

# **An Introduction to Engineering Through an Integrated Reverse Engineering and Design Graphics Project**

**Ronald E. Barr, Philip S. Schmidt, Thomas J. Krueger, and Chu-Yun Twu**

Mechanical Engineering Department  
University of Texas at Austin

## **Abstract**

This paper discusses a new freshman course that merged previous topics in the “Introduction to Mechanical Engineering” and “Engineering Design Graphics” courses into a single integrated teaching effort. The main objective of the new course is to introduce students to mechanical engineering education and practice through lectures and laboratory experiences. A major effort in the course is devoted to a reverse engineering team project. The students are divided into four-member teams and are instructed to select a simple mechanical assembly, such as a door knob, pencil sharpener, or toy gun. They study and disassemble their object into basic constituent components, documenting this process with freehand sketches. They then use these sketches and other measured dimensions to construct 3-D solid computer models of each major component. The teams then obtain .STL files of the solid models, which are then used to make rapid physical prototypes using a JP System-5 prototyping machine. The teams conclude their project activities by generating engineering drawings directly from the 3-D geometric data base. All of these efforts are integrated, documented, and submitted to the instructor as a final team project report.

## **Introduction**

A new freshman course at the University of Texas at Austin merges previous topics in “Introduction to Mechanical Engineering” and “Engineering Design Graphics” courses. The main objective of this new course is to introduce students to mechanical engineering education and practice through lectures and laboratory experiences. Lecture topics include orientation to university facilities and services, teamwork skills, introduction to the mechanical design process, and guest speakers from industry. A major effort in the course is devoted to a reverse engineering team project that involves mechanical dissection [1,2]. The course also includes concomitant laboratory exercises in engineering design and graphics [3].

The course is taught using both a large lecture class and smaller laboratory sections. The large lecture class format allows direct access

to approximately 120 students simultaneously for one hour per week. In this large lecture class, students are oriented to mechanical engineering education and practice through a series of lectures and assignments. Guest lectures include representatives from the engineering library, career placement center, and coop office. In addition, speakers come from industries such as Ford Motor Company and Proctor and Gamble. Regular class lectures are supported by Power-point slide presentations on various engineering topics, as shown in Table 1. The lecture homework exercises are listed in Table 2 and include both individual assignments and team exercises that support group activities. In an effort to better communicate with the large number of students in this lecture class, a special internet web-site has been developed for the course and is located at the following URL: <http://www.me.utexas.edu/~me302/>.

**Table 1.**  
**Weekly Topics for the Large Lecture Class**

1. Course Introduction. What is Engineering?
2. Planning an Engineering Career: Coop and Career Assistance. (*Guest Speaker*)
3. Resources for Studying Mechanical Engr: Library and Internet. (*Guest Speaker*)
4. *Guest Speaker from Industry.*
5. Introduction to Reverse Engineering Team Project. Teamwork Dynamics
6. Team Project Planning and Scheduling: Graphs and Charts.
7. Mechanical Dissection Class Exercise.
8. Reverse Engineering and the Role of Design Graphics.
9. *Guest Speaker from Industry.*
10. Mathematical and Computer Modeling in Engineering Design
11. Materials and Manufacturing Processes.
12. Rapid Prototyping in Engineering Design.
13. Team Project Review. Project Report Writing. Project Evaluation Checklist.
14. Class Evaluation. Team Project Due.

The smaller laboratory sections of 24 students meet in the manual and computer graphics labs for approximately 4-5 hours per week. In these smaller sections, they matriculate through a series of typical engineering design graphics exercises [4]. These include freehand sketching of pictorial and orthographic views, sectioning, dimensioning practices, and 3-D computer modeling. They also are exposed to graphics applications such as mass properties and rapid prototyping. The current software used for computer modeling is AutoCAD-14, and the hardware system used for rapid prototyping is JP System-5.

