

PrISM—A Team-Based Approach for Teaching Manufacturing

Marvin McKimpson
Michigan Technological University

Abstract

PrISM—the Program in Integrated, Sustainable Manufacturing—is a new manufacturing engineering education option being offered to students at Michigan Technological University. It provides students hands-on experience with different manufacturing processes, as well as a more complete understanding of the inter-relationships between engineering, manufacturing and business activities. The class is structured as a “team of teams” which works together to design, manufacture and market at least one new product each academic year. This provides a rich environment for students to develop and practice necessary skills such as team and individual communication, integrated product/process design, environmental awareness, quality control, project management, problem solving, design, and marketing. Engineering students join the program as sophomores, and continue to participate during their junior and senior years, earning up to a maximum of 16 semester credits.

This paper will describe the objectives, structure and operation of the PrISM class, as well as lessons learned about implementing a manufacturing-oriented course built around the “team of teams” concept. It will also review experiences with incorporating business students into the program, and discuss integration of PrISM into the novel Engineering Enterprise initiative being developed at Michigan Technological University.

Program Overview

The Program in Integrated, Sustainable Manufacturing (PrISM) is an innovative new program at Michigan Technological University in which teams of students work together to design and produce commercially-oriented products using on-campus manufacturing facilities. It involves both hands-on project work and a series of new, multi-disciplinary instructional modules focused on manufacturing- and business-related topics. This program currently involves personnel from five University units—the Mechanical Engineering-Engineering Mechanics department, the School of Business and Economics, the Materials Science and Engineering department, the College of Engineering and the Institute of Materials Processing. Funding for the development of PrISM has been provided by the Society of Manufacturing Engineers, the National Science Foundation and six industry partners—C. Thorrez Industries, DaimlerChrysler, GM Powertrain, Johnson Controls, Inc., the National Center for Manufacturing Sciences, and the John Deere Product Engineering Center.

It is well recognized that there is an urgent and growing need for engineering graduates to have a more comprehensive understanding of both professional and technical elements of

manufacturing. The 1999 Manufacturing Education Plan developed by the Society of Manufacturing Engineers, for example, reported that newly-hired graduates working as manufacturing engineers or manufacturing technologists were found to perform “below” or “well below” employers’ expectations in a number of key professional and technical areas.¹ Some of the most important areas identified are summarized in Table 1.

Table 1.		
Percentage of New Manufacturing Engineer/Technologist Hires Performing Below or Well-Below Employers Expectations		
Professional Areas		
	Business Knowledge/Skills	55%
	International Perspective	46%
	Project Management	40%
	Written Communication	38%
	Oral Communication	30%
Technical Areas		
	Supply Chain Management	45%
	Manufacturing Processes	42%
	Manufacturing Process Control	34%
	Manufacturing Systems	31%
	Quality	29%

The PrISM program seeks to address these needs by providing engineering and business students with a team-based learning experience designed to:

- Provide hands-on exposure to manufacturing operations,
- Improve understanding of the engineering and human factors essential for successful manufacturing,
- Expand awareness of environmental issues associated with manufacturing, and
- Increase appreciation for the business elements of commercial manufacturing activities.

The program is built around development of new commercial products using integrated product/process development (IPPD) methodologies. This provides students with both hands-on experience relating to different manufacturing processes and enables them to experience the fundamentals of project management, customer support, marketing, supply chain management, and written/verbal communication skills.

The need for innovative approaches to manufacturing engineering education is well-recognized within the engineering education community, and a number of university initiatives are exploring ways to meet this need most effectively.²⁻¹¹ Many of these programs, however, focus heavily on either the design side of IPPD or on commercial production of existing designs. PrISM strives to provide students with a learning experience spanning both design and manufacturing, while also

providing students with an improved understanding of the business elements of product development and manufacturing.

PrISM is open to all Michigan Tech students, but is targeted primarily toward those enrolled in mechanical engineering and manufacturing. Students join PrISM during the first term of their second year and continue in the program during their 3rd and 4th years. They earn two semester credits per term during their second year and an average of three credits per term during subsequent years, up to a total of 16 semester credits. Seven of these credits are earned for participating in the hands-on IPPD project work. At the beginning of the academic year, PrISM students, in conjunction with participating faculty and the industrial partners, select a new product development project and divide the class into business/technical product realization teams. These teams then work together to design the product and identify required manufacturing facilities, as well as produce and evaluate prototypes.

