

# **Introduction to Product Design and Innovation: A Cross-Disciplinary MiniCurriculum**

**Patricia Ryaby Backer and Seth Bates  
San Jose State University**

## Abstract

For the past two years, faculty at San Jose State University (SJSU) have implemented a three-semester minicurriculum in Product Design and Manufacturing. The project follows the Project-Based Learning (PBL) model and is central to the Certificate Program in Product Design in the Mechanical Engineering Department, the Manufacturing Systems concentration in the Department of Aviation and Technology, and the Industrial Design Program in the School of Art and Design. Students in the three courses in the minicurriculum face design challenges while being instructed about the constraints of manufacturability. In each course, students develop three to four products. All products are developed using advanced solid modeling software, donated by EDS Unigraphics, capable of high levels of simulation and analysis. Instead of segregating the design, materials, and processing instruction, the minicurriculum uses design projects as a medium to learn product design basics including CAD, manufacturing materials, design for assembly, planned innovation process, and functional aesthetics. This initiative, a partnership between the College of Engineering and the School of Art and Design, models successful industry examples of integrated design and manufacturing and allows students to learn relevant collaborative skills early in their undergraduate education. The minicurriculum serves as a model of interdisciplinary education at SJSU.

## Introduction

The overarching goal of this project was to produce and evaluate new cross-disciplinary educational materials in Product Design and Manufacturing between mechanical engineering, industrial technology, and industrial design; and to promote their dissemination, both locally to community colleges and nationally to faculty in other institutions. Secondary goals were to improve the ability of faculty to model effective use of technology in instruction, to empower the students to use technology effectively to deepen learning, and to model an integrated model of product design and manufacturing for students in Mechanical Engineering, Manufacturing Technology, and Industrial Design. The prototype work for this project was funded by a San Jose State University (SJSU) curriculum grant, a seed grant of \$20,000 from Hewlett Packard for computer equipment, and Unigraphics software donated by UGS. The project team developed a three-course sequence using solid modeling as a medium to teach design, materials and manufacturing technology constraints through innovative design case studies. Students learn by facing design challenges while being instructed about the constraints of manufacturability including properties of materials and modern manufacturing methods. In each course, students develop three to four products. All products are developed using Unigraphics, an advanced solid modeling software capable of high levels of simulation and analysis. Studies of materials and

*“Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education”*

manufacturing technologies are based on a combination of traditional and on-line instruction and are coordinated with the production project demands.

This prototype work was built upon a research basis of previous curricular work in product design and manufacturing (Bronet, Eglash, Gabriele, Hess, & Kagan<sup>1</sup>; Carroll<sup>2</sup>; Lamancusa, Jorgensen, & Zayas-Castro<sup>3</sup>; Liou et al<sup>4, 5</sup>; Oslapas & Harris<sup>6</sup>; Steiner, Quick, & Fisher<sup>7</sup>). Overall, a review of the literature in engineering design (Sullivan et al<sup>8</sup>) indicates that there is a “trend of evolving from a systematic approach with major emphasis on the analytical tools used in the design process, to a holistic approach in which the main emphasis is to create a multidiscipline solution to a design problem.” This current project expands this multidisciplinary approach to cover four distinct areas: mechanical engineering, industrial design, materials, and manufacturing.

The curriculum review completed before the prototype work included a thorough evaluation of innovative teaching methodologies in manufacturing education and how these teaching methodologies can be used at San Jose State University (Bates & Obi<sup>9</sup>). This was accomplished by a literature review, coupled with interviews and data gathering from program directors at model institutions nationally. There was found to be overwhelming consensus that the world of manufacturing is changing dramatically in response to a variety of forces, including improved process technologies, improved information technologies, email and the internet, global competition, and changing customer expectations. The Society of Manufacturing Engineers (SME) developed a Manufacturing Education Plan that defined the critical competencies expected of all engineering and technology students entering manufacturing (SME<sup>10, 11</sup>). These include, on the technical side: knowledge of specific manufacturing processes, manufacturing systems (including design-manufacturing interfaces such as CAD/CAM systems) and product/process design. On the professional side, key gaps included critical thinking or problem solving, written and oral communications, and character and interpersonal skills. The project targets four competency gaps - product/process design, problem solving, specific manufacturing processes, and manufacturing systems. In addition, the Accreditation Board of Engineering and Technology (ABET) has placed a greater emphasis on design and product realization for all engineering graduates (ABET<sup>12</sup>). According to Ramers<sup>13</sup>, the nature of manufacturing problems requires concurrent engineering and a systems view that is often missing in courses that are discipline-specific. By its multidisciplinary focus, this project takes a concurrent engineering approach to product design and manufacturing.