**Table 2.**  
**Homework Exercises for Lecture Class**

1. Computer and Email Accounts (I)
  2. Internet and Library Resources (I)
  3. MBTI Survey and Team Questionnaire (I)
  4. Reverse Engineering Project Proposal (T)
  5. Planning Charts and Diagrams (T)
  6. Mechanical Dissection Sketches (T)
  7. Computer Solid Modeling (T)
  8. Materials and Manufacturing Processes (I)
- (I) = Individual, (T) = Team Assignment

### **Integrated Reverse Engineering Project**

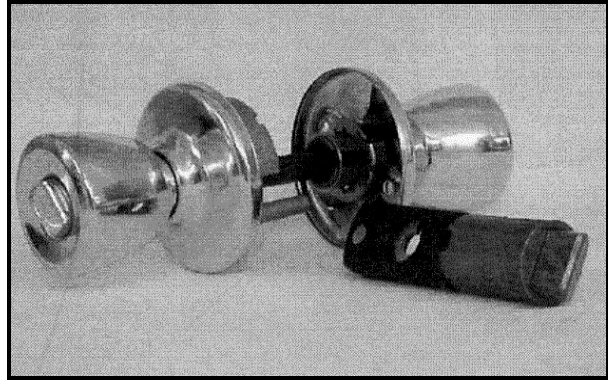
A major effort in the course is devoted to a reverse engineering team project. The students are divided into four-member teams based on the results of a Myers-Briggs Type Indicator (MBTI) survey and a team questionnaire (homework assignment #3). This is done in an effort to foster healthy team dynamics for the project. Team members are also chosen based on their common enrollment in the graphics laboratory sections. The teams are instructed to select a simple mechanical assembly, such as a door knob, pencil sharpener, or toy gun, which will be used for the mechanical dissection process.

The team members submit their selected object in the form of a reverse engineering project proposal (homework assignment #4). This proposal includes a cover page, a general written description of the object, and a graphic picture. Selection of this object tends to be crucial for the success of the team, and instructor approval is warranted before the object is accepted. Typical objects selected in the Spring 1999 course are listed in Table 3. The team project involving a door knob (Figure 1) has been selected for illustration in this paper.

**Table 3.**  
**Objects Selected for Reverse Engineering**

Toy Gun (5)*	Bike Pump (1)
Toy Car (5)	Pencil Sharpener (1)
Toy Aircraft (3)	Hose Nozzle (1)
Door Lock (3)	Fishing Reel (1)
Can Opener (2)	Hand Tool (1)
Cylinder Asm. (2)	Dog Nail Clippers (1)
Toy Game (2)	Yo-Yo (1)

\* Number of Teams Selecting That Object.



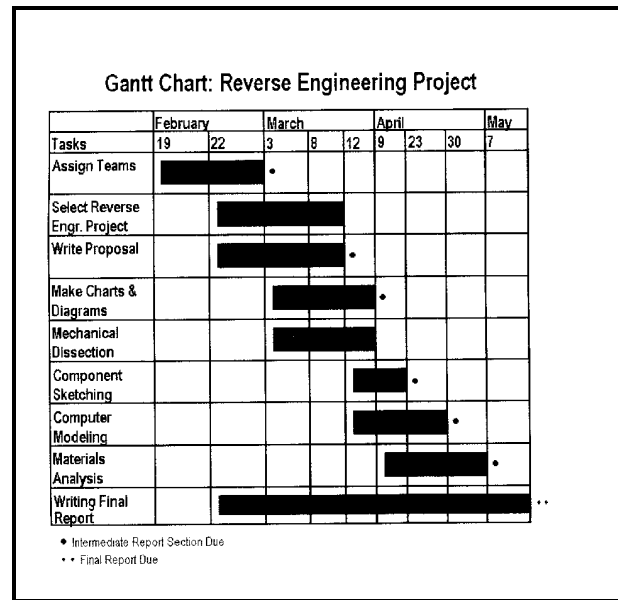
**Figure 1.** Graphic picture of the door knob assembly used for dissection. This object must first be approved by the instructor.

