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Creating innovative products : a development process and educational guide

Michael E. Kennedy

To the Graduate Council:

I am submitting herewith a dissertation written by Michael E. Kennedy entitled "Creating innovative products : a development process and educational guide." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Mechanical Engineering.

Clemet C. Wilson, Major Professor

We have read this dissertation and recommend its acceptance:

Frank Speckhart, Osama Soliman, Bill Snyder, Stan Becker, Charlie Moore, Richard Sanders

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Clement C. Wilson, Major Professor

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and recommend its acceptance:

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Associate Vice Chancellor
and Dean of the Graduate School

CREATING INNOVATIVE PRODUCTS:

A DEVELOPMENT PROCESS AND EDUCATIONAL GUIDE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Michael Earl Kennedy

December 1994

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ABSTRACT

Many measures of industrial competitiveness reflect that many United States industries are no longer leaders in developing and manufacturing world-class new products. A significant portion of this difficulty can be attributed to shortcomings in the processes used by these firms to develop their new products.

Some U.S. firms, particularly those facing world-class Japanese competitors, have responded by greatly improving the processes that they use to develop their new products. Case studies of successful product development projects from these responding firms have been used to develop a nine-phase model of the product development process. The model is comprehensive, spanning from "Product Ideas" through to "Product Manufacture, Delivery, and Use." Some "essential elements" are identified for each phase to emphasize the "critical few" considerations that have the most significant impact on the outcome of that process.

The development process, essential elements, and other information gathered from this research project are organized and communicated through the *Product Development Guide* ("PD Guide"), a computer-based aid for product development. The 1400 information displays contained in PD Guide are organized and accessed from the nine-phase development process, which serves as the "home menu". A set of associated items, named *PDG Tools*, accompany PD Guide and assist users with specific product development tasks.

PD Guide has been utilized over two years to teach product development concepts to senior-level and graduate engineering students. It also has served as the basis for a half-day professional continuing education course exercise. Survey results and other feedback from these users indicate that PD Guide and PDG Tools can be used successfully to teach the principles of product development and to assist students with design project efforts.

An evaluation review by 14 expert product development practitioners confirms that PD Guide generally reflects sound product development practices. One small firm has used PD Guide as the basis for creating their firm's product development process.

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PROJECT AND CONCLUSIONS SUMMARY

Chapter Summary

This chapter summarizes the research effort. The rationale for the project, method of research, development of the product development process model, and creation of the Product Development Guide are briefly described. Key conclusions and recommendations resulting from the effort are listed.

Rationale for Effort

Many competitiveness measures and the specific performance of many firms suggest that many U.S. industries no longer lead in the development of new, innovative products. Since firms need competitive products (and services) in order to exist, difficulty in new product development presents a serious national problem. Some U.S. firms have responded successfully to the product development challenge presented by world-class competitors, particularly those from Japan. Many firms will need to improve their ability to create, design, and manufacture innovative products if they are to survive within an intensely competitive world economy. Improving the *product development processes* that are used by U.S. firms is imperative for restoring U.S. industrial competitiveness.

The increasingly competitive environment described above has led to a reassessment of the educational system that produces the workers and managers for U.S.

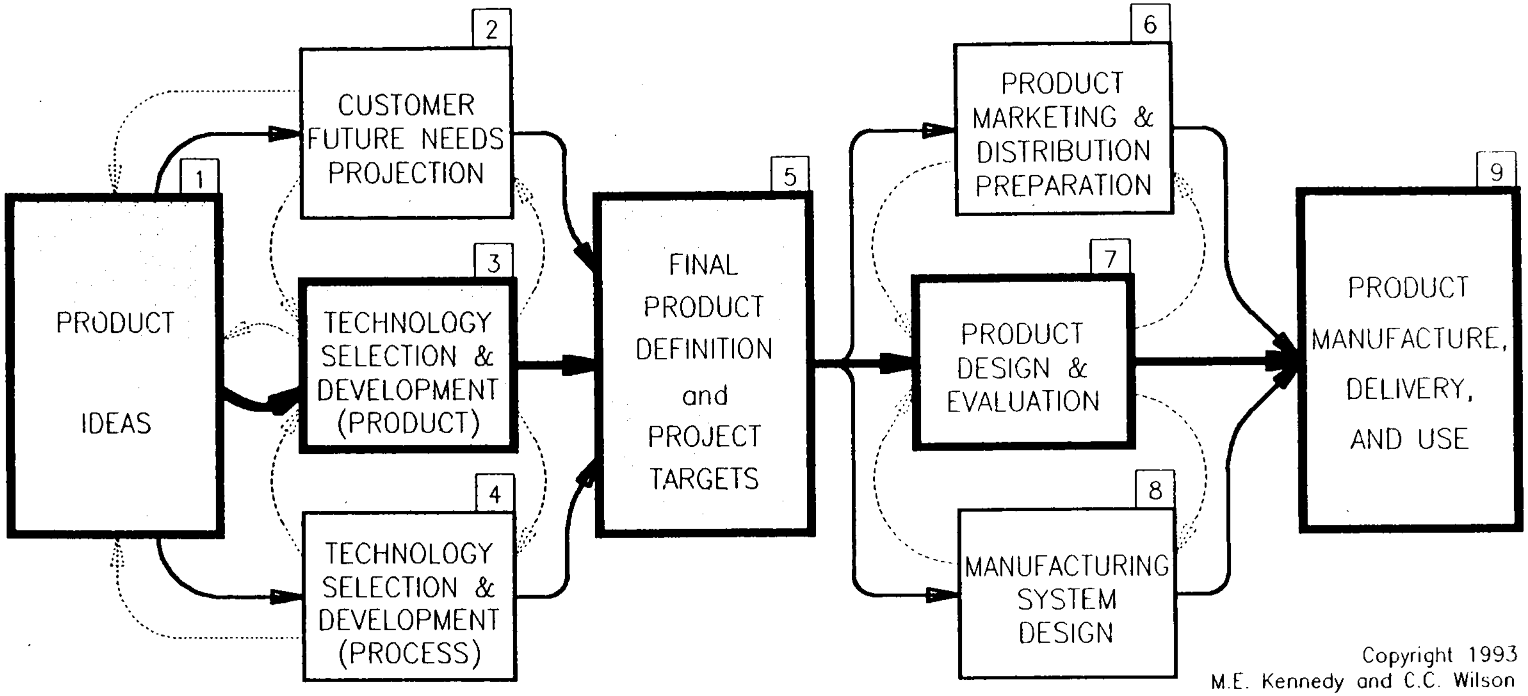
industry. A prominent criticism of a National Research Council report on engineering design education was that their curricula generally fail to address the entire product development process.