The remaining nine credits are earned by taking one-credit instructional “modules” in parallel with this product development work. The breakdown of these project and module credits by academic term is shown in Table 2. All project and module work is graded using a traditional A through F grading scheme. Students who complete the entire 16-credit educational experience receive a notation on their transcript showing that they participated in the program.

Table 2.			
Breakdown of PrISM Enterprise Coursework by Semester and Credits			
Fall Semester		Spring Semester	
2nd-Year Students			
PrISM Orientation	(1 cr.)	IPPD Project Work	(1 cr.)
Teaming	(1 cr.)	Communications Contexts	(1 cr.)
3rd-Year Students			
IPPD Project Work	(1 cr.)	IPPD Project Work	(1 cr.)
PrISM Fundamentals	(1 cr.)	PrISM Fundamentals	(1 cr.)
Elective Modules	(0-2 cr.)	Communications Strategies	(1 cr.)
		Elective Modules	(0-2 cr.)
4th-Year Students			
IPPD Project Work	(2 cr.)	IPPD Project Work	(2 cr.)
Elective Modules	(1-3 cr.)	Elective Modules	(1-3 cr.)

Second-year students entering the program first take a one-credit “orientation” module to familiarize them with PrISM. In this module, each student builds a small, working heat engine. This involves casting the base of the engine, machining a number of aluminum and steel parts, and then assembling the entire machine. Through this activity, students gain an understanding of basic fabrication and assembly practices as well as hands-on exposure to foundry and machine shop operations. In addition, students are given a tour of a local manufacturing facility and expected to attend several class meetings with the main PrISM group. At the end of the term, these students make a formal presentation to other PrISM students describing construction of their engine.

All PrISM students are also strongly encouraged to take a two-credit (year-long) module sequence providing an overview of IPPD and manufacturing fundamentals. This sequence (“PrISM Fundamentals”) is taken during their third year. These modules are currently taught using two texts—*Integrated Product and Process Design and Development* by E. B. Magrab and the *Advanced Product Quality Planning and Control Plan (APQP) Reference Manual* developed by Chrysler (now DaimlerChrysler), Ford and General Motors.^{12, 13} The first module is devoted largely to a summary of the product development process (as described in the APQP Reference Manual), quality, and team-based engineering tools such as quality function deployment and failure modes and effects analysis. The second module is more focused toward manufacturing issues, including lean manufacturing, design of experiments, and statistical process control. The module sequence is primarily designed to provide students with the engineering tools that they are expected to use in the project portion of PrISM.

The “Teaming”, “Communications Contexts” and “Communications Strategies” modules are required of all students, and the three credits earned in these classes help fulfill general education degree requirements. The elective modules cover a range of business, engineering and manufacturing topics, including cost analysis, occupational safety and health, environmental awareness and design for manufacturing. Credits earned in both these elective modules and the IPPD project work help fulfill senior design and technical elective degree requirements. Plichta and Raber¹⁴ provide additional information about these required and elective modules.

PrISM was initially developed under a 1998 Manufacturing Education Plan grant from the Society of Manufacturing Engineers. In parallel with this effort, however, the College of Engineering at Michigan Technological University was also working with the National Science Foundation and other industrial partners to develop a major engineering curriculum redesign implementing student-led “Engineering Enterprises” throughout the College. Like PrISM, these “Enterprises” are designed to operate much like private companies, with students working on real-world problems supplied by industry. Accordingly, the two programs have collaborated very closely, and PrISM has adopted many of the structural elements of the Engineering Enterprise program, including academic credit structures and degree options. This collaboration has provided PrISM with several benefits, including a College-wide “template” for multi-disciplinary student participation, assistance with fundraising, and improved student access to machine shop facilities and expertise.

Product Development Programs

The PrISM program started in July 1998. During the Fall 1998 and Winter 1999 academic quarters, participating faculty met regularly to plan this new program and prepare necessary coursework. PrISM was first offered to students as a pilot 3-credit, elective course in Spring 1999. At the beginning of the term, the class was divided into seven product realization teams: Marketing and Sales, Packaging, Distribution and Supply, Design Engineering, Component Engineering, Assembly Engineering, Accounting, and Enterprise Staff. Their first challenge was to select an appropriate product concept. During the third week of the term, the class settled on

development of a cast aluminum coaster shaped like a Husky, the University mascot. Students designed this coaster using IDEAS[®] software, converted the drawing into NC code, and machined a prototype. This prototype was taken to the University foundry, mounted on a matchplate, and used as a pattern to cast over 60 coasters. These coasters were finished and sold before the end of the quarter.