### *Project Planning*

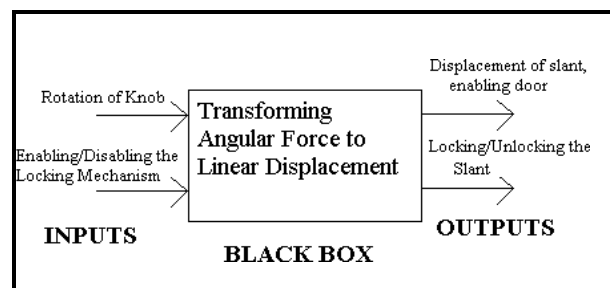
Once the object has been approved by the instructor, the teams meet and plan their dissection project activities through exercises involving charts and graphs (homework assignment #5). They organize their entire semester schedule, week-by-week, using a Gantt chart (Figure 2). An initial engineering study of the object is conducted and they establish its major input-output function using a black-box diagram (Figure 3). This allows to team to study the functionality of the device before the dissection process is initiated. They also prepare a list of functional requirements for the device.

### *Mechanical Dissection*

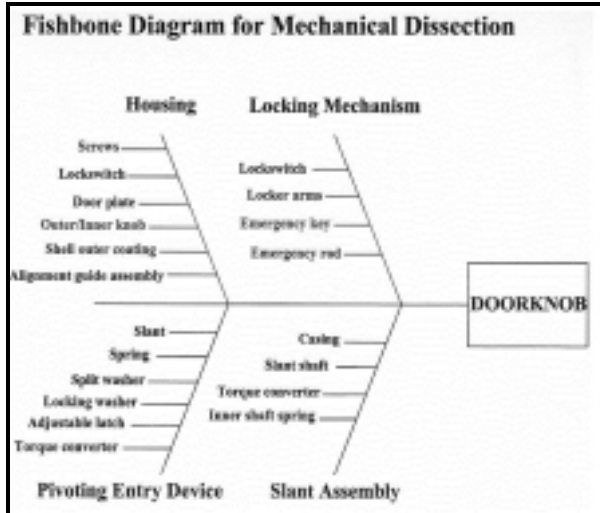
The team disassembles the mechanical object to study sub-assemblies and individual components. In order to help them organize the dissection process, a fishbone diagram (Figure 4) is used to show relationships of these sub-assemblies and components. This forces the students to study each individual component's functionality, and to name each part appropriately. They work in teams (Figure 5), and use scales and calipers to measure the geometry of each major component. This information is later used for building computer models of the parts.



**Figure 2.** The team plans their reverse engineering project using a Gantt chart. This chart serves as a week-to-week planner.



**Figure 3.** Black-box diagram showing the major input-output relationships for the door knob assembly.



**Figure 4.** Fishbone diagram is used to illustrate sub-components and assembly relationships in mechanical dissection.

### *Sketching Assemblies and Components*

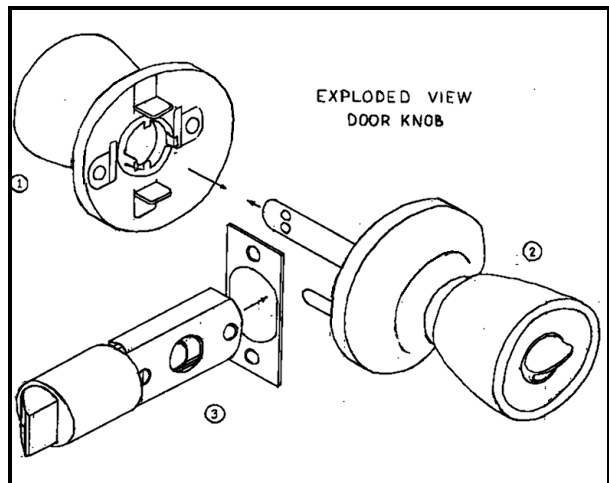
In order to aid in visualizing the dissection process, the students make isometric sketches of the whole assembly (Figure 6) and of key individual components (Figure 7). These sketches are submitted as team homework assignment #6 so that the instructor can comment on their quality, and so that the students can improve them for the final report. The sketches also prove useful as visual aids when the students start to build the 3-D computer models.