A model was developed by Moller and Lee<sup>14</sup> who created a Design and Manufacturing course for upper division Mechanical Engineering students at Rensselaer Polytechnic that combined aspects of computer-based design and manufacturing theory in a new way. The laboratory sessions for this course involved prototyping, manufacturing processes, production, inspection, and testing. At the University of Missouri-Rolla, design was integrated into the Mechanics of Materials course to assist students in the transition from freshman design classes to the engineering design process required for the capstone course<sup>2</sup>.

King and El-Sayed<sup>15</sup> reported on a curriculum development project at Kettering University to integrate manufacturing into mechanical design courses. The student teams, from two classes

(one from the department of Mechanical Engineering and one from Manufacturing Engineering), were tasked to design, analyze, fabricate, install, and test a robot gripper using a set budget and time constraints. Another multidisciplinary curriculum project, IME Inc, developed by Simpson et al<sup>20</sup> targeted juniors in industrial engineering, electrical engineering, and mechanical engineering. IME Inc featured a two-semester sequence that covered product design and manufacturing process design and production.

A product-oriented manufacturing curriculum (Liou et al<sup>4, 5</sup>) was developed and tested at the University of Missouri-Rolla (UMR) and St. Louis Community College at Florissant Valley (FV) with students from UMR's two BS programs and one MS degree in manufacturing and the manufacturing engineering and technology programs at FV. In this curriculum, interdisciplinary teams with students from various technology and engineering disciplines worked together to design, manufacture, and assemble a product. The Learning Factory, a product of the Manufacturing Engineering Education Partnership between three major universities (Penn State, University of Puerto-Rico-Mayagüez, University of Washington), is a practice-based, interdisciplinary project that involves teams of students from Business and Industrial, Mechanical, Electrical, and Chemical Engineering<sup>3</sup>. In the Learning Factory, students actively engage in the product realization process and complete this entire process—from design concept to finished hardware—throughout their educational careers. Senior design projects are cross-disciplinary and require the use of advanced design and manufacturing techniques. Our current project builds upon the lessons learned from these curricular efforts and adds the additional content area of industrial design to the curriculum.

For true curricular improvement, it is not enough to include topics of continuous improvement in education; rather, manufacturing education must shift to a new paradigm of learning<sup>16</sup>. Chisholm<sup>19</sup> draws a parallel between the design of curriculum in the university and the design of products and systems by industry. His theme is that, to better prepare future engineers for their roles in a rapidly changing world, there needs to be a completely new approach to the education and training of manufacturing engineers. This approach should follow an integrated or concurrent model of design and manufacturing. This integrated approach assists the students in learning and applying the subject matter in a consolidated fashion.

The three courses in the minicurriculum require students to work in groups during the laboratory experiments, project development and execution and oral presentation. This will develop problem-solving skills and will foster cooperation, communication skills and ability to work towards a common goal. This is consistent with the research conducted by Behm and others<sup>18</sup> “Connections across Cultures: Inviting Multiple Perspectives into Classrooms of Science, Technology, Math, and Engineering” and funded by the National Science Foundation.