To complete this effort in 10 weeks, the class was forced to adopt integrated product/process development practices. The Component Engineering team ordered molding flasks as soon as the size of the coasters was finalized, and poured several prototype castings before the final coaster design was chosen. The Assembly Engineering team developed finishing practices on prototype rather than final castings. The Packaging, Distribution and Supply team had final packaging materials in-house well before the first coaster was completed. The course also enabled students to actually experience manufacturing challenges like making an initial product design which could not be cast successfully, wrestling with large part-to-part variations in a manufacturing process and striving to maintain an aggressive product development schedule. But it also showed students how the combination of teamwork and good engineering can overcome these challenges.

The class was offered to students as a year-long sequence during the 1999-2000 academic year. This time, the class was divided into five product realization teams: Marketing and Sales, Finance, Product Engineering, Process Engineering and Production Engineering. In addition, the team leaders of each team formed a sixth team—the Integration Team, which provided overall management coordination of the enterprise. After reviewing the lessons learned from the Spring 1999 class, the teams selected two possible products for the year—an improved beverage coaster and a Michigan Tech key rack. Students redesigned the Husky coaster to improve both its aesthetics and manufacturability. Results from the Marketing and Sales team, however, indicated that even an improved Husky coaster was not likely to compete successfully with existing commercial products.

Accordingly, the class decided to focus its attention on the key rack. Product design was “completed” just after Thanksgiving, and students produced about 30 key racks before Christmas. These prototype key racks—and an associated market survey form—were distributed to selected students, staff and alumni. The market survey results prompted redesign of the MTU logo on the key rack and highlighted the need for improved process control (and better tooling) for some operations. The final product involved using an N/C-controlled abrasive water jet cutter programmed from an AutoCAD drawing to cut an Upper Peninsula (Michigan) shape from local bird’s eye or tiger-stripe maple. Two routed hanging slots were then cut into the back of the piece using a simple student-designed fixture. The face of the key rack was hand-finished with a waterbase polyurethane chosen to minimize solvent usage. Finally, a copper “MTU” logo was cut from rolled sheet using the water jet cutter, vacuum-annealed to produce a coarse, specular grain structure, and then fastened to the front of the rack. Students produced and sold about 70 of these key racks during the year.

During the 2000-2001 academic year, the PrISM class has worked to develop and commercialize a novel bicycle pump that weighs less and has higher pumping capacity than most currently available small pumps. It is believed that this pump will compete effectively with other bicycle pumps that are presently on the market. During the year, the class refined the initial pump concept, rapid-prototyped pump components, built and tested the final pump design, and then produce a number of pumps to be used for marketing purposes.

As PrISM matures, the class will continue to move toward producing more sophisticated products using more complex manufacturing processes. These provide students with a better understanding of the inter-relationships between engineering, manufacturing and business activities, as well as provide a wider range of hands-on experiences. They also provides a richer environment for students to develop and practice necessary skills such as team and individual communication, manufacturing process design, environmental awareness, quality control, project management, problem solving, design, marketing, and finance.

Lessons Learned

When PrISM began, it was envisioned that as students became engaged in the program they would “take ownership” of their product development concepts and assume responsibility for scheduling and completing the activities needed for successful product realization. Accordingly, the program would naturally evolve into a student-directed and student-managed organization. In the future, as PrISM gains a more extensive history of successful product development work, this is still likely to be true.

To date, however, this vision has not been realized. Students have little, if any, prior exposure to the complexities of integrated product/process development, no internal “roadmap” of how the project should evolve, and limited ability to anticipate potential stumbling blocks. Students managing and directing other students in a graded, academic course is also a somewhat awkward situation for everyone involved. Finally, PrISM students must use a variety of skills, including team engineering, conceptual design/problem solving and engineering drawing, which they may not use extensively in other courses. All of these factors make it difficult for PrISM to operate entirely as a student-directed organization. Rather, the students need to be given a clear set of expectations about what is required at each step of the product development process and about what product development timeline is to be followed. It has not been effective to ask PrISM students to develop these items entirely on their own, even as graded assignments. They simple do not have enough prior familiarity with the IPPD process to do it effectively and confidently.