### *Computer Modeling and Analysis*

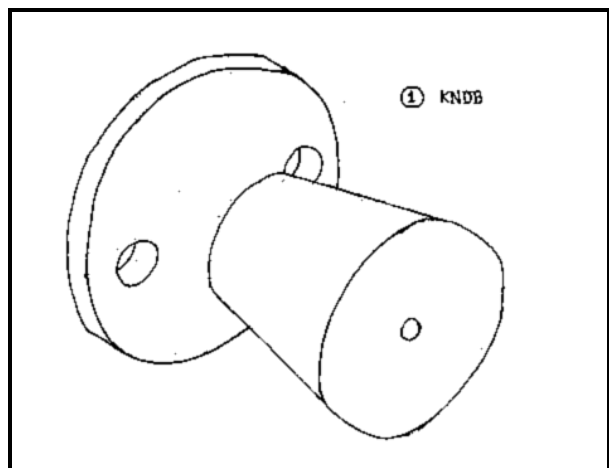
The next phase in the reverse engineering project is to build 3-D computer models of the key components of the assembly. Relying on the sketches and measured dimensions for each component, the students build 3-D computer models using the available commands in the software (in this case AutoCAD-14). When finished, the computer models can be visualized on the screen through the rendering capabilities of the software (Figures 8 and 9). They also get color hardcopies of the images to submit as homework assignment #7.



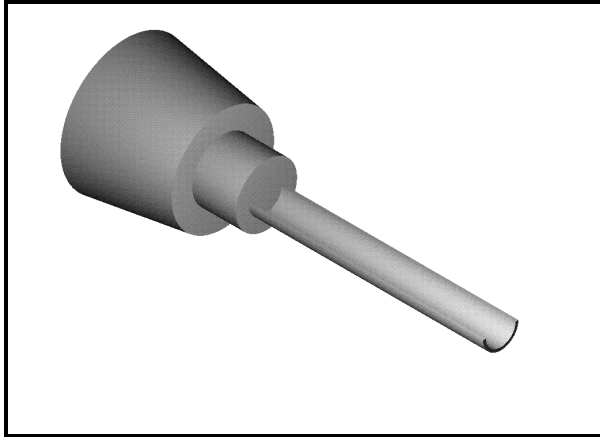
**Figure 5.** Team members measure and record the geometry of each major component during mechanical dissection.



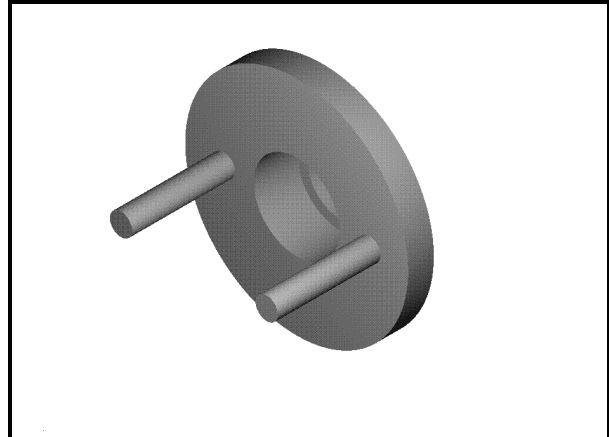
**Figure 6.** Freehand sketch of the assembly provides a visualization aid during dissection.



**Figure 7.** Sketch of an individual component.



**Figure 8.** Rendered image of a door knob component: Knob and shaft.



**Figure 9.** Rendered image of a door knob component: Casing.

Once the 3-D computer model is built, its digital data base is available for other applications. One of these applications is mass properties analysis. The software used for this project has a built-in mass properties report function. The students load the model and then perform the analysis, which generates a mass properties report file (.MPR) that can be printed out, as show in Figure 10.

