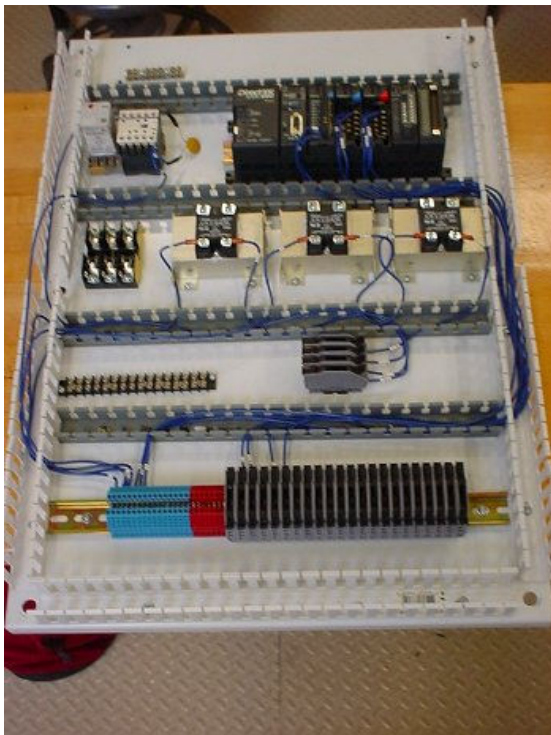


FIGURE 2 – BLOW MOLDER ELECTRICAL PANEL



FIGURE 3 – ARBURG INJECTION MOLDING MACHINE

## PROJECT ORGANIZATION

The project is the central feature in a capstone course, and for this course projects are selected to build, or perform significant upgrades on a production machine. The end use of these machines is the education laboratory. This simplifies the task for students to define the scope of the project, as they have some experience in the application.

Since the focus of the course is plastic manufacturing systems, projects are machines that incorporate some manufacturing process, such as injection molding, blow molding, extrusion, or bow molding. Figure 3 illustrates a typical project. The basis for this project was a small injection molder manufactured by Arburg in the 1970's. Students were charged with renovating the machine to include adding modern controls, rebuilding the hydraulic system, adding safety equipment consistent with current OSHA standards, and documenting the entire machine. In addition the students were required to control all functions of the machine, except for the Emergency Stop, through a PLC.

One of the problems encountered in planning capstone courses is too decide how complex the project may be and still allow completion in a one semester time frame, while challenging the students and simulating the type of work that one will encounter in industry. In addition it is desirable to have the project incorporate some of the more mundane tasks involved in implementing a project in industry such as wiring and mounting of components. It may be argued that these tasks do not contribute to the body of knowledge needed by an engineer, but they do illustrate the time and cost necessary to actually build a machine.

A related issue is selecting the size of the team. This course has lab sections that are typically have 12 to 15 students. In the first offering of this class the project teams were sized at 3 students per team, based on previous experience with other project courses. This proved to be too small for projects of this scope so the author was faced with the prospect of simplifying the project or increasing team size.

Rather than simplify the projects the author decided to try increasing the team size and on the second iteration of the course the team size was increased to 4-5 students. The primary arguments against the larger teams are that some students will choose to not participate, and the increased complexities of planning work with a larger group.

Practical experience in the second and third offerings of the course has indicated that the increased planning requirement for the larger teams is not a significant factor in the success of the team.

Participation was an important factor and a peer review system was implemented to motivate students to participate and to reward those students who contribute more to the project [9]. A system was devised to allow students to rank their own and their peer's contributions to the project on a 10 point scale. These rankings are used to develop a "participation factor" by which the student's project grade is multiplied. If all students participated equally then they would all have a factor of 1.

Grading is another important consideration in a project based course. In this course, approximately 50% of the student's grade is based on the project. It is important to understand, and base grading, on the idea that the value of the project is in the process used to complete the project as well as the ultimate success

of the project. To support this idea, each of the four formal project progress reports is graded and that grade is weighted at 5% of the course grade. At the end of the semester, before he final project report, the student has already earned half of the total grading weight of the project.

## CONCLUSIONS

This course was taught once a year for three years under a development course number (MET 490) and was approved as a permanent course offering (MET 442) in 2003. From this experience several issues have emerged.

The first is that this type of project requires a great deal of time to plan and execute both on the part of the students and of the faculty. Understanding the load on the faculty is very important. In the first offering there were many projects so the project group size could be held to not more than 3 students. In addition, cancellation of other elective courses drove a large student enrollment in this class. The large number of projects overwhelmed the instructor and prevented the individual attention and guidance that is necessary in this type of course.

The second factor is expense. Every effort is made to use industrial quality parts in order to simulate the quality of work expected in industry. Expenses for these projects have run as low as \$1500 to a high of over \$10,000. Most of the expense was seen in the initial offering of the class. In subsequent offerings there were some surplus parts available, reducing new expenditures.

It is difficult to quantify the results of this course. Over the 3 semesters that it has been offered, student satisfaction with the course, as measured by survey, has risen steadily.

## REFERENCES

- [1] Society of Manufacturing Engineers, <http://www.sme.org>
- [2] AutomationDirect website, <http://www.automationdirect.com>
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