Teaching Manufacturing Using The Golden Key – Reverse Engineering

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I. Introduction

The United States will be able to continue its unprecedented economic growth and maintain its lead as one of the greatest manufacturing countries only if it finds ways to stimulate the minds of its young engineers - manufacturing's future. The engineering program is the vehicle to teach the students how to convert their brightest ideas into manufacturing realities by introducing them to the importance and fundamentals of manufacturing processes, systems and organization. When engineering students thoroughly understand and can freely employ these methods, will they then be better able to positively contribute to world class manufacturing for the United States.

In the Engineering Department at the College of New Jersey, the aforementioned concepts and ideas are being taught by way of laboratory experiences involving hands-on learning activities. The department is committed to engaging the students in practical learning experiences where possible. It believes that this approach positively helps students better understand theoretical concepts. In the Engineering Department's Manufacturing Processes course, all mechanical and management engineering students are introduced to manufacturing concepts during their sophomore year using the practical learning experiences approach. This course provides students the opportunity to:

- Work in teams
- Develop communication skills
- Study design principles
- Practice critical and creative thinking
- Operate processing equipment
- Participate in hands-on learning

The Manufacturing Processes course goes one step further to stimulate the creative thinking process and will be detailed in the following paragraphs.

In a standard manufacturing process course, a class assignment might be the engineering of a product and the manufacturing design it requires. The real problem is how to elevate this course from a routine let's-make-a-product type assignment to one that fans the flames of creativity and inquisitiveness that separates the engineering mind from all others. In the Manufacturing Processes course at The College of New Jersey, we have hit upon a method that stimulates the desire found within every successful engineering student to learn – what makes it tick? The answer is reverse engineering. Using the student's natural curiosity, we use mass produced commercial products and ask the student to do, in essence, thinking in reverse to learn what the manufacturing process sequence is and what systems of production are used leading up to the finished commercial product(s). The Manufacturing Processes course is the perfect union of the hands-on approach and reverse engineering.

The hands-on approach uses laboratory activities and is ideally suited for teaching the concepts of design and analysis of metallic and plastics welded fabrications and castings, CNC milling and lathe turning, as well as the set-up and analysis of plastics molding (injection, compression, thermoforming and extrusion blow) investigations. The laboratory environment, a custom facility containing laboratory size equipment, encourages students to develop and present solutions to manufacturing processes, organizational and production systems problems through the use of Pro/Engineer, CNC plus metallic and plastics processing facilities.

It is the other half of the aforementioned perfect union, reverse engineering, that asks the student to discover what procedures led up to the final product. This is where student inquisitiveness leads to learning about product design and manufacturing, product costs (direct materials and labor plus overhead) and control, breakeven calculations, routing, flow process charting, Gantt charting, network diagramming, bill of materials development, manufacturing completion probability analysis and package design.

This paper describes how the reverse engineering project experience serves as the teaching vehicle, or the golden key, that ties or relates all of the course concepts together. The reverse engineering project is the course centerpiece that provides the transfer of learning from concept to concept. The following paragraphs detail how the Manufacturing Processes course is taught using the hands-on approach and reverse engineering.

II. Facility

The course utilizes two large materials manufacturing laboratories and a lecture area. One laboratory houses space for all of the needed metallic production equipment. These items include lathes, manual mills, CNC mills, band saws, drill presses, heat treating ovens and a green sand foundry. A second laboratory provides space for all of the needed plastics production equipment. The equipment includes a plastics welder, a thermoformer, an injection molder, a compression molder and an extrusion blow molder.

III. Course Structure

Each student receives three credits for the course which meets five hours per week for fourteen weeks. Approximately two hours per week are devoted to lecture/demonstration while the remaining three hours are used by students to work on laboratory activities.

The following narrative describes how the reverse engineering laboratory component term project is utilized during the course. Table 1 illustrates where the reverse engineering (RE) concepts and assignments are introduced throughout the fourteen week course.

Table 1 Course Topics Time Line

WEEKS	COURSE TOPICS	(RE) RELATED
1	Reverse Engineering (RE) Introduction Plus Single Point Machining	Yes
2	Metallic / Plastics Welding	
3	Organization of the Enterprise	Yes
4	Engineering Economics, RE Project Approved and CNC Programming	Yes
5	Metallic and Plastics Casting	
6	Manufacturing Engineering	Yes
7	Gantt, CPM and PERT Planning	Yes
8	Mid-term Exam	
9	Plastics Processing	
10	Materials and Labor Costs Plus Bill of Materials	Yes
11	Hot and Cold Forming	
12	Materials Handling and RE Presentation Techniques	Yes
13	Materials Packaging and Multi Point Machining	Yes
14	RE Class Report Presentations	Yes

IV. The Reverse Engineering Assignment Structure

The reverse engineering product development and manufacturing design term project activity entails the designing of the manufacturing process sequence and systems of production for each part of a commercial product. There are numerous assignments involved in the project:

