Educating Product Development Leaders

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Educating PRODUCT DEVELOPMENT Leaders

PRODUCT DEVELOPMENT is inherently interdisciplinary, a process that includes contributions from engineers, marketers, industrial designers, and many others. This reality stands in sharp contrast with the traditions of academe, where the professions are separated. At MIT, Karl Ulrich and Steven Eppinger have devised a course that more closely mirrors corporate design management, where engineers and MBA students are challenged as a team to apply decision-making methodologies to the design and fabrication of an actual product.

By Karl T. Ulrich and Steven D. Eppinger

Over the past ten years, several major universities have initiated programs to understand and improve manufacturing performance. Initially these efforts were aimed at improving the quality and efficiency of production—the activities within the walls of the factory. Many people have since realized that the criticisms of US and European manufacturing capabilities are at least partly criticisms of the design of the products, and not just of the way the designs are produced in the factory. (At MIT we have come to call the comprehensive manufacturing system, including product design and development, Big M Manufacturing.) This article describes some of our efforts to educate professionals who will be able to lead manufacturing firms in developing excellent products.

Current Concerns
Two weaknesses plague existing efforts in product development education: disciplinary myopia, and the lack of an explicit development process methodology. The first weakness is visible in the treatment of product development in business, engineering, and industrial design schools. In business schools it has traditionally been localized in marketing courses. Most engineering schools are focused on engineering science; those addressing product development issues typically limit their scope to engineering design. Industrial design schools have a strong product focus, but often concen-
trate their curriculum on aesthetics and ergonomics, with somewhat superficial treatment of market and technological issues.

Yet product development is a fundamentally integrative activity. Industrial product development teams vary in size from a handful to thousands of people, but almost always include representatives from several different disciplines, including design engineering, marketing, industrial design, and process engineering. At some point in the development process, a typical project will also involve people from finance, research, field service, and sales as important contributors. Effective product development requires that the contributions from these disciplines be understood, appreciated, and seamlessly integrated.

The second weakness is the lack of an explicit development process methodology. In our opinion, product development has been viewed both by universities and practitioners as a free-form and creative activity that defies systematic approaches. While creative problem solving is a basic skill necessary throughout the development process, we believe that structured procedures and methodologies can be as usefully applied to product development as they have been to the production processes in other parts of the manufacturing system.

We are also concerned that students are rarely exposed to the interdisciplinary richness and excitement of product development while making critical choices about the directions of their careers. Because product development is not a very public activity (and unlike law or medicine, product development is not glamorized on network television), the university is one of the only places to attract students to career options in product development.

Finally, we believe that universities can play a central role in educating leaders who understand the integral nature of product development, who can apply a basic portfolio of development methodologies, and who know how to approach development process improvement systematically.

**Our Course’s Philosophy and Approach**

The remainder of this article describes a product development course we teach at MIT. Our course, Product Development in the Manufacturing Firm, is offered jointly by the School of Engineering and the School of Management. We have taught variants of the course since 1988, and for the past two years have collaborated in the teaching with Professor Thomas Edgar of the MIT Department of Material Science and Engineering. Annual enrollment is between 30 and 40 students, about evenly divided between graduate students in management and engineering. The target audience for the course is both those who intend to be product development practitioners and those who expect to work in related areas. Of course, a single course cannot address all of the concerns we have raised, but courses do represent an explicit codification of educational approaches and are therefore useful focal points for discussion.

Product development practice is not currently based on fundamental scientific theories, and because of the importance of economic, aesthetic, and social factors, we are not sure it ever will be. Yet product development is not pure art either. Our belief is that a set of principles and structured methodologies for product development can form a middle ground between science and art, enlightening and guiding industrial practice.

Student projects are the common thread we employ to reinforce principles and methodologies. We use projects that are simple enough to allow students to perform almost all phases of the development process over one semester. This is one technique for exposing students to multiple disciplinary perspectives. We devote one of the subsequent sections of the article to an in-depth description of our course projects.

