Session 2563

# Combining Design and Manufacturing Into a First Year Course

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**Abstract:**

For several decades, Kettering University has taught an introductory course for first year engineering students to acquaint them with the manufacturing processes that they might encounter as part of their cooperative work experience. The revision of the curriculum in 2001 caused a redesign of the course and added some design experiences to further enhance the educational process. This paper discusses the development of the new course called Interdisciplinary Design and Manufacturing and discusses relationship of course coverage to the SME competency gaps. The manufacturing portion describes the lecture topics and laboratory experiments that were an integral part of the course. The mechanical and electrical design portions describe the use of commercial toys and a self-designed toy platform that formed the basis of the new design laboratory portion of the class. It will be demonstrated that it is possible to make a meaningful first year experience for all engineering students combining mechanical and electrical design with manufacturing theory and laboratory.

**Development of a Philosophy:**

Kettering University is a cooperative education university where students begin their cooperative work experience at the beginning of their first year and alternate school and work in three-month increments throughout their five-year academic experience. This close-coupled relationship of work and school requires the students to become knowledgeable in manufacturing processes as most of the work experiences begin with assignments in the manufacturing operations of their industrial environment. During the curriculum reform, it was decided to add a design component to the course.

When first conceived, it was believed that the design and manufacturing portions of the course could be close-coupled such that the extensive manufacturing laboratory facilities available at Kettering University could be used to create prototypes of the design projects. Weekly meetings with an interdisciplinary team of faculty developed interesting projects but topics that would not lend themselves to the close-coupling philosophy. The major obstacle was that the manufacturing facilities would be used in a non-traditional manner and would not allow the students to see the proper utilization of the equipment. An example of this would be using a lathe running at very low speeds to wind an electrical coil. The end could be achieved but the means would not create the educational outcome desired.

The close-coupling concept was difficult to discard but the impossibility of implementing that philosophy for the class was conceded. When the design projects were totally separated from the manufacturing projects, success was achieved. The design portion would not require any physical manufacturing to occur. Any manufacturing ideas arising from the design labs would be "paper solutions" only and not physically-realized ones. The use of the manufacturing facilities was limited to a fixed set of experiences directed at helping the students understand materials and their manufacturing processes.

In addition to the carry-over manufacturing topics and laboratory from the previously taught course, both mechanical and electrical design were added. This resulted in a course with two hours of manufacturing lecture a week and four hours of hands-on laboratory per week – two of manufacturing and two of either mechanical design or electrical design (sections were exchanged between these classes midway through the term).

To tie all of the parts together, the students are asked to prepare a final design laboratory project describing how materials, manufacturing processes, and mechanical or electrical design changes to the basic product investigated in the Mechanical and Electrical Engineering laboratories would improve these toys.

**SME Competency Gaps:**

The SME Competency Gaps and Criteria for 2002 lists fourteen (14) gaps as identified by industry. Recognizing that the course herein described is a first year course, it would seem unreasonable to expect many of the gaps to be satisfied. Yet, the course addresses ten (10) of the fourteen specified gaps. Five of the criteria concern materials and their processing. Lecture and laboratory experience in material testing, welding, material removal, sheet metal forming, foundry and polymers provide an excellent foundation to satisfy these criteria. Students operate the equipment in each laboratory to become acquainted with the processes. This is extremely important for these students as they will work for a cooperative work employer who will probably start them working in a production environment. Five criteria concern working in an industrial environment and the skills needed to institute, develop and present the solution to a problem. These are addressed in each laboratory exercise, whether manufacturing, mechanical design or electrical design. Each of these ten competencies will be highlighted throughout the remainder of the paper.

The remaining four criteria are related to the operation of an enterprise and are not covered in this class but are treated in subsequent classes.

**Manufacturing Processes Lecture and Laboratory:**

Using the laboratories identified above, the lecture and laboratory were coordinated to provide students both the theory and practice of "smoke-stack" industry manufacturing. This portion of the class addresses the five materials and processing criteria address by SME. Topically, these included the following subjects with the associated laboratory practice also noted.

Metallic materials: Metallic materials are discussed beginning with the unit cell structures, and then proceeding to mechanical properties, changes in properties and structure through the application of heat, and production of the metallic shapes. Laboratory experience includes the analysis of tensile testing and hardness testing. These topics are treated more extensively in later materials courses.