Product Development Process Model

Developing a new product is a complex, difficult process involving many interacting activities. A "product development process" describes the comprehensive set of tasks that are needed to convert a customer need (as initially represented by an "idea") into a "physical product" that meets that need. The overall objective or "milestone goal" of the product development process is to create a product with a superior combination of value, robustness, and fast availability (ie. development speed).

This research project was undertaken to develop a workable framework for teaching engineering students about a comprehensive product development process. Over 20 product development projects were studied to define a competitive product development process, its "essential elements", and related objectives. The case study information was supplemented by numerous other information sources to take advantage of, and to build on, existing techniques and processes for developing a new product, its manufacturing processes, and/or its customers/market. The results from these efforts have been compiled into the "Product Development Guide", which serves as a method for communicating key product development considerations to students.

A Product Development Process for an innovative product has been constructed, based on the case study information collected in the research (Figure 1.1). Much of this



DEVELOPMENT PHASE GOALS:

1. Potentially "high value" product concepts, consistent with future customer needs and the firm's goals/strategies.
2. Definition of target customers and their future needs, understanding of competitive offerings ("benchmarking").
3. Appropriate, timely selection and development (as necessary) of robust product technologies.
4. Appropriate, timely selection and development (as necessary) of robust process technologies.
5. "Frozen" final product definition (of "base" product plus derivatives); market, business, and resource targets.
6. Development of marketing/sales, customer support, and distribution systems that reflect customers' value needs.
7. Development of product design specification that addresses customer needs; "design-build-test" of product and its subsystems; verification of product's value and "fitness".
8. Selection and construction of cost-effective, capable processes for parts manufacture and product assembly.
9. Manufacture and assembly of quality product, consistent with customer demand; process control and improvement.

Figure 1.1: The Product Development Process for an innovative product, derived from the research.

information comes from leading U.S. firms that are competing successfully against worldwide competitors, particularly those from Japan. The process is comprehensive, originating with Product Ideas and concluding with Product Manufacture, Delivery, and Use. Each of the nine major phases in this process has "milestone goals" that define what is needed to complete that phase successfully. Although they may appear to be independent, all phases are highly interconnected and interactive in practice.

The product development process provides three imperative viewpoints that must be reflected throughout any product development process: customer, product, and manufacturing process. All three viewpoints must be considered *concurrently* throughout the product development process. Not only must they be considered concurrently, but all three viewpoints must also be "converged", or integrated, at multiple times throughout the process. Detailed descriptions of each phase is contained within the Product Development Guide software itself (discussed below), so only an introduction is provided in this document.

The term "essential elements" is used to reinforce the idea that there are some fundamental concepts, activities, or approaches ("elements") that are critical ("essential") to the development and manufacture of *superior* new products. The case studies demonstrate that successful product development projects utilize "essential elements" consistently throughout their efforts. While the Product Development Process provides a general framework for accomplishing new product development successfully, the essential elements define the key traits that the process (or a specific phase within that process) needs if it is to be successful. To most people experienced in product development or manufacturing, the essential elements are neither "new" nor "revolutionary"; indeed, they are seemingly so obvious that they tend to be overlooked and thus, poorly executed. However, success in case studies was predicated on how well essential elements were *implemented* throughout the product development process and in the manufacturing facility.

The four "most essential" essential elements" are: (1) to select and utilize a single marketing/engineering/manufacturing team to control the project throughout the development process; (2) to create a product "vision" describing how the product will meet customers' future needs; (3) to "converge", or integrate, the three major viewpoints throughout the product development process; and (4) assuring the continuity of information about critical product characteristics.

Product Development Guide

A computer-based learning tool, named "Product Development Guide" ("PD Guide"), has been developed based on the product development research and process described earlier. The primary objective for PD Guide is to help senior and graduate engineering students learn competitive product development practices and processes. PD Guide provides the student with a comprehensive view of the product development process.

The fundamental objective for PD Guide is to help students understand how competitive products can be developed successfully. Based on the general structure of design courses, and accounting for other desirable objectives related, six overall objectives for PD Guide were derived; PD Guide should: (1) be applicable to a range of problems; (2) not make decisions, but rather be a "consultant"; (3) stimulate student thought about development issues; and (4) be broad in scope; (5) provide specific assistance where appropriate; and (6) be easily used and operated.

PD Guide uses process maps, critical questions, essential elements, menu options, recommendations, examples, and references to other sources to guide the student through the development process.

PD Guide (and its corresponding PDG Tools) have been used in the year-long capstone design experience and in a graduate product development course at the University of Tennessee for the last two years.