**Product Development Principles**

Two examples of product development principles are the what-not-how principle of product requirements definition and the driving-frequency principle of project management. The what-not-how principle states that requirements for a product should be expressed in terms of what the product has to do, rather than in terms of how the product should be physically implemented. For example, according to the principle, a requirement that a screwdriver be rust-resistant should be stated as “the appearance and function of the screwdriver are unaffected by moisture,” rather than “the screwdriver is made of 301 stainless steel.”

The driving-frequency principle states that the time required for a product development team to make decisions is driven by the frequency with which decision-making information is exchanged. This principle suggests that teams with twice-daily electronic mail communication will make faster decisions than teams which rely primarily on a weekly meeting to exchange information. Some of our principles are not well-developed scientific theories, but nevertheless are useful in helping students to develop insights about the product development process. In each class session we try to present and discuss several such principles.

**Methodologies**

An example of a methodology, which we use in our course, is concept selection. The methodology we have adopted is derived from Pugh’s concept selec-
tion method^ and the Kepner-Tregoe method. A table is prepared with the concept alternatives as the columns and the key product requirements as the rows. One of the concepts is identified as the “reference concept,” against which the other alternatives are compared (better than, same as, or worse than) for each of the product requirements. We have developed or adapted a collection of methodologies for other development steps; most are structured around a simple procedure and a graphical template for the key information.

We present these principles and methodologies to our students as starting points for further improvements, rather than as dogma. In fact, a central theme of our course is that development processes can be analyzed and improved in much the same way as can production processes. Because most of our students are familiar with physical process analysis and improvement, the analogical leap to organizational and intellectual processes is relatively simple.

**Interdisciplinary Knowledge**

Another approach we take to illustrating the benefits and feasibility of interdisciplinary knowledge is to demonstrate comfort with several disciplines in our teaching. For example, over the course of three class sessions, one of us may lead a case discussion on the product requirements process, lecture on the basic economics of product development, and conduct a hands-on exercise on design for manufacturing. We hope that an interdisciplinary approach in the classroom will help to ease some of the tension we see in


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**Table 1: Course Syllabus**