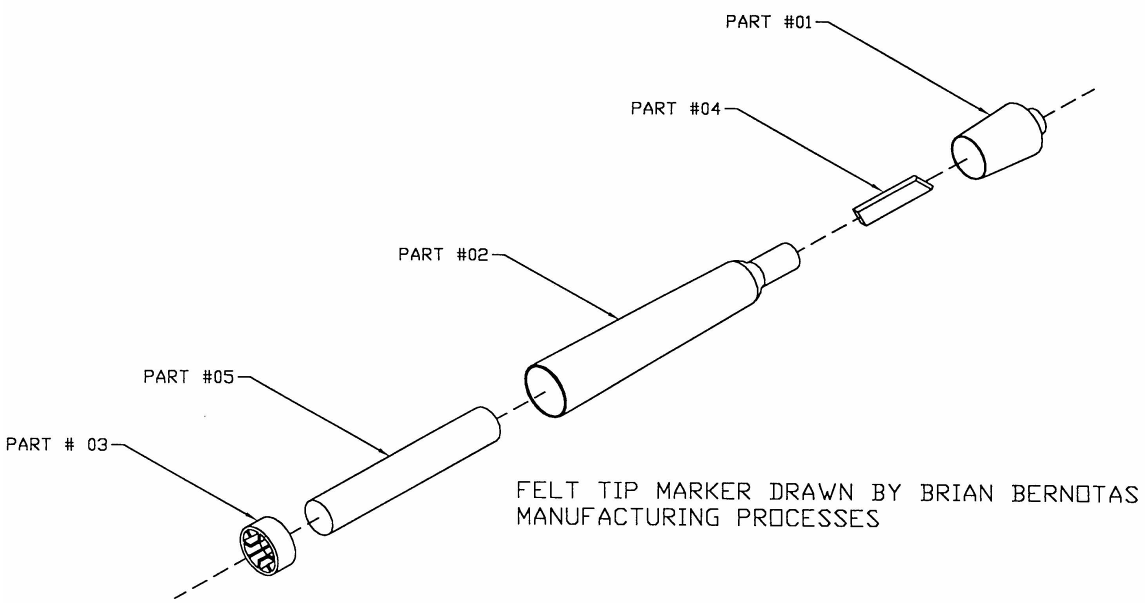
- Product identification and approval
- Production lot (initial) size determination
- Product structure tree and parts list development
- Route sheet development
- Breakeven chart development
- Network diagramming with critical path and slack times
- Costs (materials and labor) determination
- Presentation (oral and written) production

These reverse engineering related laboratory based hands-on assignments are also introduced as the course progresses (see Table 1).

During the first week of the course the problem solving reverse engineering product development and manufacturing design term project is assigned. Student groups organize a company and select a commercially mass produced product (five parts minimum) plus all accompanying packaging. The product must be mass producible and not the result of custom manufacturing.

As a result of the instructor's lectures and demonstrations, each group must develop an exploded pictorial sketch (see Fig. 1) of the product including all part names and numbers. Also, the purchase price of the original product with a written outline of the processing needed to manufacture it must accompany the product at the time it is submitted for approval during the fourth week of the course.

Figure 1 Pictorial Drawing of a Marker



From weeks four through five, the student groups study and develop a start-up production lot size for their reverse engineering product. Breakeven charts containing all direct and indirect costs are examined and applied to successfully complete this activity. Students must utilize their knowledge of Materials Science (a prerequisite course) to select the appropriate material needed for each part of the product.

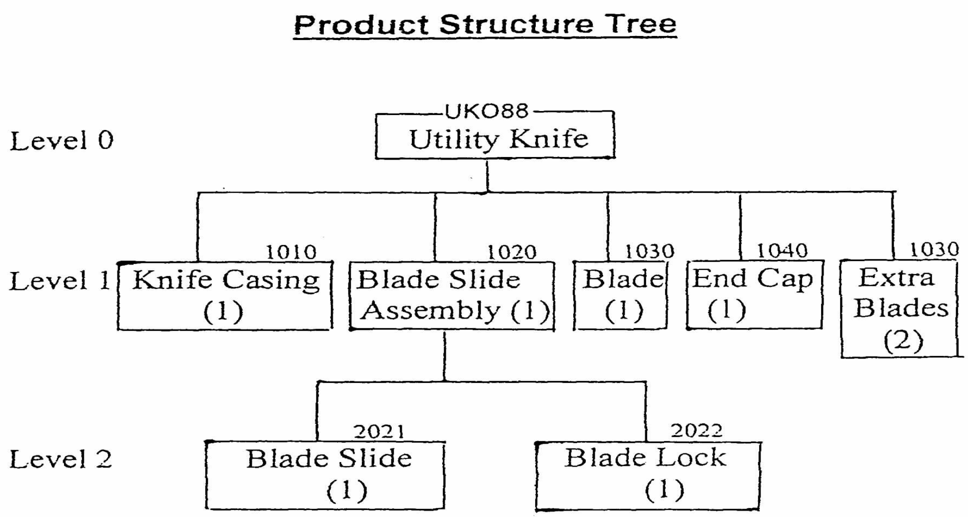
Laboratory oriented hands-on production processes (metallic and plastics) are studied by the students throughout the course. For example, single point machining is introduced during week one and by week eleven (see Table 1) all of the processing concepts have been studied. The student groups use this processing information to determine what processes will be selected for the manufacturing of each reverse engineered product part.