Accordingly a PrISM student handbook is currently being prepared. This handbook will detail course procedures (e.g. purchasing, computer usage, phone/fax/copier access, etc.), milestone assignments for each phase of the product development process, and the required product development timeline. The handbook is likely to be somewhat similar to existing web-based product development guides, (see, for example, Ref. 14) but will contain additional emphasis on manufacturing-related topics, as well as other items geared toward carrying out product development work using University-based facilities. This handbook is initially being put

together as a paper document, but will probably be converted into a web-based format at some future time.

Experiences during the first three years of PrISM have also shown that student recruiting plays a major role in the overall success of the program. Originally, it was anticipated that current, participating students would take a very aggressive, proactive role in recruiting new students. Sometimes, however, this has not happened. Students recognize the importance of recruiting, but become so involved in other (engineering-oriented) PrISM activities that they tend to neglect recruiting issues until just before class registration each term. At that point there is very little opportunity to do anything that is particularly effective. Over the three years, PrISM has explored a number of recruiting tools, including the student newspaper, on-campus electronic display systems, a PrISM web page, table tents and flyers in campus buildings (including the dorms) and the local student radio station. As one might expect, however, none of these have proven nearly as effective as word of mouth from interested students and faculty. PrISM continues to look for novel ways to address student-recruiting issues most effectively.

Successful integration of business issues and business students into PrISM has also been somewhat challenging. Business issues are clearly an integral part of PrISM, and upper-level business students have been encouraged to enroll in the project portion of PrISM for one or more terms. The credits earned count toward the “Technology Core” requirements of their business degree, and a number of business students have participated in the program. Indeed, the “student CEO” of the class for one term was actually a female marketing student from the School of Business and Economics. These business students have made a very valuable contribution to the program, but tend to be viewed as “outsiders” by the engineering students, even when they are put together on the same team. Similarly, the engineering students have been reluctant to undertake “business” tasks such as marketing studies and financial analysis either with or without business student involvement. Several approaches have been tried for assigning students to teams and teams to tasks in order to ameliorate this issue, but none have been particularly successful.

Accordingly, an entirely different approach was adopted for the 2000-2001 academic year. No attempt was made to enroll new business students directly into PrISM. Seniors in the School of Business and Economics at Michigan Tech, however, are required to take an integrative Business Policy class prior to graduation. This class is somewhat analogous to the culminating, senior-level design experience in an engineering curriculum. During the 2000-2001 academic year, a School of Business and Economics faculty member teaching this Business Policy class agreed to use commercialization of the 2000-2001 PrISM bicycle pump as the “business project” for the students in his class. Accordingly, these senior-level business students performed marketing, financial, and other business analyses for the bicycle pump in parallel with the engineering work being done by the PrISM students. The two groups of students exchanged information as needed (most of the time), providing more realistic experiences for both classes—and much more effective business input for the PrISM program. Although the logistics of having a team-based engineering class working with a team-based business class are somewhat daunting—and have

not yet been fully worked out—this approach promises to be much more successful, and effective, than any of the previous options.

Concluding Comments

Over the last three years, the PrISM program has attained a number of important accomplishments. The PrISM class has been taught successfully for six academic terms (four quarters and two semesters), producing and selling two products—a cast aluminum coaster and a water-jet cut key rack. The PrISM organization is also now recognized as a licensed supplier of Michigan Tech merchandise. Substantial progress has also been made toward commercializing the 2000-2001 bicycle pump. For engineering students, participation in PrISM is recognized as an approved option under the College-wide “Engineering Enterprise” degree path. A group of PrISM students met with the Michigan Tech National Advisory Board during one of their semi-annual meetings and reviewed the program with them. These senior-level industrial representatives strongly endorsed the program, as have several other departmental and College-level industrial advisory groups. Students also report that they receive a very favorable response to the PrISM program from corporate interviewers. The University looks forward to continuing to build this novel University-industry partnership for improved manufacturing education at Michigan Technological University.

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MARVIN McKIMPSON

Marvin McKimpson is a program manager at the Institute of Materials Processing and an adjunct faculty member in the Mechanical Engineering-Engineering Mechanics Department at Michigan Technological University in Houghton, MI. He received his Ph.D. and M.S. in Metallurgical Engineering from the Ohio State University. Before joining Michigan Tech, he worked in product/process development at both Deere & Co. and Atlantic Richfield.