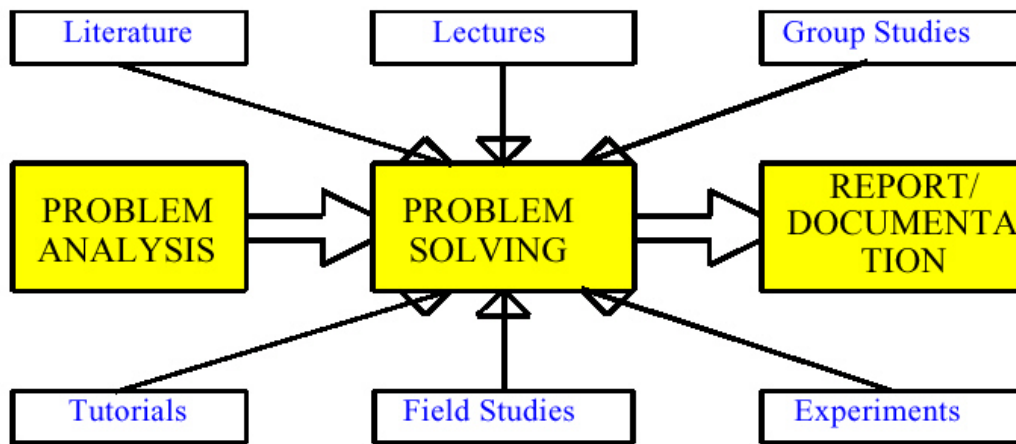
#### Prototype for this Project

In the prototype stage from 2002 to 2004, we developed a minicurriculum uniting programs in Industrial Design, Mechanical Engineering, and Industrial Technology/Manufacturing Systems to explore the possibilities of teaching technology, materials, product design, and creative innovation through the use of solid modeling and a case-based approach. The program is based

*“Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education”*

on the principles of curricular integration and project-based teaching to enhance the learning skills and competitiveness of the diverse student body at SJSU. The prototype minicurriculum was organized to be taught as problem-based group work that allows the students to develop their analytical skills and work cooperatively as multidisciplinary teams to solve increasingly complex problems. The three courses are sequenced to provide the students with more complex projects as they proceed through the three courses. This model for project-based, problem-based learning stems from seminal work done at Aalborg University in Denmark (Fink<sup>19</sup>). Figure 1 shows the main principles in project-based learning as proposed by Fink. There are three steps to this team-approach model: problem analysis, problem solving, and report/documentation. The lectures and laboratory activities designed by professors in all three disciplines are integrated to provide students with the background information to develop their project solutions.

**Figure 1.** Principles of project-based problem solving (Fink<sup>19</sup>)



This initial prototype project involved 60-75 students during the 2002-2003 academic year. After the first pilot year of this project, additional faculty were added to this project. By AY 04-05, each course in the minicurriculum will be offered each semester to approximately 150-250 students each year. The three-course curriculum is described below (the three-part prefix indicates that the courses are cross-listed):

**Tech/ME/DsID 040, Product Design I.** Introduction to product design process. Introduction to three-dimensional solid modeling. Computer-aided design, manufacturing, and analysis using commercially available software. Familiarize students with the design process and design for manufacturing. Prerequisite: BSIT: Tech 20, Tech 25; ID: DsID 32A; ME: ME 20. Misc/Lab: Lect 2 hours/lab 3 hours.