### ***Rapid Prototyping***

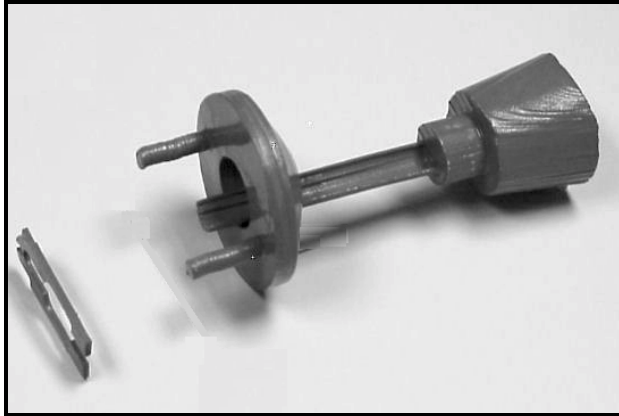
Another application of the computer model data base is for rapid prototyping. The students generate an .STL file directly from the digital geometric data base, and the .STL file is transferred to a rapid prototyping system (in this case the JP System 5 from Schroff Development Corp.). The rapid prototyping system slices the geometric solid into many thin layers, and each layer outline is cut on adhesive paper using a digital plotter equipped with a sharp blade (Figure 11). The thin slices are assembled together manually on a registration board by the students. The end product is a 3-D physical prototype of the component, which can then be finished with a glue or paint covering. The whole process takes the student team about 3 hours per component. In this case, several components were produced using the system (Figure 12).

----- SOLIDS -----	
Mass:	2.5164
Volume:	2.5164
Bounding box:	X: 1.7000 - 4.3000
	Y: 1.7000 - 4.3000
	Z: -1.2000 - 0.8349
Centroid:	X: 3.0000
	Y: 3.0000
	Z: 0.2233
Moments of inertia:	X: 23.9782
	Y: 24.0982
	Z: 47.3818
Products of inertia:	XY: 22.6474
	YZ: 1.6856
	ZX: 1.6856
Radii of gyration:	X: 3.0869
	Y: 3.0946
	Z: 4.3393

**Figure 10:** Mass Properties Report of Casing.



**Figure 11.** The students cut the slice outlines on adhesive paper using the JP System 5 rapid prototyping system.

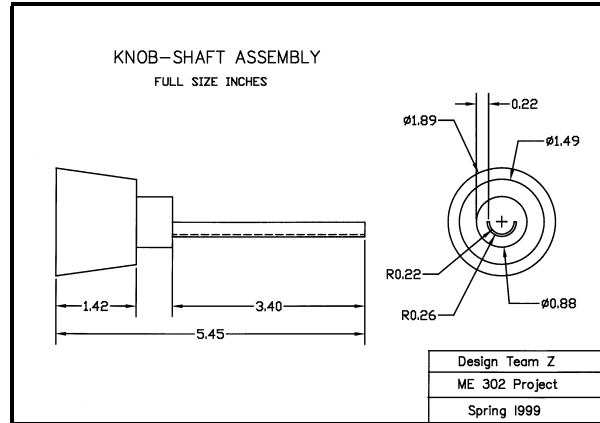


**Figure 12.** Prototypes of the door knob parts.

### Documentation and Final Report

The final graphics documentation is in the form of engineering drawings. The drawings are projected directly from the 3-D geometric solid model using available functions in AutoCAD-14. The drawing is then completed using dimensions and annotations (Figure 13). In this manner, the students generate drawings for each major component in the assembly. They also include a completed parts list of all the parts (Figure 14) of the assembly. The parts list includes determination of the part's material, which is also the subject of the final lecture homework assignment #8.

The last activity in the team project is the generation of a final report. All of the written and graphics materials are assembled in proper order and bound together. This includes a final section on product *re-design*, in which the team discusses ways to improve the design of the object. The project is submitted to the instructor for a final team grade. To facilitate this process, a project grading sheet has been prepared which lists all obligatory components for the report and the point value for each (see Figure 15). Also included is the opportunity to distribute each team member's contribution to the project as a percent of the total effort.



**Figure 13.** Drawings are projected directly from the 3-D solid model, and are completed with dimensions and annotations.