Foundry practice: The basic foundry methods are discussed including sand casting, investment casting, and permanent mold casting, both gravity and die casting. Two laboratories reinforce these topics as the students first ram up and pour a green sand casting in the form of square blocks from a match plate (Figure 1), and then fabricate their own design in expanded polystyrene patterns and pour lost foam castings (Figure 2). All castings are in aluminum. An advanced course in foundry practice is offered for upperclass students as an elective.

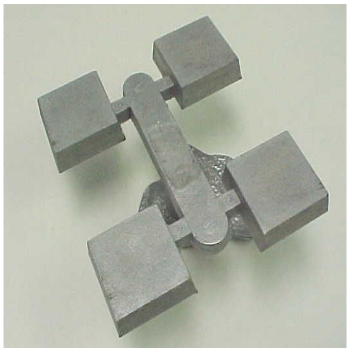

Figure 1. Blocks cast by green sand process.


Figure 2. Example of lost foam casting.

Material removal: Since castings require machining, this topic follows casting. Basic lathe operations are discussed as are horizontal milling, broaching and drilling. These operations are combined with the block in Figure 1 and a round bar into a project called a "pencil holder" that the students take home (Figure 3) as a reminder of the work in the material removal lab. This project is done in teams of two. Advanced courses in material removal and NC machining are available as options for upper level students.

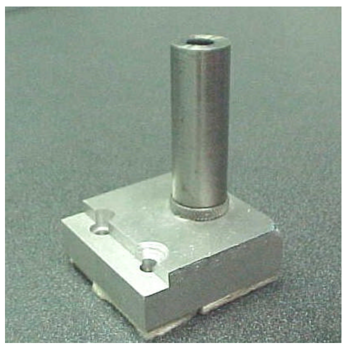

Figure 3. Pencil holder assembly.

Bulk deformation: This category includes the topics of flat rolling, shape rolling, forging and extrusion and are covered as lecture topics only

Surface deformation: The topics of shearing, bending, drawing and stretching are covered showing the many ways that sheet metal can be formed. In the laboratory, disks are blanked and then formed into cups (Figure 4) to demonstrate the formability of sheet steel. Circle grid markings demonstrate the flow of the material during drawing. An advanced optional course in sheet metal forming is available to investigate further details of the forming processes.

Powdered Metals: This topic is covered in lecture but time does not permit the use of existing laboratory facilities to make small powdered metal parts.

Joining Processes: The processes of welding, brazing, soldering and bonding are covered in lecture. The intent is to familiarize the students with the many different processes available for joining materials. A laboratory experience allows the students to practice oxyacetylene welding and brazing. A second experience introduces them to shielded metal arc welding. An upperclass elective in joining processes is offered for those who wish to go further.

Figure 4. Gridded cup

Polymers and their processes: The last topic covered is polymers and their manufacturing processes. The basic structure of polymers and the methods used to turn resin or preformed shapes into useful product are discussed. A laboratory experience permits the students to vacuum-form a 12" x 12" sheet (Figure 5) as well as injection mold a system producing three different parts. An advanced course in polymer processing extends this basic knowledge and adds mold design and rapid prototyping.

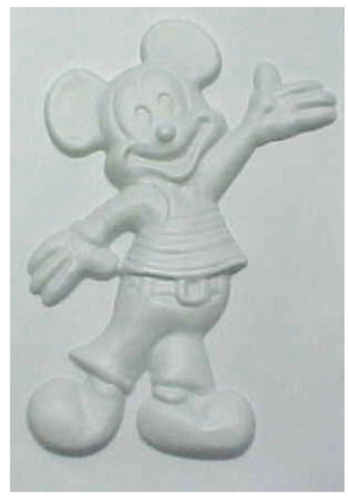

Figure 5. Vacuum-formed shape.

**Relationship of Manufacturing Lecture and Laboratory to SME Criteria:**

The above described lecture and laboratory experiences directly attack the five criteria concerning specific manufacturing processes, manufacturing process control, manufacturing systems, materials and their properties, and production and process design. Students completing this course are well prepared to enter the industrial community with a foundation to build upon. Since over 80% of our students have a work experience associated with production, the employers are hiring a student with a sense of manufacturing, its vocabulary and its processes.