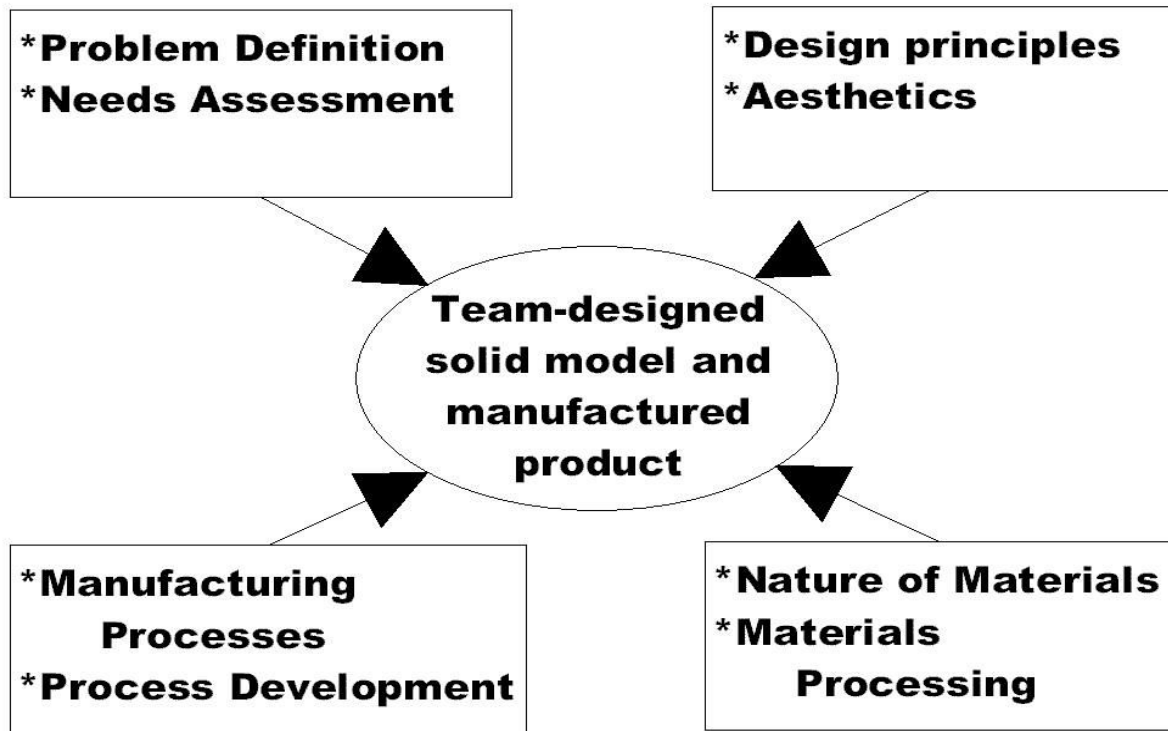
**Tech 140/ME/DsID, Product Design II.** Product design with emphasis on process and material selection. Laboratory exercises in process design and development. Planning for manufacturing. Prerequisite: Tech 40. Misc/Lab: Activity 6 hours.

**Tech 141/ME/DsID, Product Design III.** Explorations of interrelationships of design to function and aesthetics. Focus on solid model representations, design-build decisionmaking, design for manufacturability, and assembly based on aesthetics and product functionality. Prerequisite: Tech 140.

*“Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education”*

Figure 2 shows the interrelationships between the content and the student team project for the minicurriculum. Each project has different constraints, manufacturing and materials content, and design criteria. Also, since there are students from three different disciplines, the students come to these classes with different prerequisites and different skill sets. The students in Mechanical Engineering have a background in product configuration and design; the students in Industrial Technology—Manufacturing Systems have a background in materials and manufacturing processes; and the students in Industrial Design have skills in methodology and aesthetics of elementary product design. The URL for the SJSU minicurriculum prototype is available at <http://www.engr.sjsu.edu/minicurric/>.

**Figure 2.** Interrelationships between the content and the student team project for the minicurriculum



Students in each course in the minicurriculum design three to five projects over the course of a semester in project teams with participants from each of the three disciplines in this project. The faculty team teaching this course rotate among the three classes and provide lectures and laboratory activities to the students relating to their expertise. All the content of the class is centered around the projects. The students are provided with lectures and laboratory experiences in materials, manufacturing processes, and design that relate to their project on a just-in-time basis. The lecture sessions are focused on introducing the students to the theory for a particular project. The laboratory sessions are focused on having the students apply the skills needed to

*“Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education”*

develop their project using Unigraphics as well as the manufacturing techniques needed to build their project design. In addition, there is supplemental information regarding materials and manufacturing processes that is available to students on the project website.

#### Facilities used in this project

San Jose State University, through the College of Engineering, has provided support for the project in several ways. The College of Engineering has dedicated two adjoining laboratories to the use of this project and curriculum, totaling over 2400 square feet, as well as two process laboratories for metals and polymers, totaling over 6000 square feet. The College of Engineering has committed to the project through the recent purchase of two HAAS CNC Toolroom Milling machines, which are now on the laboratory network and support design and process work for the target curriculum.

The prototype minicurriculum project currently uses four Pentium-based computer laboratories in the College of Engineering at SJSU. One of these laboratories is a small prototyping laboratory that was donated by Hewlett Packard for this project. The UGS Global Strategic Partnership has agreed to license its very expensive and powerful Unigraphics software system for product design and engineering. UGS will provide 300 seats, allowing us to install the system at every lab station and every faculty desktop. This powerful software allows us to conduct drafting, sketching, solid modeling, rendering, CNC program development, and engineering analysis such as Finite Element Analysis (FEA) in the same system. The software also supports factory floor functions such as production scheduling.