<table>
<thead>
<tr>
<th>CLASS</th>
<th>TOPIC</th>
<th>FORMAT</th>
<th>READINGS/CASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course Introduction Project Description</td>
<td>Lecture/Discussion Slides of past projects</td>
<td>(O'Boyle 1990)</td>
</tr>
<tr>
<td>2</td>
<td>Project Team Formation</td>
<td>Two-minute student presentations of project ideas</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Voice of the Customer I</td>
<td>Lecture/Discussion</td>
<td>(Sterrett et al., 1992), (Hauser and Clausning, 1989), (Griffin and Hauser, 1991)</td>
</tr>
<tr>
<td>4</td>
<td>Voice of the Customer II</td>
<td>Case Discussion</td>
<td>(Bahco, 1991)</td>
</tr>
<tr>
<td>5</td>
<td>Concept Generation</td>
<td>Lecture/Discussion</td>
<td>(Zau et al., 1992)</td>
</tr>
<tr>
<td>6</td>
<td>Development Timing</td>
<td>Case Discussion</td>
<td>(Sun A, 1989)</td>
</tr>
<tr>
<td>7</td>
<td>Concept Selection</td>
<td>Lecture/Discussion</td>
<td>(Howlett et al., 1991)</td>
</tr>
<tr>
<td>8</td>
<td>Visual Expression and Drawing Skills</td>
<td>Hands-on Exercise</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Industrial Design</td>
<td>Case Discussion</td>
<td>(Braun, 1991), (Lorenz, 1990), (Hamilton, 1990)</td>
</tr>
<tr>
<td>10</td>
<td>Product Architecture</td>
<td>Lecture/Discussion</td>
<td>(Ulrich, 1991)</td>
</tr>
<tr>
<td>11</td>
<td>Materials Selection</td>
<td>Lecture/Discussion</td>
<td>(Eagar, 1991a), (Eagar, 1991b)</td>
</tr>
<tr>
<td>12</td>
<td>Production Process Selection</td>
<td>Lecture/Discussion</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Design for Manufacturing</td>
<td>Hands-on Exercise (disassembly of a videocassette)</td>
<td>(Dewhurst and Boothroyd, 1987)</td>
</tr>
<tr>
<td>14</td>
<td>Prototyping</td>
<td>Lecture/Discussion</td>
<td>(Ashley, 1991), (Schrage, 1991)</td>
</tr>
<tr>
<td>15</td>
<td>Careers in Product Development</td>
<td>Guest Panel (entrepreneur, industrial designer, engineering designer)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Product Development Economics</td>
<td>Lecture/Discussion</td>
<td>(Daetz, 1987)</td>
</tr>
<tr>
<td>17</td>
<td>Project Management</td>
<td>Lecture/Discussion</td>
<td>(Raab et al., 1992), (Eppinger, 1992)</td>
</tr>
<tr>
<td>19</td>
<td>Regulatory and Liability Issues</td>
<td>Guest product liability attorney</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Environmental Issues</td>
<td>Lecture/Discussion</td>
<td>(Hocking, 1991), (Fischetti, 1992)</td>
</tr>
<tr>
<td>21</td>
<td>Product Release</td>
<td>Case Discussion</td>
<td>(Sun B, 1989)</td>
</tr>
<tr>
<td>22</td>
<td>Intellectual Property</td>
<td>Guest patent attorney</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Product Development Case Study</td>
<td>Guest product development professional</td>
<td></td>
</tr>
<tr>
<td>24-26</td>
<td>Project Presentations</td>
<td>30-minute slide presentations and demonstrations of prototypes (with guest jurors)</td>
<td></td>
</tr>
</tbody>
</table>
our students to be familiar with both the traditions and the trends in product development.

While the syllabus lays out a linear and sequential process, we frequently discuss the need to revise previous decisions based on new information. For example, the students, mostly through their project work, quickly recognize the interdependence of the three "front-end" activities—requirements definition, concept generation, and concept selection.

Student Projects
As in many courses, we use student projects to integrate the topics covered in class. Each student in the course works in a team to develop a new product, or a portion of a new product, from the initial identification of a need through pre-production prototyping. Because the semester lasts only fourteen weeks, the projects are simple—we suggest that they contain fewer than ten parts.

Figure 1 shows a graph which illustrates the trade-offs we considered in designing the project experience. We have tailored the projects to allow students to experience all phases of the development process first hand, to practice the methodologies we present in class, and to reflect on and improve their development process skills. We believe that most traditional single-discipline course projects fail to provide this experience because they do not encompass the entire development process from interviewing potential customers to producing physical prototype hardware. We also observe that in most industrial settings there is little emphasis on methodology and virtually no opportunity for reflection and process improvement. To achieve our goals we compromise on project realism in two ways: first, by insisting that the products be simple, we limit technological complexity and uncertainty; and second, because the project teams are small—from 3 to 10 members—and because the projects take place outside of a corporate setting, the students face very little of the bureaucracy which often burdens industrial product development teams.

Over the past four years we have experimented with two types of projects—student-conceived projects and company-sponsored projects—and we will continue to experiment with other project formats. With the student-conceived project option, each student group chooses a market opportunity to develop into a product. Examples of these projects, shown in Figure 2, are a test tube rack accommodating different tube sizes and a holder for a tape player. The teams pursuing this type of project usually involve four students. Limited project expenses for materials and parts fabrication are funded from a course budget.

With the company-sponsored project option, student groups work with an industrial sponsor to
redesign an existing product. The motivation for these projects may include cost reduction, quality improvement, or performance enhancement. This project format adds several dimensions of realism, including real customers, real quality problems, and real engineering costs. Examples of these projects, shown in Figure 3, are a lumbar support system for an auto seat and a clamp for spinal surgery.

