Solid Modeling and Reverse Engineering: The Stimulus For Teaching Manufacturing

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I. Introduction

Engineering programs must motivate students to participate in the globally important topic of manufacturing. Required courses may be the first and only chance to stimulate the students' desire to study the basic concepts of manufacturing processes, organization and production systems. Unfortunately, this can be a very labored process and if the material is not geared to the creative mind, potentially outstanding engineering students may be lost to other fields. Solid modeling and reverse engineering are two highly effective methods used at The College of New Jersey (TCNJ) in the Department of Engineering to enliven and stimulate great subject interest in the students for the manufacturing processes and will be the subject of this paper.

The previously mentioned concepts of manufacturing processes, organization, and production systems are being taught in the Engineering Department's Manufacturing Processes course. The required course is taken early in the engineering students' college experience during the sophomore year and has proven to be quite positive for the students.

Because the course relies heavily on involving the students in hands-on learning activities, it assists them to better understand theoretical concepts. The hands-on approach utilizes laboratory activities and is ideally suited for teaching the concepts of design and analysis of metallic and plastics welding fabrications and castings, lathe turnings, 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 solid modeling software, solid object processing plus metallic and plastics processing facilities.

The course emphasizes the practical learning experiences approach and makes it possible for the students to:

- Use modern engineering design tools
- Use modern engineering manufacturing processes
- Apply product design
- Work in groups

- Participate in hands-on learning
- Develop communication skills
- Practice critical and creative thinking

The course description may sound similar to many other courses, but this is where the similarity ends. In a standard manufacturing processing course assignment, the students design a part or a product along with the manufacturing processes, organizational, and production systems it requires. The challenge for the instructor is to employ exciting teaching assignments and learning activities to stimulate the students' creativity and interest. At TCNJ, in the Manufacturing Processes course, solid modeling and reverse engineering manufacturing have proven to be the instructor's fire keg that lights the imaginations of the engineering students. The instructor provides the course concepts and laboratory activities, and now, the students, armed with this new knowledge of solid modeling and reverse engineering, are able to develop ideas and present manufacturing solutions that were once far beyond their scope. The quest for engineering processes has now been awakened. The students have just been made aware that it is only when they possess this firm foundation, that their engineering abilities will be bound only by their knowledge.

The mechanics of how solid modeling and reverse engineering are employed at TCNJ in the Manufacturing Processes course are outlined in the following paragraphs. The solid modeling manufacturing assignments include computer aided modeling along with solid object printing processing. Once a modeled design is approved, the students apply commercial manufacturing software to the design and troubleshoot the manufacturing sequence they developed with the software. The part is then tested using computer controlled processing stations. The students positively identify with this type of real world production problem solving. This type of assignment has been found to highly motivate student learning and interest in all manufacturing processes.

The reverse engineering element assignment has been found to spark the desire found within engineering students to learn-what makes it work? Capitalizing on the students' natural curiosity, and using mass produced commercial products, students are asked to do thinking in reverse to learn what manufacturing processes sequences are required and what systems of production are used leading up to the finished commercial product(s).

In the Manufacturing Processes course, by way of the hands-on teaching approach, the solid modeling and reverse engineering elements provide the stimulus for student learning. Solid modeling manufacturing and the reverse engineering projects provide the learning adhesive that unifies all of the course concepts and are the course centerpieces. They provide the transfer of learning from course topic to topic. The following pages outline how the Manufacturing Processes course is organized using the hands-on approaches of solid modeling and reverse engineering.

II. Facility

Two large materials manufacturing laboratories, one small solid object processing room and a lecture room are utilized for the course. One laboratory houses all of the needed plastics processing equipment. The equipment includes a plastics welder and packaging sealers, a thermoformer, an injection molder, a high pressure laminating press, an extrusion blow molder and a compression molding press.

A second laboratory provides space for all of the necessary metals processing equipment. These items include lathes, mills, CNC mills, band saws, drill presses, heat treating ovens, a green sand foundry and sheet metal processing equipment.

The solid object processing room contains a solid object printer and accessories for manufacturing prototype parts from computer generated solid model designs. All of the course lectures, demonstrations and lab activity sessions are conducted in these facilities.

III. Course Layout

Due to the presence of a large laboratory component in the course, there is a maximum course student capacity of twenty-four. 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/demonstrations while the remaining three hours are used by students to complete laboratory assignments.