Summary of Conclusions and Recommendations

The Product Development Guide (and the underlying product development process) was well received both by students and by a distinguished group of industrial reviewers. The industrial reviewers were unanimous in recommending PD Guide as a valid result from product development research. Students indicated that PD Guide is generally easy to use, and that it helped them learn about product development. PD Guide provides a resource for the senior capstone design, an expressed need of both students and of design course professors. Objectives for both the development process itself and for communicating the process have been largely met.

As would be expected for any undertaking, some "continuous improvements" have been identified for enhancing the presentation, usefulness, and quality of PD Guide. The expert reviewers indicated that their comments relating to problems were not indicators of fundamental flaws in PD Guide, but rather were proposed in the spirit of improving PD Guide. Improvements to PD Guide content, information display layouts, and access features are proposed. Implementation of these improvements in future versions would enhance PD Guide's utility.

Some of the largest and most-irritating problems with PD Guide are results of the software "engine" used to generate and control the information displays in PD Guide. Among its biggest drawbacks are its lack of graphics support, problems in storing and accessing information displays, and compatibility with some systems. A "new" engine with additional capability could greatly enhance PD Guide.

"Lessons learned" from class sessions in which PD Guide has been used suggest that the instructor's initiative in making PD Guide and Tools an integral part of the design course or project plays an important role in achieving successful use. PD Guide, which is a comprehensive resource (about 1400 information displays), has been described by one professor as much like an encyclopedia. Like an encyclopedia, PD Guide can appear large and intimidating, and some practice in its use can be helpful for appreciating the amount and usefulness of its contents. Several specific class assignments are proposed to help the instructor make maximum use of PD Guide in engineering classes.

Document Chapter Organization

The product development results resulting from this project are divided into specific chapters to organize the discussion. This chapter provides a summary of the overall project, significant conclusions, and recommendations. Chapter 2 explains why the product development process is so important to U.S. industrial competitiveness. Chapter 3 describes how research information was collected and processed.

Chapter 4 provides an overview of the Development Process for an Innovative Product, including a partial discussion of the "essential elements" for superior product development. Next, development and use of the *Product Development Guide* as a vehicle for communicating the product development process is explained in Chapter 5. Chapter 6 describes some "tools" (called "PDG Tools") that have been established to assist teams with specific development tasks.

Chapter 7 presents significant results from repeated student use and evaluation of the PD Guide and PDG Tools. Results from the expert practitioner review of PD Guide are described in Chapter 8. Finally, Chapter 9, Conclusions and Future Directions, examines the overall achievements of this effort and suggests areas for additional work.

It is the Product Development Guide itself (located "in pocket") that reveals and describes the specific phases of the Product Development Process in more detail. This comprehensive exposition will not be repeated in this document. Instead, the document is intended to provide some insight into how PD Guide was developed, how it has been used, and its potential benefits.

Significant content from this document and from Product Development Guide will appear in the upcoming book, *Superior Product Development: Managing the Process for Innovative Products* [Wilson, Kennedy, and Trammell, 1994 (upcoming)].

CHAPTER 2

COMPETITIVENESS AND PRODUCT DEVELOPMENT

Chapter Summary

The primary purpose of this chapter is to review competitive challenges facing U.S. industry with respect to the development and manufacture of technologically innovative products. Many competitiveness measures and the specific performance of firms suggest that many U.S. industries no longer lead in the development of new, innovative products. Since firms need competitive products (and services) in order to exist, difficulty in new product development presents a serious national problem.

Some U.S. firms have responded successfully to the product development challenge presented by world-class competitors, particularly those from Japan. The Xerox Corporation example illustrates both the dangers and the opportunities facing an increasing number of U.S. firms and industries. Many firms will need to improve their ability to create, design, and manufacture innovative products if they are to survive within an intensely competitive world economy.

Portions of this chapter also appear, or are derived from, Chapter 2 of the upcoming book, *Superior Product Development: Managing the Process for Innovative Products* [Wilson, Kennedy, and Trammell, 1994 (upcoming)].

The U.S. Competitiveness Challenge

Evidence of U.S. Problems

One need only consider these news items to understand the potential hazards and problems that can occur in the development of new products (emphasis added to quotes):

> General Electric refrigerator: "GE's new compressor flopped so badly that the company had to take a *$450 million* pretax charge in 1988. And since early last year (1989), it has voluntarily replaced nearly *1.1 million* defective compressors." [O'Boyle, *Wall Street Journal*, 1990, p.A1]

> The US Air Force B-1 bomber: "One of the plane's worst problems has been its electronic countermeasures (ECM) system, which protects it from enemy radar ... *The system sometimes jams itself.*" [*Business Week*, February 9, 1987]

While they may be particularly spectacular, these examples are by no means isolated cases of problems faced by U.S. firms as they attempt to develop world-class products. Indeed, many competitiveness measures and studies ominously conclude that U.S. firms no longer lead in creating, designing, and manufacturing many key products that are expected to provide the country with its future economic growth.

It is easy to find examples of uncompetitive U.S. product costs, excessive "development times" (the time it takes to turn a product idea into a product), and inadequate product design/manufacturing capabilities that threaten the existence of significant industries:

- the U.S.-made share of consumer electronics products has declined from almost 100% to a mere 5% over thirty years [Dertouzos *et al*, 1989, p.217];

- one firm found that its "development time to market" was actually three months of work, plus nine months of delays while waiting for required management approvals [Brazier and Leonard, 1990, p.53];

- Oldsmobile removed its "rocket" logo from the new Aurora luxury car after customer tests showed that customers liked the car much less once the logo helped them to recognize that the vehicle was made by Oldsmobile. [Kerwin, 1994]

During the 1980's in particular, the competitiveness gap became truly pervasive, invading not only general household and small consumer products but also impacting high-technology products like copiers, computer memory, and automobiles.