Each milestone in the development process is also a course assignment. The use of project tasks as course assignments ensures that the projects are paced appropriately and that students practice using the development methodologies we present in class. The teams post their assignments on a course bulletin board for evaluation by members of the other teams. We find that students enjoy following the other teams’ efforts, although we observe that students are often harsher project critics than are the faculty. Figure 4 illustrates the progression of one project from start to finish, and shows some of the intermediate milestones. The product is a "stripping basket" for salt-water fly-fishing, a device used to prevent the line from tangling in the surf. This team identified their product opportunity by interviewing staff members at Orvis, a fly-fishing equipment retailer which subsequently commercialized the product through a licensing agreement with the students.

**Figure 2: Example of Student-Conceived Projects**

TEST TUBE RACK ACCOMMODATING DIFFERENT TUBE SIZES

HOLDER FOR TAPE PLAYER

**Other Issues**

We are not the only faculty to have attempted interdisciplinary education; we have learned from previous efforts at Stanford University, Carnegie Mellon University, Boston University, and the University of Michigan, as well as from related efforts by our colleagues at MIT. We hope to encourage others to build on our experience.

Faculty must make a leap of faith—that the projects will succeed—in a project-based course requiring working prototypes. To encourage other faculty, we note that we have never seen a project fail miserably. Students do impressive work when given some structure and methodology. Project success often surprises the students, and can be a confidence-building experience, which supports their professional endeavors.

We enjoy collaborating with faculty from multiple disciplines and we think representation from multiple disciplines is pedagogically important. This collaboration may not always be as efficient, in terms of faculty time, as when a single faculty member teaches a course. This is partly because our course faculty choose to attend most class sessions, even when not actually teaching, and partly because there are inefficiencies associated with coordination. We find that because our course is an official offering of both the engineering and management schools, we have been able to secure teaching credit for both engineering and management faculty.

We have also found that members of the local product development community have been willing to participate as guest lecturers, discussion panelists, and project jurors. Because we have no industrial design faculty at MIT, for example, we have had to rely on practicing industrial designers to contribute to our course. We suspect that almost any faculty member interested in offering a course similar to ours, but without willing collaborators within the university, could solicit help from local professionals.

In addition to faculty time, some other modest resources are required. We rely on a budget of a few thousand dollars to reimburse project expenses, and we rely on the students being able to find...
access to shop and laboratory facilities through their home departments or through the research group of a team member. Students now regularly spend several hundred dollars on course books, so we see no reason some of the project expenses could not be borne by the students, if university funds are not available. Further, most universities have some kind of shop facilities, which could probably be accessed for project tasks.

One of the benefits of teaching product development, which we see as researchers, is that our classroom experience exerts a constant demand for clarity and relevance in research. Students are among the least skeptical consumers of university research, yet they still have little patience for ideas that do not improve their ability to develop good products. We enjoy the challenge of translating our research into concepts that can be taught. Teaching product development is also fun. Graduate students have energy and skill to devote to activities that excite them and they seem especially to enjoy creating new products.

Acknowledgments
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Suggested Reading


Hocking, Martin B. “Paper Versus Polystyrene: A
Figure 4: Example of Project Milestones for the "Stripping Basket" Project

4A: GATHERING THE "VOICE OF THE CUSTOMER"

4B: COMPETITIVE ANALYSIS

4C: CONCEPT GENERATION AND SELECTION

SKETCH OF SELECTED CONCEPT

FLAT SOLID POUCH
FLEXIBLE METAL FRAME
WEIGHTED BELT LOOPS
INSIDE EDGE
VELCRO CLOSURES

NOTES
1. NOT TO SCALE
2. FEATURES EMBODY THE BEST ALTERNATIVES FOR EACH COMPONENT (SEE THE PRODUCT DESCRIPTION ATTACHED)

4D: CONCEPT REFINEMENT AND TESTING

4E: PRE-PRODUCTION PROTOTYPE

4F: PRODUCT LAUNCH