The remainder of the paper describes how solid modeling and reverse engineering laboratory components are utilized during the course. Table 1 illustrates where the solid modeling (SM) and reverse engineering (RE) concepts and assignments are introduced throughout the fourteen-week course.

Table 1 Course Topics Time Line

SEMESTER WEEKS	**COURSE TOPICS**	**RELATED (SM)**	**RELATED (RE)**
1	Reverse Engineering (RE) Introduction Plus Single Point Machining		Yes
2	Metallic/Plastics Welding		
3	Organization of the Enterprise Plus Engineering Economics and RE Project Approval		Yes
4	Automated Manufacturing and CNC Programming	Yes	
5	Solid Modeling Design	Yes	

Table 1 (continued) Course Topics Time Line

SEMESTER WEEKS	COURSE TOPICS	RELATED (SM)	RELATED (RE)
6	Metallic and Plastics Casting		
7	Manufacturing Engineering and Solid Modeling Processing	Yes	Yes
8	Mid-term Exam		
9	Gantt, CPM and PERT Planning		Yes
10	Plastics Processing		
11	Materials and Labor Costs Plus Bill of Materials and Solid Object Manufacturing	Yes	Yes
12	Hot and Cold Forming Plus Materials Handling and RE Presentation Techniques		Yes
13	Materials Packaging and Multi Point Machining		Yes
14	RE Class Report Presentations		Yes

IV. The Subtractive Processing Solid Modeling Manufacturing Element

One exciting manufacturing course assignment is to involve the students in part design, part solid modeling and then the manufacturing of the part in the laboratory. Using commercial engineering solid modeling and manufacturing software being utilized by their future employers, the students positively identify with the real world production problem-solving environment. One activity that stimulates this environment using the element of solid modeling is presented in the following manner.

During the fourth week of the course (see Table 1), the instructor provides the students with a quick review of the basics of computer solid part modeling and design. The students were exposed to this topic while taking a freshman course titled Fundamentals of Engineering Design. That course exposed the students to the following concepts.

- Explore parametric based solid modeling of parts, engineering drawings and assembly representations
- Apply feature-based, parametric, solid modeling solutions to engineering design problems

- Present design solutions graphically by way of two and three dimensional sketches

During the fifth week of the course (see Table 1), student groups are now assigned a part to be designed and modeled. Once each group's part design is approved, the students are taught how to apply commercial manufacturing software to the part. The software allows each student to view a simulation of each processing step for manufacturing the part. Manufacturing efficiency can now be monitored and improved and the part redesigned if necessary. The part is then manufactured (see Figure1) at a computer controlled milling station.

Figure 1 Solid Modeled and CNC Mill Manufactured Wax Parts

After successfully manufacturing the part, the students must submit the product with a laboratory report. The report contains an account of the programming and operating problems encountered. Also, calculations with logical conclusions concerning processing speeds, feeds, depth of cuts, production times and estimated product costs at various production times are included in the report. The students are also required to determine pulses, inches, and millimeters per revolution for all drive screws in the mill and conclude how replacing these items along with processing program changes can influence part production times.

V. The Additive Processing Solid Modeling Manufacturing Element

Another stimulating and challenging manufacturing course assignment is to have groups of two students form a racecar body design, manufacturing and race team. Using the same software as described in the aforementioned subtractive processing solid modeling manufacturing element, the instructor presents an additive processing (solid object printing processing) element in the following manner.

During the seventh week of the course (see Table 1), each student race team researches small scale racecars and then designs one to a specific size and performance specification. Once the design specifications are met, each team solid models the vehicle body, solid object print manufactures it, assembles all vehicle parts (see Figure 2) and then races it on a test track to check the actual performance of each manufacturing specification. The excitement of creating a computer driven solid part design and then manufacturing and using it in a matter of hours is evidenced by the students' high interest in this real world activity assignment.

Figure 2 Solid Modeled, Solid Object Print Manufactured and Assembled Racers

After completing all testing, the teams must develop and submit the racecar with a laboratory report. The typical laboratory report would contain the following sections.

- Table of Content
- Abstract
- Introduction

- Background Research
- Analysis and Results
- Conclusions and Recommendations
- Calculations and Simulations

Each report contains an account of all operating problems encountered and their solutions. Also, all production times and cost estimates are determined and reported along with their necessary improvements.

VI. The Reverse Engineering Element

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.