The Japanese Challenge

The Japanese have issued the loudest wake-up call to many U.S. industries. Over the last twenty years, leading Japanese firms have repeatedly demonstrated the ability to develop and manufacture innovative and complex products that combine the best performance, lowest cost, and highest quality in the world.

The average consumer recognizes that the automobile industry has been led increasingly by Japanese firms. Provided opportunities in the 1970's by complacent U.S. automakers, Japanese-owned facilities now account for about 25% of total North American auto production. Leadership in this industry is no trivial matter, since motor vehicles account for almost 9% of *total* U.S. consumer spending. About 15% of the

$132.6 *billion* U.S. trade deficit (1993) can be accounted for simply from U.S. net imports of Japanese autos! [U.S. Bureau of the Census - Foreign Trade Division, 1993]

The way that Japanese car firms develop new vehicles has been critical to their success. A worldwide auto industry study concluded that the average U.S. automaker needed 80% more engineering hours and 33% more development time to create an equivalent vehicle than did the average Japanese firm [Clark and Fujimoto, 1991, p.75, 80]. This superior product development capability means that, given the same development resources, an average Japanese firm can create almost twice as many new models in only two-thirds of the time needed by an average U.S. firm.

Why develop new products?

Products (and services) are the *sine qua non* of a firm: for without products and services to offer, a firm has no reason to exist. Customers purchase products only when they find those products to be the most effective in meeting their needs. If a firm is to be successful (or to even to stay in business), its products in some way must be more valuable to their customers than other alternatives - they must be more convenient, more productive, easier to use, and/or less costly. The August 1993 cover of ***Business Week***, entitled "Flops: Too Many Products Fail...", attests to the intense interest and need to develop successful new products [Power *et al.*, 1993].

New products are truly the life blood of a firm's long-term economic existence. Most firms in one survey said that over 50% of their revenues came from sale of products developed less than ten years previous [Duerr, 1986, p.3]. The 3M Corporation has a goal to earn at least 40% of its annual revenue from products that have been on the market for less than four years. [Donaldson, 1993].

Commonly-Proposed Causes of the Competitiveness Problem

Before beginning in-depth study of product development, some perspective on theories that have been espoused for the U.S. competitiveness problem is useful. While a full discussion is beyond the scope of this document, some commonly-cited "reasons" should be mentioned briefly.

Labor Costs

As competitiveness problems started to reveal themselves in the market share and financial results of U.S. firms in the mid-1970's, many claimed that it was because foreign firms paid their workers significantly lower wages than U.S. firms. Wage differences have certainly been a factor in the shift to foreign producers for very labor-intensive products, such as clothing and shoes. But wage differences fail to account for U.S. shortfalls against other advanced countries in complex products, such as autos. Indeed, Japanese and German firms throughout the 1990's have faced substantially higher average manufacturing labor costs than have U.S. firms [*The Economist*, January 15, 1994, p.66].

Even when cheaper labor is a factor, other significant factors are often found. In the GE refrigerator compressor case, the problem was not just that foreign labor was cheaper, although it indeed was. A more-fundamental problem was that the GE compressor required 65 labor minutes to assemble, while better-designed Italian and Japanese compressors could be built in 25 minutes [Magaziner and Patinkin, 1989; O'Boyle, 1990].

National Factors/Policy

In *California Management Review*, Nelson [1992, p.127] reports on his survey of writings on what he described as the "competitiveness issue." He observed that discussions of U.S. competitiveness problem causes tend to divide into three basic focus areas: (1) the "internal factors" within firms that make them strong or weak; (2) macroeconomic performance of national economics, such as monetary policy and government deficits; (3) microeconomic government policies (such as "industrial policies", industry targeting/subsidy, etc.).

Based on these readings, Nelson concluded that national factors do constrain or facilitate what individual firms can do, but that firms also have significant discretion in their actions. Further, the "very-detailed comparative studies of firms demonstrate that there is much that many American firms can do on their own to be more competitive." [Nelson, 1992, p.134]

Research Expenditures

One factor over which firms do have some control is the amount of research and development (R&D) that they perform. Some suggest that U.S. firms do not invest adequately in (non-defense) research, as compared to foreign firms. Although U.S. firms spend significant sums in defense-related research to make up much of the difference, critics point out that these efforts often do not translate well, because development skills utilized to create defense-related products are significantly different than those needed to develop high-volume, commercial products (for example, Brandt [1990]).

While research is clearly important as a long-term source of technological capabilities, other studies suggest that research alone does not necessarily lead to renewed competitiveness. A London Business School study, for example, found that the firm creating a new invention often is not the one that eventually profits the most from it, and a University of Pennsylvania study indicated that 60% of patented and successful innovations had been imitated within four years of their introduction. [*The Economist*, Jan 11, 1992, p.17-18]

Instead, it is the ability to *apply* research results to the firm's products and services that determines whether research contributes to the firm's competitive standing. Dr. Barry Bebb, former vice-president of Xerox, says that Japanese firms have not beaten U.S. firms with high technology, but rather with basic design and engineering processes and practices [Bebb, 1987]. The videocassette recorder (VCR) is a clear example: originally invented by a U.S. firm, Japanese firms eventually came to dominate the VCR market by applying superior design and manufacturing skills to the U.S. invention.