#### Successes and Shortcomings

Because the curriculum has been in place for a number of semesters, we can now get ideas as to its strengths and weaknesses. This has been done by way of end-of-semester questionnaires, and by discussions with student groups. Not surprisingly, some of our early problems were caused by a common teacher weakness: a tendency to allow students to take one or more of the courses out of sequence or without proper prerequisites. These and other problems and successes will be related below.

**Successes.** The design of the class projects in the first semester is set up so that students work individually. Although they can collaborate in their work, they remain individually responsible for each project. This makes for more work for instructors, but insures that each student understands and can use the underlying design tools, namely the UGS software, and is learning the materials and process content as well. This design has been an unqualified success, as it prepares the students for very successful teaming in the second and third courses, in which all project work is done in teams.

The teams in the second and third courses are also multidisciplinary. An aggressive class management forces equal distribution of students from each available major; industrial design, manufacturing systems, and mechanical engineering. Thus, each team has students who are prepared slightly differently and are heading toward different careers, and most importantly, who have different skill sets to offer for addressing each design problem. There is a no-fault process

whereby teams may disassociate and re-form in case of severe problems, however, the instructors work hard to get teams to resolve difficulties before this is done. Resources are provided for team building and problem resolution. Instructors work closely with the teams to anticipate interpersonal problems and assist if needed in solving them. We remind students that they will in fact have to work with people of all types in the workplace, and this program is a great place to learn this.

**Figure 3.1<sup>st</sup>** Design Project Timeline and Deliverables for Tech/ME/DsID 140

**Product Design II  
Product Design and Manufacturing  
Polymers and Composites**

**Design Projects:** Design projects will be done in groups of 3 to 4 students from different fields. There will be three design projects this semester.

1<sup>st</sup> Design Project Timeline and Deliverables  
**Small Appliance or Handtool**

☉Product selection – Due date, TBA  
You will select a product to design, based on modifying an existing one (produce the “2006” version of...) from one of the following categories;

- Small electric kitchen appliance such as blender, can opener, mixer,....
- Small power tool such as drill, circular saw, sander ...
- The product must include an electric motor

Prepare a one-page description of the product and a list of the modifications including the reason for changing the design, if improving on an existing design.

☉Product Teardown – Due Date, TBA  
o submit solid model drawing of all parts.  
Product teardown is a process of taking apart a product to understand how it functions, and to understand how the company making the product succeeds. A product teardown serves three primary purposes:

- Dissection and analysis during reverse engineering.
- Experience and knowledge for individual’s personal database.
- Competitive benchmarking.

Obtain the competitor’s product similar to the one you have selected to design or modify and take it apart. Measure all components and build solid models of the parts (3D). During the disassembly, the design team should complete a list of components.

☉Product Redesign – Due Date, TBA  
o Redesign the product and submit the final report. Include the following in your report:

- Cover page and introduction, list and describe all modifications
- Assembly drawing; solid model of the product (3D, rendered in color).
- Solid model of essential components (3D).
- Exploded view of the product (3D).
- Describe manufacturing processes needed to make the product.

The contributions of each student create synergy that has led to really excellent projects showing innovation, full comprehension of the scope of the issues in each problem, and generally sound approaches to design, materials, and process issues. Each team gradually builds a portfolio of projects that he or she can take with them on graduation. Project designs completed include motorcycle wheels, faucets, small appliances, outdoor furniture, and can crushers. Figure 3 shows the project instructions for the first group project in the second courses of the minicurriculum. Other examples have been posted to the program website, <http://www.engr.sjsu.edu/minicurric/>.