**Mechanical Engineering Design:**

The search for a design project that was comprehensive enough to be of value and yet not beyond the first year students led to selection of battery-powered electro-mechanical toy animals. Each animal performs many different functions such as walking, sitting, making a noise, and various body movements. Students are shown the toy as commercially available and, after a brief introduction to mechanical systems, they are asked to anticipate the mechanical design within and prepare a presentation for the class on their conjectures. The next week, the students make their presentation using PowerPoint and are presented with the animals stripped of their plush skins so that the mechanical and electrical components could be seen. Working with the software "Working Model 2-D", students model the action of the animal during weeks three and four to understand how various features are integrated into the toy. This use of reverse engineering, supplemented by short lectures and introductions to technological tools, helps the students to understand the mechanisms of the animal. Figures 6 and 7 show one of the animals in both the as-received and as-skinned condition.

The specific goals of the Mechanical Engineering laboratory are:

1. Understand the basic principles of design and the relationship of design to manufacturing.
2. Understand the basic operation of gears and change-of-motion devices.
3. Develop functional skill with PowerPoint and Working Model 2-D.
4. Develop oral and written presentation skills
5. Practice teamwork.
6. Develop enthusiasm for the engineering disciplines.
7. Experience a creative, fun, energizing, hands-on design project.

Figure 6. Plush pig in as-received condition

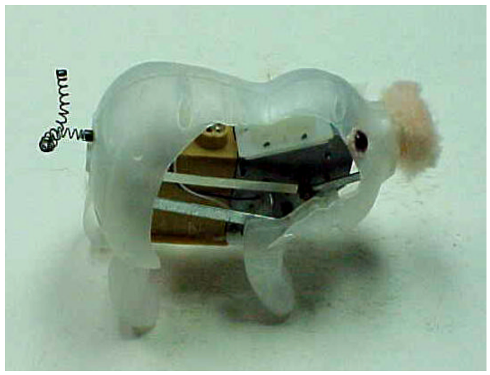

Figure 7. Pig in as-skinned condition.

**Electrical Engineering Design:**

A "hexapod" – a six-legged creature designed and built by the Electrical Engineering faculty – was constructed from aluminum to form the chassis for further development. In its raw form, it includes servomotors connected to moveable legs and articulation joints between the three basic body parts. The students soldered components onto a circuit board, joined the circuit board to the hexapod, and programmed the diode ROM controller board to make the hexapod move at various gaits and speeds. The similarities and differences in mechanical and electrical design were impressed upon the students in these laboratories.

The hexapod – affectionately referred to as Robobug – used eight RC servo motors, eight pulse width modulation (PWM) boards for controlling the servos, a controller board to control the PWM boards and two 6V battery packs (1.5V x 4). Six servos control the leg movement and two coordinate the body articulation to facilitate movement. An LM555 timer provides the "heartbeat" and timing for the Robobug. This control timer allows for sequential stepping through 16 diode ROM states before returning to the initial state. Diode jumpers, made in-house, permit students to program the ROM in any of 4096 possible gaits. Many of these gaits do not create desirable locomotion characteristics, requiring students to reprogram their Robobug.

The lab is broken down into four two-hour segments. The first includes an introduction to robots and the 555-timer circuit and its behavior. The second segment is devoted to the PWM board and soldering the proper components to the board. The next segment has the students using a digital multimeter (DMM) and scope to preset and refine the PWM signal. During the last segment, the students program the robot to establish some self-locomotion. Students are required to make the robot move from its initial placement position; for some, the movement is forward, for others backward or in a circular motion; still others experience no motion at all. Figures 8 and 9 show the Robobug before components are added and after assembly, ready to move.

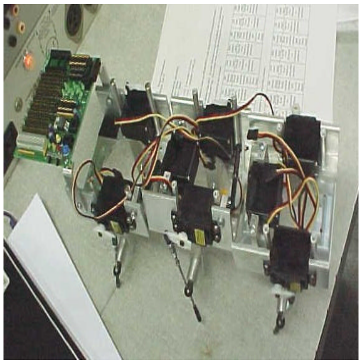

Figure 8. Robobug before component assembly

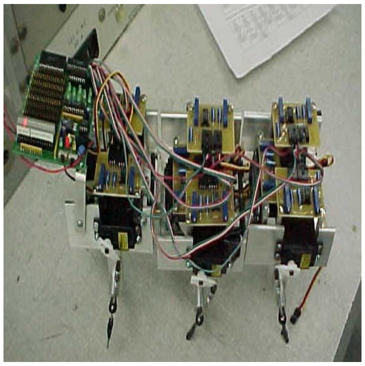

Figure 9. Robobug assembled.