Parts List			
Door Knob			
Part No.	Part Name	No. Required	Material
1	Front Casing	1	Aluminum
2	Rear Casing	1	Aluminum
3	Inner Knob	1	Aluminum
4	Outer Knob	1	Aluminum
5	Slant Assembly	1	Aluminum
6	Door Plate	1	Steel
7	Emergency Key	1	Steel
8	Extrusion Rod	1	Plastic
9	Coil Spring	2	Steel
10	Screw (1.5")	2	Steel
11	Screw (0.5")	2	Steel
12	Split Washer	2	Steel

**Figure 14.** Parts list for the door knob assembly, including identification of part material.

### Conclusions and Recommendations

This integrated reverse engineering and design graphics project has now been conducted for three semesters. It has been found to stimulate the students' interests in Mechanical Engineering by giving them hands-on activities that apply engineering principles with significant visual feedback.

Specific observations about the success of this project in accomplishing class goals include the following.

1. Reverse engineering and team projects are effective means for introducing freshmen to the engineering discipline. The related activities mesh well with topics pertinent to engineering education and practice. It is not necessary to have a strong background in mathematics or physics to understand the various engineering phases of the product design cycle.

2. The students learn about team dynamics and about the importance of inter-personal communication skills. They select a team leader and learn about the responsibilities of individual team members. They also must make judgements on the percent contribution each team member makes to the overall project effort.

3. They gain hands-on experience with various mechanical components during the dissection exercise. Most of the objects operate according to mechanical energy principles, and the students become familiar with these principles when determining the functionality of the device.

4. The students are able to relate what they learn in the graphics laboratory with a real-life engineering problem. The various graphical exercises associated with the project offer strong visual communication modalities for the reverse engineering process.

5. The students witness first-hand the various modern applications of the 3-D geometric data base. They see the 3-D digital data base being directly used for mass properties analysis, rapid prototyping, and design drawing documentation. In this manner, they gain an appreciation for the near-future concurrent engineering design paradigm.

ME 302 Project Grading Sheet	
Team Name _____	Points Earned
<b>Enclosure</b>	
Cover Sheet, Binding, and Boxing (20)*.....	<input type="text"/>
<b>Introduction</b>	
Written Description of Reverse Engineered Object (20).....	<input type="text"/>
Black Box Diagram Showing Object's Major Function (20).....	<input type="text"/>
Engineering Specifications Table (20).....	<input type="text"/>
Gantt Chart Showing Planning of Project (20).....	<input type="text"/>
<b>Dissection Process</b>	
Description of Dissection Process (20).....	<input type="text"/>
Fishbone Diagram Showing Preliminary Object Dissection (20).....	<input type="text"/>
Exploded Assembly Sketch of Object Dissection (50).....	<input type="text"/>
<b>Analysis of Individual Parts</b>	
Complete Parts List with Part Name, Number Required, and Material (20).....	<input type="text"/>
Isometric Sketches of Individual Parts (50).....	<input type="text"/>
Color Print of Solid Computer Model of Each Individual Part (50).....	<input type="text"/>
Mass Properties Report of Each Individual Computer Model Part (20).....	<input type="text"/>
<b>Documentation of Selected Parts</b>	
Rapid Physical Prototypes of Selected (2-4) Individual Parts (80).....	<input type="text"/>
Dimensioned Orthographic Drawings of Each Prototyped Part (50).....	<input type="text"/>
<b>Re-Design of Reverse Engineered Object</b>	
Description of Potential Re-Design of the Reverse Engineered Object (20).....	<input type="text"/>
<b>Grading Sheets</b>	
Grading Sheet Handed Out in Class (10).....	<input type="text"/>
Team Member Contribution Sheet (10).....	<input type="text"/>
(*) = maximum points for each item	Total Score (500) <input type="text"/>

Figure 15. Evaluation form used to grade the final team project.

6. The teams work together to assemble and submit a final team project report that constitutes a significant portion of their course grade. In this manner, they learn valuable written, oral, and graphical communication skills.

While this reverse engineering design project has been quite successful during its first year, improvements can still be made. The overt objective of reverse engineering is to improve the product through a re-design process. That objective is not currently fulfilled, since the students merely deal with and mimic the current geometry of the object in all their graphics work. It would be nice to move the re-design phase of the project earlier in the semester and have the students incorporate improved geometry into their graphics work.

