Product Design and Innovation: Results of a Cross-Disciplinary Mini-curriculum

Patricia Ryaby Backer
Department of Aviation and Technology
College of Engineering
San José State University
pabacker@email.sjsu.edu

Seth Pardee Bates
Department of Aviation and Technology
College of Engineering
San José State University
sbates@sjsu.edu

Abstract

For the past three years, faculty at San Jose State University (SJSU) have implemented a three-semester mini-curriculum 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 that make up the mini-curriculum face design challenges while learning about the constraints of materials and 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 mini-curriculum uses design projects as a medium to learn product design basics including CAD, materials selection, process selection, design for assembly, planned innovation process, and functional aesthetics. This initiative, a partnership between three departments in 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 mini-curriculum 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 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 [1]; Carroll [2]; Lamancusa, Jorgensen, & Zayas-Castro [3]; Liou et al [4, 5]; Oslapas & Harris [6]; Steiner, Quick, & Fisher [7]). Overall, a review of the literature in engineering design (Sullivan et al [8]) 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 [9]). 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 [10, 11]). 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 [12]). According to Ramers [13], 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 [14] 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 [2].

King and El-Sayed [15] 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 [20] 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 [4, 5]) 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 [3]. 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 [16]. Chisholm [19] 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 mini-curriculum 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 [18] “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 mini-curriculum 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 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 mini-curriculum was organized to be taught as problem-based group work that allows the students to develop their analytical skills and work cooperatively in 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 [19]). 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.

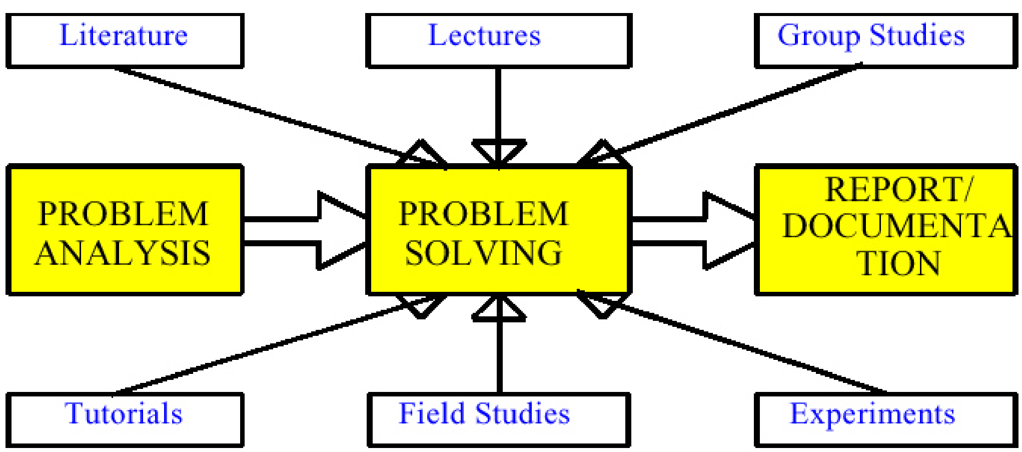

Figure 1. Principles of project-based problem solving (Fink [19])

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 mini-curriculum was 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.

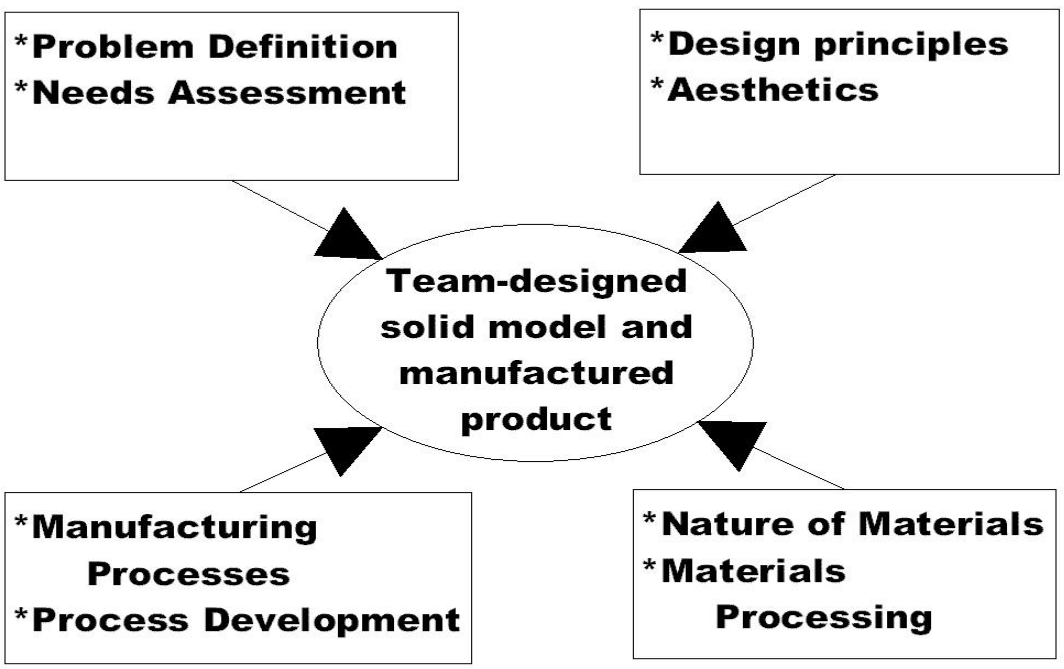

Figure 2. Interrelationships between the content and the student team project for the mini-curriculum

Figure 2 shows the interrelationships between the content and the student team project for the mini-curriculum. 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 mini-curriculum prototype is available at http://www.engr.sjsu.edu/minicurric/.