The feeling of success generated in the students is overwhelming. As an introduction to electrical engineering and electrical components for first year students, this laboratory qualifies as most unique.

**Final Electro-Mechanical Design Project:**

To tie together the various parts of the manufacturing and design laboratory experiences, the student teams were asked to describe a mechanical, electrical or manufacturing improvement for either the mechanical toy animal or the Robobug. These were then prepared into a final report and submitted as the term project for the design labs. Students were not required to perform any analysis of the proposed changes, only to describe what they would like to see changed and how it would affect the design or manufacture of the item.

These functions relate directly to the SME Competency Gaps identified as project management, written communication, oral communication/listening, problem solving, and teamwork. While all laboratory experiences build upon these concepts, it is the design laboratories that place the most emphasis on them.

**Summary:**

A course devoted to both manufacturing processes and mechanical and electrical is not only possible, it generates three major benefits:

**1. Students are exposed to the engineering disciplines available at the University and they can use this course experience to either confirm their initial selection or consider a change. Because of the co-op plan, our students choose a discipline at the time of entering the University.**

**2. Students become knowledgeable about the product cycle in industry from concept through design to manufacture. This is of great benefit to the co-op employers as they employ the students beginning with their first year of University.**

**3. Subsequent courses in all of the disciplines can depend upon a practical knowledge base from the students. Since the University is primarily an undergraduate school, it emphasizes the close-coupling of an academic education with the practice of engineering in the industrial world.**

This interdisciplinary course would not be possible without the dedication of faculty from each of the disciplines.

While it appears that the course described above meets all of the criteria that anyone could desire, there are still areas for modification and improvement to make it more relevant for the students and their sponsoring companies.

Comments from students who have completed the course and returned from their co-op jobs indicate that the course provided an excellent foundation in manufacturing and the process of design. In some cases, the knowledge gained from the course assisted them in obtaining the employment.

Design and manufacturing **CAN** be taught in the same course to first year students with substantial planning and dedication by a dedicated faculty.

**Acknowledgement:**

Credit must go to fellow faculty members who made large contributions to this class. These include Manufacturing Engineering professors Lucy Siu-Bik King for coordinating the interdisciplinary faculty, and B. Lee Tuttle for managing the manufacturing laboratories; Mechanical Engineering professors Henry Kowalski and Gary Hammond for conceptualizing the reverse engineering of the electro-mechanical animals; and Electrical and Computer Engineering professor James McDonald for aiding in the design of the Robobug.

WILLIAM J. RIFFE – Professor Riffe is a Professor of Manufacturing Engineering and teaches the lecture and manufacturing laboratory portions of this course and also a senior Sheet Metal Forming course. He is a former member of the Board of Directors of SAE and a past-chairman of AFFT/SME. Prior to academia, he had 20 years experience in the steel industry as a design consultant.

LAURA RUST – Professor Rust is an Associate Professor in the Electrical and Computer Engineering Department. Where she teaches courses in circuits, signals and digital signal processing. Her research area of interest is in predictive maintenance. She teaches the electrical engineering laboratory portion of the class.

DOUGLAS MELTON – Professor Melton is an Associate Professor in the Electrical and Computer Engineering Department. His background is in signal processing and audio systems and his current research is in the field of intra-vehicle communication systems. He teaches the electrical engineering laboratory portion of the class.

BRENDA LEMKE – Ms. Lemke is a lecturer in the Mechanical Engineering Department with a special interest in thermal sciences. She teaches the design lab from this course and Energy Systems Laboratory. She is working to incorporate new technology into the classroom.

JACQUELINE EL-SAYED – Professor El-Sayed is an Assistant Professor in the Mechanical Engineering Department. She teaches in the design lab from this course. Other courses she teaches include Mechanics, Finite Element Analysis and Kinematics of Machine Tool Design. Her research interest is optimization of manufacturing processes.