**Shortcomings.** The shortcomings of the project design are related to its strengths: the challenge is in innovation. When managed carefully and thoughtfully, this leads to success. When not watched and managed, problems arise. We have had some problems with students attempting to work with another CAD/Design platform than the UGS adopted by the program. This has led to inconsistencies in the abilities of students to contribute to team work and to carry out more advanced design challenges, and we have begun to monitor and measure learning of and use of UGS software carefully to eliminate this problem. Again, students have not uniformly taken each aspect of the curriculum seriously (materials and processing, specifically) so the team will be implementing regular class quizzes to measure individual learning of each aspect of the curriculum. In addition, the curriculum leans heavily on the use of internet sources (including a program website at <http://www.engr.sjsu.edu/minicurric>) and email communications. Students, who are internet and/or email-challenged, have some difficulty keeping abreast of class expectations and resources. This must be started aggressively in the first course and maintained throughout. Finally, the teaching team must maintain close communication and cooperation. As with students, internet or email-challenged faculty cannot contribute effectively to the management and development of this program.

## Summary and Conclusions

This curriculum development project has a focus on collaborative learning that is expected to better prepare students for the ever-evolving career paths they might choose and better prepare them to live in a truly global society. Traditional higher education formats isolate teaching and research into specific, non-integrated curricula and disciplines. The dynamic work environment of the 21<sup>st</sup> century requires new approaches to breaking down these traditional divisions which form barriers to learning and behavior. The same is true in industry, where territorial barriers ('walls') between workers and management and between designers and manufacturers are increasingly challenged because of their negative effects on product quality and manufacturing productivity. Collaborative and project-based education and higher levels of computer integration into interdisciplinary courses can foster creativity and more innovative thinking among students in Mechanical Engineering, Industrial Technology, and Industrial Design working together.

After two years of delivery, the program is having some success, both internally and externally. Students in the program are responding to an increasingly well-developed curriculum and set of resources, as well as to the challenges of working in teams. The skillsets that are developed in

*"Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition  
Copyright © 2005, American Society for Engineering Education"*



the curriculum now include design techniques and principles, ergonomics, materials engineering, process engineering, and production prototyping, based on a wide range of materials including metals, polymers, and composites. The student projects developed in all three courses are steadily improving in quality and detail, and the students are beginning this year to develop professional portfolios of their work. In the greater community, early feedback suggests that graduates are pleased with this part of their preparation, and industry professionals are beginning to express interest in the program for professional development. Certificate programs are being considered in each department to capitalize on this external interest.

While no formal evaluation of the curriculum has been completed, baseline measures of student knowledge and skills have been made and will continue to be taken in a time-series study to determine trends among the students in the program. The Minicurriculum faculty are pleased with progress to date and excited and optimistic about the future of the program. The three departments involved have plans to conduct a complete evaluation of the minicurriculum in the next academic year to assess the content and goals of this program.

### Looking Towards the Future

This program continues to grow in depth and sophistication as the teachers and students compile a growing set of curricular and research resources, and new techniques to challenge the mind and the imagination. Currently, the program is seen as a success by all three programs which use it, and this success seems likely to grow and spread in influence through the student population it serves. It is exciting, builds student confidence and team working skills, and prepares all students for cross-disciplinary work in the real world.

### Bibliography

1. Bronet, P., Eglash, R., Gabriele, G., Hess, D., & Kagan, L. (2003). Product Design and Innovation: Evolution of an Interdisciplinary Design Curriculum. **International Journal of Engineering Education**, 19(1), 305-318,
2. Carroll, D. R. (1997). Integrating design into the sophomore and junior level mechanics course. **Journal of Engineering Education**, 86(3), 227-231.
3. Lamancusa, J. S., Jorgensen, J. E., & Zayas-Castro, J. L. (1997). The Learning Factory—A new approach to integrating design and manufacturing into the engineering curriculum. **Journal of Engineering Education**, 86(2), 103-112
4. Liou, F., Allada, V., Leu, M., Mishra, R., Okafor, A., & Agrawal, A. (2002). A product focused manufacturing curriculum. **ASEE Annual Conference Proceedings**. Available: [http://www.asee.org/conferences/caps/document/2002-476\\_Paper.pdf](http://www.asee.org/conferences/caps/document/2002-476_Paper.pdf)
5. Liou, F., Allada, V., Leu, M., Mishra, R., Okafor, A., & Agrawal, A. (2003). An integrated and distributed environment for a manufacturing capstone course. **ASEE Annual Conference Proceedings**. [http://www.asee.org/conferences/caps/document/2003-111\\_Final.pdf](http://www.asee.org/conferences/caps/document/2003-111_Final.pdf)
6. Oslapas, A. P. & Harris, F. D. (1995). Integrating design and manufacturing in the undergraduate curriculum. **ASEE Annual Conference Proceedings**.
7. Steiner, S. J., Quick, N. J., & Fisher, P. J. (1997). Product design and manufacturing systems (PAMS) in manufacturing engineering. **ASEE Annual Conference Proceedings**. Available: <http://www.asee.org/conferences/search/00977.pdf>