Time to Market

Many U.S. firms are learning that reducing the time it takes them to develop their new products is critical to their competitiveness. In response, some executives have declared major "corporate objectives" that mandate much shorter development times. But management edicts do not by themselves reduce product development time. Rushing through a traditional development process to meet an arbitrary development time reduction target is often just a quicker way to create an inadequate, poor-quality product. Boeing, for example, learned this lesson while attempting to design a new composite aircraft wing; the wing ended up costing twice as much as its existing counterpart and was finished "way behind" schedule [Carley, 1989; Wilson and Kennedy, 1991].

Need New Equipment

Managers will not be able to solve their competitiveness problems simply by buying new CAD systems or automated manufacturing equipment. The MIT study, for example, found that highly automated GM plants achieve "only average productivity" versus less automated Japanese firms [Dertouzos *et al.*, 1989, p.183]. Indeed, when products are designed effectively for automated assembly, the design itself often makes the automated production equipment economically unjustifiable [Galatha, 1988; Janssen, 1987].

Design for "X"?

Figure 2.1 lists but a small fraction of the many design and manufacturing methodologies that have been proposed over the past decade to improve a new product or how that product is developed and made. Many of the methods in this ever-growing list have proven to be useful. However, these individual methodologies can be executed

▸ Design-for-Assembly (DFA)	▸ Computer-Aided-Design (CAD)
▸ Design-for-Manufacturing (DFM)	▸ Computer-Aided-Engineering (CAE)
▸ Early Manufacturing Involvement	▸ Computer-Aided-Manufacturing (CAM)
▸ Quality Circles (QC)	▸ Just-In-Time Manufacturing (JIT)
▸ Quality Function Deployment (QFD)	▸ Taguchi/Experimental Design Methods

Figure 2.1: Some of the many proposed techniques for developing competitive products.

perfectly, yet products developed using these methodologies can still fail to win customers!

A major shortcoming of individual techniques is that their effectiveness in improving a firm's products is limited unless they are used within a coherent and integrated *product development process*. The goal cannot be merely to execute the best computer-aided design, fastest assembly, or best advertising, but instead must be to create a product that provides the maximum value, robustness, and quality to customers in the shortest possible time.

The Importance of Product Development

Management Attention on Product Development

One reason why Japanese firms have excelled is because their product development processes are a high management priority. In a 1991 *Harvard Business Review* survey [Kanter, 1991], Japanese managers said that product development, management, and product quality were the most important factors affecting their firm's success. In contrast, U.S. executives emphasized customer service, product quality, and technology. While one should not suggest that U.S. priorities are not important, the competitive results from many industries certify the effectiveness of the explicit Japanese emphasis on improving their product development abilities.

The National Research Council study [1991, p.68] cites the need for firms to implement a comprehensive, coherent product realization process.

Product Development Process Often Lacking

Given the difficulty in (and importance of) developing an idea into a new product, one might anticipate that firms would have well-defined, effective processes for developing new products. It is surprising to find, however, that many firms have not established effective methods; a survey of 200 practicing engineering designers and design managers in the U.K. found that 37% did not use a formal method/process in their design work [Court *et al.*, 1993, p.1711]. Wheelwright and Clark [1992, p.114-115] show the convoluted "funnels" that two development teams drew to illustrate the process that they use to develop products. Carter and Baker [1992, p.57] derived similar conclusions:

> "(What many companies lack) is a process for total product development - an integrated vision of how the product moves from design conception to manufacturing and beyond."

When they do exist, product development processes are often not as effective as they could be. Stanford business professor Dr. Charles Holloway, for example, told the *New*

York Times that he has found the "product development process (to be) very disjointed in many companies" [Holusha, 1994].

What is a "product development process"?

Developing a new product is a complex, difficult process involving many interacting activities. A "product development process" describes the comprehensive set of tasks that are needed to convert a customer need (as initially represented by an "idea") into a "physical product" that meets that need. Dr. Eric Walker, President Emeritus of Penn State (and former Dean of Engineering), describes these efforts as: [Walker, 1989, p.12]

> "a continuing process which begins at the 'bright idea' and invention stage and which continues through development, design, testing, possibly redesign for manufacturing, marketing, selling, and, in many cases, maintenance of the device during its life."

This process of converting a product idea into a customer-usable entity has come to be known by several different names. Xerox uses "Product Delivery Process", while the National Research Council adopted the term, "Product Realization Process". The term, "Product Development Process", is generally used throughout this work.

U.S. Product Development - A Fundamental Problem

Comprehensive studies by the MIT Commission on Industrial Productivity [Dertouzos *et al.*, 1989] and the National Research Council [NRC, 1991] concluded that many U.S. product development efforts are too slow, too expensive, and too often fail to create products with the features, performance, and quality that customers want. Because of these problems, foreign competitors in general, and Japanese firms in particular, have won an increasing number of the significant marketplace battles during the last two decades. A General Motors manager defines the issue clearly: [Costello, 1992]

> "Our system of product delivery is inherently flawed and incapable. World Class (product development processes) will be the key enabler in the battle where quality, cost and speed will determine the survivors."

Thus, improving the *product development processes* that are used by U.S. firms is imperative for restoring U.S. industrial competitiveness.

Potential Benefits From Improved Product Development

Higher Development Productivity

Better selection and execution of product development efforts have the potential for tremendous savings in development costs. A McKinsey study of German machine-tool firms, for example, found that the firms that performed best spent proportionally less on product development, because their spending was better focused [*The Economist*, May 25, 1991, p.75]. Foster [1986, p.108] reported that R&D VP's from large firms said in a survey that their R&D productivity could be doubled by a more effective choice of projects and by improvements in work performed. However, even a relatively modest reduction in a typical multi-million dollar development effort can generate substantial savings.