A second problem is the selection of objects for the reverse engineering project. Some of the object's selected (see Table 3), such as toy guns and airplanes, proved to be difficult to model and prototype because of the sculpted surfaces incasing the inner mechanical workings. On the other hand, objects like the door knob assembly and can opener turned out to be quite amenable to this application.

In conclusion, the integrated reverse engineering and design graphics project proved to be an effective way to orient freshmen students to the field of Mechanical Engineering. It allowed them to work in teams, to hone inter-personal skills, and to get to know their freshmen peers better. It also demonstrated an integrated process that relies heavily on a central computer data base for product design. In this manner, they have gained a glimpse of the future of engineering design in practice.

### **Acknowledgements**

The door knob examples were taken from the project report by team members Terry Grumbles, Edgar Castro, Michael Daywood, and Tony Rogers. The class web page design <http://www.me.utexas.edu/~me302/> was supported in part by an Academic Development grant from the UT College of Engineering.

### **References**

- [1]. Sheppard, S.D., "Dissection as a Learning Tool," *Proceedings of the FIE Conference*, Nashville, TN, November, 1992.
- [2]. Mickelson, S. K., Jenison, R. D., and Swanson, N., "Teaching Engineering Design through Product Dissection," *Proceedings of the 1995 American Society for Engineering Education Annual Conference*, Anaheim, California, June 1995.
- [3]. Barr, R. and Juricic, D.: Classroom Experiences in an Engineering Design Graphics Course with a CAD/CAM Extension, *Engineering Design Graphics Journal*, 62(1):9-21, 1997.
- [4]. Barr, R., Juricic, D., Krueger, T., and Wall, L.: The Freshman Engineering Design Graphics Course at the University of Texas at Austin, *Journal for Geometry and Graphics*, 2(2):169-179, 1998

### Biographical Sketches

**Ronald E. Barr** is Professor of Mechanical and Biomedical Engineering at the University of Texas at Austin, where he has taught since 1978. Barr is active in the American Society for Engineering Education and has served on the ASEE Board of Directors (1997-1999). Barr received the A.T.&T. Foundation Award (1990) for Excellence in Engineering Teaching and the ASEE Chester F. Carlson Award (1993) for Innovation in Engineering Education. His research interests are in Biosignal Analysis, Biomechanics of Human Movement, and Engineering Computer Graphics.

*Email: rbarr@mail.utexas.edu*

**Philip S. Schmidt** is the Donald J. Douglass Centennial Professor of Engineering and University Distinguished Teaching Professor at the University of Texas at Austin, where he has taught since 1970. He has been a member of ASEE and ASME for over 30 years. Schmidt has received a number of teaching honors, including the 1993 Ralph Coates Roe Award from ASEE's Mechanical Engineering Division. In 1994 he was named as one of the 50 U.S. Professors of the Year by the Carnegie Foundation for the Advancement of Teaching and the following year was named as one of the inaugural members of the Academy of Distinguished Teachers at UT Austin. His research interests include microwave and radio frequency heating processes, thermal process design and industrial ecology.

*Email: pschmidt@mail.utexas.edu*

**Thomas J. Krueger** is a Teaching Specialist in the Mechanical Engineering Department at the University of Texas at Austin, where he has taught since 1994. He received his Ph.D. from Texas A&M University in 1975, and has taught previously at TAMU, Brazosport College, and Southwest Texas State University. He is a member of ASEE and SME. His interests are in the areas of Engineering Design Graphics curriculum development, Solid Geometric Modeling, Rapid Prototyping, and Engineering Computer Graphics.

*Email: tkrueger@mail.utexas.edu*

**Chu-Yun Twu** is currently an Engineer at Advanced Micro Devices in Austin, Texas. She received her B.S. from National Taiwan University in 1997 and her M.S. from the University of Texas at Austin in 1999. She served as a Teaching Assistant and web page designer for ME302 "Introduction to Engineering Design and Graphics" while at the University of Texas. Her research interests are in solid state devices.

*Email: chuyun.twu@amd.com*