8. Sullivan, W. G., Lee, P., Luxhoj, J. T., & Thannirpalli, R. V. (1994, Fall). A survey of engineering design literature: Methodology, education, economics, and management aspects. **Engineering Economist**, **40**(1), 7-40.
9. Bates, S. P., & Obi, S. (2001, November). Innovative learning models for manufacturing. **Proceedings of the 2001 Annual Meeting of the National Association of Industrial Technology**, Pittsburgh, Pa
10. Society of Manufacturing Engineers (1997). Manufacturing Education Plan: Phase I report. Society of Manufacturing Engineers Education Foundation. Dearborn, MI.
11. Society of Manufacturing Engineers (1999). Manufacturing Education Plan: Review of findings. From Competency Gaps and Criteria, SME Website, Society of Manufacturing Engineers Education Foundation and Readex, Inc.. Dearborn, MI.
12. ABET (2000). **ABET EC 2000 Criteria**. Available: <http://www.abet.org>.
13. Ramers, D. (2002). Integrating manufacturing projects into mechanical engineering programs. **ASEE Annual Conference Proceedings**. Available: [http://www.asee.org/conferences/caps/document/2002-1351\\_Paper.pdf](http://www.asee.org/conferences/caps/document/2002-1351_Paper.pdf)
14. Moller, J. C., & Lee, D. (1996). Development of a design and manufacturing course. **ASEE Annual Conference Proceedings**. Available: <http://www.asee.org/conferences/search/01240.pdf>
15. King, L. S., & El-Sayed, J. (2003). A Structure for Integration of Manufacturing and Mechanical Design Engineering Courses. **ASEE Annual Conference Proceedings**. Available: [http://www.asee.org/conferences/caps/document/2003-1630\\_Final.pdf](http://www.asee.org/conferences/caps/document/2003-1630_Final.pdf)
16. Minnesota manufacturing learning center embodies a new discipline in manufacturing (1998). **Journal of Applied Manufacturing Systems**, **9**(2), 89-99.
17. Chisholm, A.W.J. (1990). An engineering design analogy for engineering education. **Computers in Industry**, **14**(1-3), 197-204.
18. Behm, C. et al. (1996). Connections across cultures: Inviting multiple perspectives into classrooms of science, technology, math, and engineering. ERIC Document Reproduction Services No. ED 408 171.
19. Fink, F. K. (1999). Integration of engineering practice into curriculum—25 years of experience with problem based learning. 29th ASEE/IEEE Frontiers in Education Conference Proceedings. Available: <http://fie.engrng.pitt.edu/fie99/papers/1229.pdf>
20. Simpson, T. W., Medeiros, D. J., Joshi, S., Lehtihet, A., & Wysk, R. A. (2001). IME, Inc—A new course for integrating design, manufacturing, and production into the engineering curriculum. ASEE Annual Conference Proceedings. Available: [http://www.asee.org/conferences/search/00466\\_2001.PDF](http://www.asee.org/conferences/search/00466_2001.PDF)

#### PATRICIA RYABY BACKER

Patricia Backer is a Professor and chair of the Department of Aviation and Technology in the College of Engineering at SJSU. She holds a BS degree in Chemical Engineering from Rutgers University, a MA and MS degree from Tennessee Temple University, and a MA and PhD from Ohio State. Her research interests are in the integration of multimedia and web-based learning into technology instruction.

#### SETH PARDEE BATES

Seth Bates is a Professor in the Department of Aviation and Technology at SJSU with research interests in the area of materials selection and modes of production. He teaches in the Product Design and Manufacturing curriculum, providing expertise in manufacturing and materials. He holds a BS in Philosophy from UC-San Diego, a MA in Industrial Arts from SJSU, and a Doctor of Industrial Technology from the University of Northern Iowa.