Design "Cost" Savings

Beyond the direct savings to be achieved by being more effective in performing direct product development activity, there is a far higher potential for savings in the costs that are incurred because of the *decisions* that are made during the development of a product. Basic product decisions "lock in" certain (often-large) costs later in the process and in production. Even small decisions incur future costs: choosing material for a part or defining a machining operation establishes that cost in the overall product.

Several studies suggest that the determination of the product's basic configuration effectively defines 50-75 % of the entire life-cycle cost of the product [NRC, 1991, p.1; Lemon and Dacey, 1990, p.3]. Clearly, then, a more-effective process for defining that configuration could generate tremendous future savings in the product.

Speed to market

"Being first" to market with a new product provides significant and profitable advantages. The speed at which a firm can develop its new products, then, is an increasingly important factor in achieving competitiveness. Indeed, a McKinsey study found that the "cost of being late to market overwhelmed the cost increases for accelerating development." [Foster, 1986, p.104-5]. Thus, in many cases, the sales revenue benefits of being first (or at least earlier) is more than worth the extra development costs needed to speed the product development process. Of course, this "speed" has to be bought in the right way: simply going faster can lead to "faster disasters" like the one described earlier in the chapter. An improved product development process can enable firms to "go faster" by making their process more effective.

Caveats

Before closing discussion on overall U.S. competitiveness, several additional points should be made to assure that readers do not misinterpret the above discussion.

Use of Examples. One should be cautious whenever one is considering a project example. Just because it failed to develop one refrigerator compressor properly, one should not conclude that GE is a failed U.S. company that never designs and manufactures competitive products. GE is indeed a market leader for many products. The examples simply illustrate some of the pervasive problems in U.S. industry and bring issues to a "more-concrete" level. That generally successful firms experience tremendous difficulties in developing new products demonstrates how difficult product development is, even among those who generally do it well.

International Comparisons. While this chapter has generally lauded the practices of Japanese firms, one should not assume that Japanese firms never err in their product development efforts. Mitsubishi Heavy Industries, for example, reportedly ran into trouble trying to develop its FS-X fighter aircraft. Only partially through the development process, development costs were already projected to run at least 80% over estimates, and the project was expected to miss its scheduled completion date by at least two years [*The Economist*, August 24, 1991, p.58]. Nonetheless, the *overall* performance of Japanese firms has been impressive; as David Kearns, former CEO of Xerox, has stated, "Japanese business practices were better." [Kearns, 1990]

Worldwide Issue. Lastly, it must be pointed out that "competitiveness" is not only a U.S. issue; it is a global one. The president of the German car makers association admits that German auto manufacturers "produce too expensively." [*The Economist*, May 23, 1992, p.69] Firms and countries all over the world face the continuing challenge of being competitive to maintain or grow their "share" of the global market.

Educational Competitiveness

The increasingly competitive environment described above has led to a reassessment of the educational system that produces the workers and managers for U.S. industry. Many have concluded that changes are needed in how scientists, engineers, managers, workers and others are educated [Bloch and Conrad, 1988, p.10].

Inadequacies in Engineering Curricula

Engineering curricula have come under criticism relative to their ability to present the product development process and the broad integration of topics needed to execute a product development process. The National Research Council study [1991] assessed engineering curricula nationwide and found many aspects of engineering design instruction to be inadequate. Engineering design was the most often cited accreditation deficiency in 1989, according to ABET statistics. Approximately 11% of schools that were evaluated were judged deficient in their engineering design programs [ABET, 1989].

Product Development Topics. Many universities historically have failed to teach the product development of innovative products, in either the undergraduate or the graduate curriculum. A prominent criticism of the National Research Council report was that engineering colleges generally fail to address the entire product development process. A survey of over 1,000 professionals from high-technology firms confirmed the view that "university education ... (is) deficient for adequately explaining the transition process (of bringing a product from development to production)." Students, they said, needed more knowledge of the "overall design process, hands-on design, producibility, manufacturing, and technical management." Over 62% of the respondents recommended changing the university curriculum to improve "education and knowledge of the technical risks and engineering fundamental concepts" related to product development processes [Priest and Bodensteiner, 1992].

Integration of topics. In many cases, universities fail to communicate the "multi-disciplined" approach needed to develop new products. Dr John Prados, 1991-2 president of ABET (and former vice president for academic affairs at The University of Tennessee) states: [Prados, 1992, p.3]

> "The fragmented curricula that characterize engineering education are poorly suited to provide the integrative perspective needed for an engineer to function effectively in a total quality environment."

Stuart Pugh, a long-time leader of "Shared Experiences in Engineering Design" (SEED) program in the U.K., claimed that the ".. realization of these interconnections (of design with many disciplines) is somewhat stifled in the academic environment because of the way it is almost universally structured around specialisms .." [Pugh, 1986, p.167]. Beyond the specialism, though, former Amherst Dean of Engineering James E.A. John [1991] finds integration difficult because of a "culture in engineering schools which downgrades work in design and manufacturing."

Inadequacies in Business Curricula

Business management curricula are sometimes criticized for failing to address key technology and manufacturing challenges related to the development of the sophisticated, high-value products (eg. vehicles, machinery, computers). But even when these issues are considered, Harvard Business School professor Kim Clark complains that the R&D management principles that are taught arise from "scholars and managers who studied basic laboratories conducting basic research rather than carrying out development projects aimed at immediate commercialization of a product." [Clark and Fujimoto, 1991, p.168] In other words, when business schools address technical issues, they tend to consider "research", not "product development".

Relationship to this Research Effort

The need to understand and to improve the product development processes of U.S. firms is a national imperative. As more once-dominant U.S. firms find their new product development capabilities to be inadequate, many will attempt to solve their problems through massive organizational restructuring. However, firms that focus on improving their *product development processes* are likely to be the most successful in enhancing the value, robustness, and time elements of their product, the keys to industrial competitiveness.