Between weeks five and eight, the student groups study and design a detailed production route sheet (includes all processing, storage, transportation, inspections, delays and combined activities) for each manufactured and purchased part plus develop a flow process chart for the manufacturing and packaging of the reverse engineered product. A description must be provided for all steps identified on route sheets and process charts. Also, all resources necessary to complete the manufacturing processes must be identified.

During this same time period, the student groups construct a network chart of their reverse engineered production design. This affords the student groups the opportunity to identify a critical path and to locate and adjust production slack time from their production sequence. They also study the need for designing simultaneous parts production, parts processing precedence, production scheduling and equipment loading.

From weeks nine through twelve, the groups develop a parts list, product structure tree (see Fig. 2) and an indented bill of materials for their reverse engineering product production design. The study of those concepts helps the student groups revise and finalize all parts numbers and names illustrated in the exploded pictorial product sketch, plus raw materials, fasteners, adhesives, packaging material and any other materials purchased or manufactured.

Figure 2 Utility Knife Product Structure Tree



Part No.	Part Name	Quantity	Total Quantity
1010	Knife Casing	1	500
1020	Blade Slide Assembly	1	500
1030	Blade	3	1500
1040	End Cap	1	500
2021	Blade Slide	1	500
2022	Blade Lock	1	500

The study of the bill of materials concepts aids the groups in determining the quantity of each part needed to make one lot size. The groups must also contact at least two vendors to obtain bulk quantity purchased material and part prices. Materials handling and packaging theory is investigated during weeks twelve and thirteen. These theories are incorporated into each product manufacturing design.

As a culmination of every individual group's effort, each must present the results of the group's reverse engineering manufacturing and design activity laboratory experience to the class (week fourteen) by way of oral and written (includes drawings, sketches, route sheets, bills of materials, parts lists, network charts, flow process charts and breakeven charts) reports. The design work is accomplished outside of class, but the remainder of the project is completed during the course laboratory sessions. Each group of students is evaluated on how well it completes the laboratory activity by comparing the group's results with the original product and production design criteria.

V. Reverse Engineering Related Manufacturing Processing Activities

Throughout the course, various manufacturing processing concepts are presented to the student groups by way of lectures, demonstrations and hands-on laboratory activities. Table 2 illustrates where the processing concepts and assignments are introduced during the fourteen week course.

Table 2 Course Manufacturing Processing Topics Time Line

WEEKS	**COURSE MANUFACTURING PROCESSING TOPICS**
1	Single Point Machining (Metallic Turning)
2	Metallic and Plastics Welding
4	CNC Programming and Wax Part Milling
5	Metallic and Plastics Casting
9	Plastics Processing (Injection, Compression, Extrusion-blow and Thermoforming Molding)
11	Metallic Hot and Cold Working Processing

The student groups participate in hands-on laboratory activities related to each of the Table 2 topics. They are taught how to set-up, program, operate and trouble shoot processing equipment. Students also study the part design and quality assurance considerations and theory related to each process.

When the laboratory activities are completed, the student groups must submit a processed part accompanied by a laboratory report. The report illustrates and explains all processing, programming, calculations, recommendations and conclusions detailing the successful design, processing and testing of the laboratory activity part or device.

Having student groups participate in hands-on manufacturing processing activities at varying times throughout the course provides them the opportunity to understand (in a more relaxed learning environment) and apply part design considerations as each relates to specific production processing. The groups use this information to help them design the processing techniques needed to manufacture each reverse engineered product part.

VI. Conclusion

Some additional concepts taught in the course would be a variety of the following: corporate organizational structures, production control system modeling, forms of industrial ownership, law in engineering, budgets, cost estimates, loading, scheduling, parts list development and production cost analysis.

Each laboratory experience or activity is utilized as a tool for teaching and reinforcing student understanding of the course objectives. The hands-on, practical laboratory learning method found most effective in the course is designed to assist each student to apply selected manufacturing processes, production systems and methods in a real world environment.

Participation in problem solving reverse engineering activities, as in the examples given, allows the student groups to more readily learn and apply the theoretical concepts stressed in the Manufacturing Processes course. The theoretical concepts are reinforced and made applicable to actual industrial manufacturing through the union of hands-on learning and reverse engineering - the golden key.

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