Students in each course in the mini-curriculum 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 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 committed to the project through the 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. Five new Benchtop CNC machine tools were added in the summer of 2006 to ease the introductory work in CAD/CAM.

The prototype mini-curriculum 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 agreed to license its very expensive and powerful Unigraphics software system for product design and engineering. UGS provides 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.

Assessment of the Minicurriculum

There are currently two means of measuring the effectiveness of the learning processes in the minicurriculum. One of these is a comparison of performance on individual projects during the two first courses, based on the assigned grades for those projects, and the other is an entry exam for the second course that measures learning in specific areas (design, materials, and process) retained from the first course in the sequence.

The grades for the individual projects for the first two courses in the minicurriculum have been tracked over four semesters and are shown in Table 1. Prior to these assessment results, the faculty teaching in the minicurriculum perceived that they had seen considerable and steady improvement in the quality of projects produced by our students. However, a comparison of grades for individual projects in the first and second course shows that the mean assigned grades has not significantly changed over the four semesters of assessment.

Table 1. Class Means and Standard Deviations for the First Two Courses of the Minicurriculum Over Four Semesters

PDM I			
	Project 1	Project 2	Project 2
Fall 2004 PDM I			
Mean	81.710	80.710	88.870
Standard Dev	8.900	8.100	4.200
Spring 2005 PDM I			
Mean	81.500	80.000	86.570
standard deviation	8.100	10.700	7.100
Fall 2005 PDM I			
Mean	81.000	83.000	81.540
Standard Deviation	7.100	6.100	8.600
Spring 2006 PDM I			
Mean	78.960	79.420	80.500
Standard Deviation	9.967	7.262	6.770
PDM II			
	Project 1	Project 2	Project 2
Spring 2004 PDM II			
Mean	90.152	91.773	71.970
Standard Dev	10.920	7.526	18.268
Fall 2004 PDM II			
Mean	88.526	87.211	86.368
standard deviation	5.501	9.953	6.849
Spring 2005 PDM II			
Mean	88.313	89.813	80.125
Standard Deviation	10.650	5.480	12.863
Fall 2005 PDM II			
Mean	79.200	83.684	86.100
Standard Deviation	9.919	8.718	8.612

Discussion among the faculty resulted in the understanding that

1. the improvements in project quality were expected prior to the beginning of the delivery of the minicurriculum, as a natural outcome of team learning both within

and between sections, and of the collaboration of students from different majors with different mindsets and skillsets, and

2. faculty appear to be adjusting project performance expectations upward from semester to semester, so that the average assigned grade is not changing significantly.

The entry exam developed for students beginning the second course has only been administered twice, so it is a bit early to be sure of any trends in learning. Comparison of results from these two measurements shows a small average increase (about 10%) in learning of content related to materials and processes, and an even smaller increase in the average level of learning of CAD content.

It is apparent from these two sets of measures that entry examinations will be a far more effective measure of students learning than the assigned grades on projects, so the entry examinations will be improved, continued, and expanded to include students at the beginning of the minicurriculum sequence, as well as those beginning the final course in the three-course sequence.

Successes and Shortcomings

Because the curriculum has been in place for a number of semesters, we are gaining insights as to its strengths and weaknesses. This has been assisted by way of end-of-semester questionnaires, class quizzes, 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.

Successes

The design of the class projects in the first semester course 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 approach prepares the students for more 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 multidisciplinary. An aggressive class management forces the equal distribution of students in each team 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.

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.

1st 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

- 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

- 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.

Figure 3. 1st Design Project Timeline and Deliverables for Tech/ME/DsID 140

We have worked with several methods to help match teammates to avoid common team pitfalls in the academic environment (absenteeism, lack of contributions, and other problems). These methods include pretests for all students, which helps instructors match students with similar levels of focus and ability, and peer evaluations, by which students understand that the faculty and their fellow students will establish their performance grade.

Resources are provided via the website and faculty advising for team building and problem resolution. Instructors work closely with the teams to anticipate interpersonal problems and assist if needed in solving them. We encourage problem resolution rather than avoidance, and 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.

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 the team members can take with them on graduation. Project designs completed include motorcycle wheels, faucets, small appliances, outdoor furniture, can crushers, two-wheeled vehicles, and others. Figure 3 shows the project instructions for the first group project in the second courses of the mini-curriculum. Other examples have been posted to the program website, http://www.engr.sjsu.edu/minicurric/. The students have continuous access to information regarding project expectations and evaluation criteria. The most current set of guidelines for the project shown in Figure 3 is available on the curriculum website at: *http://www.engr.sjsu.edu/minicurric/images/PDM_II/tech140_ProjectTwo_Descr.pdf*. and the evaluation rubric and explanation are available at: *http://www.engr.sjsu.edu/minicurric/images/PDM_II/tech140_ProjectOne_Eval.pdf*

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 started monitoring and measuring 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). This is a side effect of team teaching, since it happens that some content may not be covered with assessment. Thus the team is now implementing regular class quizzes to measure individual learning of each aspect of the curriculum.

The curriculum leans heavily on the use of internet resources, 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 pressed 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

Traditional higher education instructional formats isolate teaching and research into specific, unintegrated curricula and disciplines. The dynamic work environment of the 21st century requires new approaches to breaking down these traditional divisions which form barriers to learning, behavior, and performance. 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.

The skill sets that are developed in 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 developing professional portfolios of their work. Certificate programs are being developed in two of the departments to capitalize on this external interest. Anecdotal evidence from local design groups have noted the improved technical preparation of the industrial design graduates, and technology and engineering students leave the program with familiarity with and the ability to collaborate with designers and others needed to complete the product development process.

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. 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.

References

[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

[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

[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

[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

[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

Bibliography

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.

SETH PARDEE BATES
Seth Bates is a Professor in the Department of Aviation and Technology at SJSU. 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.