The U.S. product development problem is multi-faceted. Its aspects cover the entire scope of product development - from finding/selecting the product idea through to sustained manufacturing. The objective in pursuing the work described in this document is to contribute to the creation of Product Development Processes that can be used to educate participants in how to develop world-class, innovative products.

CHAPTER 3

RESEARCH RATIONALE AND METHODOLOGY

Chapter Summary

Research in product development requires that a broad, integrative approach be taken in order to capture key factors which contribute to the value, robustness, and fast availability of the developed product. Improved education (and particularly engineering education) in product development requires that students be provided a "process" focus, participate in multidisciplinary experiences, and be given exposure to key product development skills. Product development research and improved education are needed to give students better preparation for developing superior new products in their future roles as engineers and managers.

This research project was undertaken to develop a workable framework for teaching engineering students about a comprehensive product development process. Over 20 product development projects were studied to define a competitive product development process, its "essential elements", and related objectives. The case study information was supplemented by numerous other information sources to take advantage of, and to build on, existing techniques and processes for developing a new product, its manufacturing processes, and/or its customers/market. The results from these efforts have been compiled into the "Product Development Guide", which serves as a method for communicating key product development considerations to students.

Product Development Research in Context

Before descending into the development process itself, it is useful to consider some basic considerations that affect the product development processes and how it should be researched.

Characteristics of Superior Products

Three basic traits of any product serve to make that product attractive to customers. In general, any new product must strike an appropriate combination of "value", "robustness", and "availability" if it is to be successful in a competitive market. "Value" is a multi-faceted concept that attempts to measure the relative benefits and satisfaction that a customer obtains from possessing and using a product, versus that customer's cost to obtain and use it. A simple way to think of "value" is consider it as a "performance to price ratio", although, in actuality, value encompasses much more that just raw performance. "Robustness" refers to the ability of a product to deliver its "value" (whatever that value happens to be) under a wide variety of potentially unfavorable conditions. "Robust" products provide a consistent, high-quality "output" in spite of being subjected to even severe variations in input and customer environments. Product "availability" is increasingly critical, because firms that are slow to deliver their new products often find much of the market already captured by others capable of satisfying customers' needs first. "Development speed", the rate at which a firm can develop a new product and bring it to market, is a significant factor affecting the availability of a product.

Need for Integration and Interdisciplinary Approaches

The need for interdisciplinary skills is pervasive throughout industry. University of Tennessee College of Business Dean C. Warren Neel and former College of Engineering Dean (now Chancellor) William T. Snyder, in *Competing Globally Through Customer Value* [1991], describe the problem clearly:

> "Most complex businesses today have their own set of 'professors' who profess a particular discipline for a particular function. They see the problems facing a particular company in highly structured vertical terms. ... Today, most executives are finding that those same specialists no longer talk to one another, yet the problems are multidisciplinary, requiring individuals from different points of view to work together, debate together, and come to a common solution."

Xerox executives [Bebb, 1987; Sable, 1992] cite pressing needs for "multi-disciplined" people to solve key problems in product development. These multifunctional people have "depth" in their primary discipline, but also have breadth in adjacent disciplines and training in multi-disciplines. A survey of Japanese high-technology firms [Perry and Song, 1991a,b] indicated that R&D-marketing integration (which, in turn, is critical to the development of an innovative product) is very-highly dependent on both the business background of the R&D ("engineering") personnel and the technical background of the marketing personnel! Almost 30% of the *marketing personnel* in these firms reported that they had earned B.S. degrees in *engineering*. The auto industry study concluded that the firms with engineers who were less specialized were "more capable of putting high-quality, high-performance products into the marketplace faster and with much better productivity than their overspecialized competitors." [Clark and Fujimoto, 1991, p.341]

Support the "Design Fors" in Their Role

As noted in Chapter 2, some in the engineering research community have recognized the need for improving the development and manufacture of new products, and have created new "design methodologies" to improve specific aspects. Boothrooyd and Dewhurst's development of "Design-for-Assembly" ("DFA"), is an often-used, effective, specific engineering design tool intended to improve the ease of product assembly [for example, Boothroyd, 1993]. One objective of the product development process, then, should be to take advantage of these techniques.

However, because these tools are relatively narrow with respect to the product, they must be considered appropriately within the larger framework of an overall product development process. For example, DFA "rules" often conflict with similar guidance concerning "design for manufacture" ("DFM"); that is, advice followed to make a product easier to assemble very well may conflict with the ability/ease to make the parts go into the assembly. "Just-in-time" manufacturing operations will not be successful without having well-designed, robust parts and highly-capable processes. Based on this broader context, a product development process is to put these more-specific techniques in proper context and invoke them at the right times during development.

Need for Product Development Research

In conjunction with the discussion in the previous chapter, Eder [1993, p.1742] suggests that the success of Germany and Japan in engineering design is due to their efforts in creating and using "important systematic methods": in Germany, the successful development and use of methods for conducting the design process itself; and in Japan the management of the product and project. After more than 20 years in design research, Pugh concluded that, "without a structured approach to design, there is no way that the user-need situation will ever be satisfied." [Pugh, 1986, p.171]

In spite of these conclusions, there remain relatively little research (especially academic research) into the field of product development. Clark and Fujimoto [1991, p.72] note in their book on the auto industry that, "despite of its central role in competition," and in contrast to numerous studies focusing on manufacturing, there has relatively little analysis of product development. The National Research Council study [1991, p.68] reported the need to aggressively support research and development activities in engineering design.