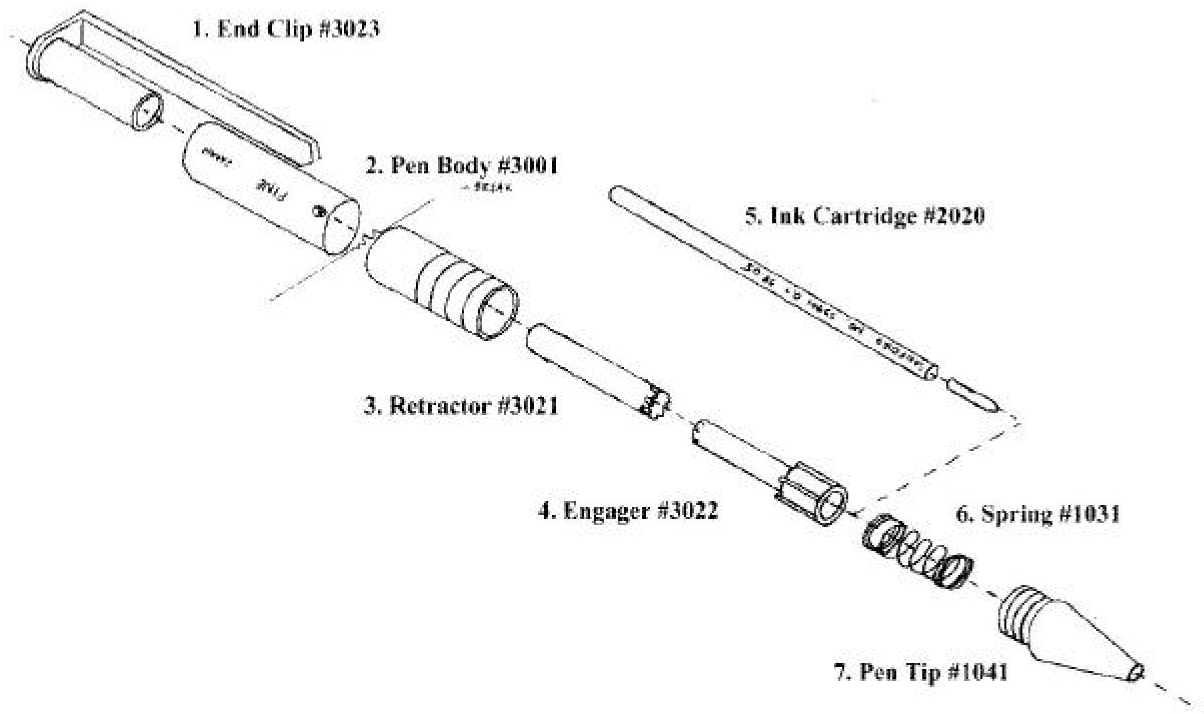
- Product identification and approval
- Production lot size determination
- Product structure tree and parts list development
- Route sheet development
- Breakeven chart development
- Network diagramming with critical path and slack times
- Costs (materials and labor) determination
- Presentation (oral 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 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 Figure 3) of the product including all part names and numbers. Also, a written outline of the processing needed to manufacture it must accompany the product at the time it is submitted for approval during the third week of the course.

Figure 3 Pictorial Drawing of a Pen



From weeks three through six, 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.

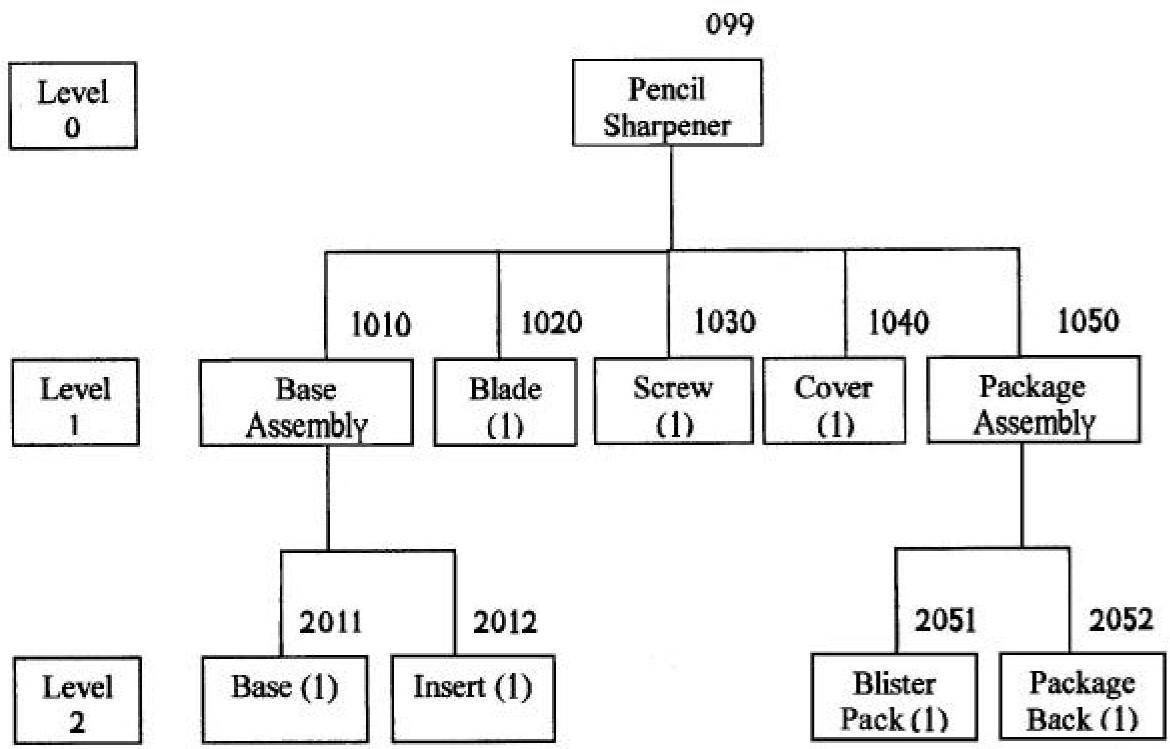
Laboratory oriented hands-on production processes (metallic and plastics) are studied by the students throughout the course. For example, single point machining is introduced during week one and by week twelve (see Table 1) all of the processing concepts have been studied. The student groups use this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

Between weeks six and ten, 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 eleven through twelve, the groups develop a parts list, product structure tree (see Figure 4) 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 part numbers and names illustrated in the exploded pictorial product sketch, plus raw materials, fasteners, adhesives, packaging materials and any other materials purchased or manufactured.

Figure 4 Pencil Sharpener Product Structure Tree



The study of the bill of materials concepts aids the groups in determining the quantity of each part needed to make one lot size. 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.

VII. Processing Learning Activities Related to Solid Modeling and Reverse Engineering

During the course, related industrial processing concepts and techniques are introduced to the students. Table 2 (also reference Table 1) shows when the laboratory oriented learning activities are presented in the course's fourteen-week structure.

Table 2 Processing Topics Time Line

WEEKS	PROCESSING TOPICS
1	Single Point Machining (Metallic Turning)
2	Metallic and Plastics Welding
4	Automated Manufacturing and CNC Programming
6	Metallic and Plastics Casting
7	Solid Modeling Processing
10	Plastics Processing (Injection, Compression, Extrusion-blow and Thermoforming Molding)
11	Solid Object Manufacturing
12	Metallic Hot and Cold Working Processing
13	Multi Point Machining

Student groups are instructed how to set-up, program, operate and trouble shoot processing equipment related to each Table 2 topic. The groups then complete hands-on laboratory experiments related to each topic. Also, during these topical time periods, students are provided with part design and quality assurance considerations specific to each processing topic.

After completing each processing activity, each student group submits a laboratory report with a processed object or part. Each report contains explanations and illustrations of the processes, required programming and calculations, conclusions and recommendations outlining the design, and processing and testing of the laboratory activity part or device.

Encouraging students to become involved in hands-on processing activities throughout the course provides them the opportunity to understand and apply part design considerations as each relates to specific production processing. Each group utilizes this information to help it design solid modeled parts and the processing techniques needed to produce each reverse engineered product part.

VIII. Conclusion

Participating in the teaching/learning activities of solid modeling and reverse engineering, students can more readily learn and apply the theoretical concepts stressed in the Manufacturing Processes course. These concepts are reinforced and made applicable to actual industrial manufacturing.

In addition, the following concepts fall into line as needed throughout the course: corporate organizational structures, production control system modeling, forms of industrial ownership, budgets, cost estimates, scheduling, loading, parts list development, production cost analysis and manufacturing completion probability analysis.

The unique hands-on elements of solid modeling and reverse engineering manufacturing laboratory teaching assignments were found to positively motivate students' learning in the course. Any method that proves successful for teaching the fundamentals of manufacturing processes, organization and production systems must be shared with the educational community. Only when we, as educators, have properly inspired our students' minds can we feel that we are doing our share to help continue this country's competitive engineering edge in the twenty-first century global economy.

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