Needed Educational Improvements

In response to the educational shortcomings described in Chapter 2, the MIT group on industrial productivity [Dertouzos *et al.*, 1989, p.157] called for the creation of "a new cadre of students" that:

- has an interest and knowledge of real problems in their contexts;
- can develop products, processes and systems as a team; and

- can operate beyond a specialized discipline.

Properly prepared, engineers are in a unique position when it comes to leading the development of innovative new products. There are many key points within in the product development processes that are best made by the design and manufacturing engineers working on that project. Lester Thurow, Dean of the MIT Business School, provides an example of such a case: [Thurow, 1985, p.170]

> "Almost by nature lawyers, accountants, financiers, and economists are not risk takers when it comes to new technologies. Only the engineers who understand a new technology can believe in it, and as a result they are more likely to be risk takers with new technologies."

To create this type of engineering student requires that engineers, professors, and students expand their working definition of "engineering" from one as a "technical specialist of narrow focus" to one that encompasses the entire product development process.

Process Focus

One key improvement is to help students understand the *process* for solving problems. Eder [1993, p.1743] emphasizes the need to provide explicit "process knowledge" to students as to how "to consciously and logically solve problems." Imperial College (Canada) [1989] established a program objective to have its graduates be able to "recognize the need for a major project to be well-organized and (to be) able to identify the way in which this may best be achieved." One method for communicating these processes is to use a "project and case-study orientation, with inter-disciplinary teams of engineering and business students working on projects that integrate design, development, manufacturing, and marketing of quality processes and products." [Prados, 1992, p.3]

Multidisciplinary Scope

Successful teaching of, and research in, product development requires that a "broad", multidisciplinary approach be taken. Some of the proposed areas to be addressed in this "broadening" of engineering design instruction include: [John, 1991, p.2; Birkhofer, 1993, p.1753; Allen, 1993, p.99]

- techniques used in design and manufacturing;
- management and business practices related to design, including financial considerations in design;
- non-analytical aspects of the engineering process, such as customer and economic considerations.

Product Development Skills/Abilities

John Dixon, one of the National Research Council study authors, elaborated on the educational needs in two issues of *Mechanical Engineering* [Dixon, 1991a,b]. In these articles, he made an impassioned case that the concept of "design" education must be broadened to include the teaching of a "generic product realization process." Other groups and persons, such as Imperial College Teaching Conference [1989], Birkhofer [1993, p.1752], and Allen [1993, p.101-102], have identified relevant topics to be addressed in this broadening. While specific items vary somewhat, most include or are included within these categories:

- essential steps in product development efforts;
- defining product requirements (from a customer/market viewpoint)
- conceptual design methods
- design methods (modularity, failure mode and effects analysis, etc.)
- design principles (iteration of design, evaluation of design, etc.);
- criteria on which decisions about a project are made, including financial considerations.

Again, the challenge in engineering education is to provide future engineers with the broad framework they need to make these decisions through full consideration of the technical, marketing, and business issues that are involved.

Goals for Effort

The basic goals for this effort can be divided into two major areas: objectives for the development process itself; and objectives for communicating the process to students (and, in particular, students in engineering design courses).

Objectives for the Development Process

The first major objective was to identify industry-based processes/tasks/practices used in the development of innovative products, then to utilize this information to create/provide a product development structure that establishes a consistent and professional product engineering framework.

The "context" of product development and research into product development (discussed earlier this chapter) dictate that any product development model be both broad and interdisciplinary. It should build on the lessons and techniques that are effective for improving various aspects of the product itself or of the processes used to develop, manufacture, and/or support that product.

Members of the Shared Experiences in Engineering Design (SEED) program in the U.K. may have the one of the longest-sustained programs of engineering design research and teaching. Leading members of SEED [Pugh, 1986, p.169; Hamilton *et al.*, 1993, p.1757] identified some key aspects of good design models. This description provides not only a good summary of objectives for developing the product development process, but also provides excellent criteria for evaluating results. In SEED's view, models of design or "the design activity" need to:

- emphasize the product as central to the business;
- be comprehensive, encompassing initial investigation of the market to the product in service;
- identify main elements of the activity, and show the relationship between those elements;
- preferably have universal application, across traditional disciplines, industry, or products;
- "allow for variations", while "retaining discipline and imparting comprehensiveness."
- relate to practice in industry.

Good design models also need to reflect a balance between realism and complexity, often utilizing graphical methods to communicate its key points. Another key consideration is that the model indeed be a model, as opposed to simply a "flowchart". The true "goodness" measure of a design model, said Pugh [1986, 1991], is how well all readers/users of that model can relate to it, understand it, and are able to practice more effectively and efficiently as a result of using it.

Objectives for Communications Vehicle - "Product Development Guide"

The second "half" of the project objective is to provide a "vehicle" for communicating the product development practices (created/defined as a consequence of the first objective) to students so that tomorrow's engineers and managers (ie. today's students) are better prepared to make meaningful contributions in the development of competitive, innovative, and profitable new products.

The Superior Engineering Design Program (SEDP) at the University of Tennessee (described further in Chapter 5) was established to improve the practice and teaching of engineering design and product development [Speckhart and Wilson, 1991, 1993]. The concept of communicating the results of product development research to engineering students (through the development of "Product Development Guide", described in Chapter 5) arose out of the desire of the SEDP to address the following needs:

- to provide a broad interdisciplinary perspective of engineering to students, as requested by the "customers" of the engineering program (employers of engineering college graduates);
- to build student cognizance of critical issues related to the successful development of competitive products, and to enhance the ability of students to perform product development activities;
- to introduce some industry "best practices" into the traditional academic program;
- to enhance the teaching of engineering by enabling the insertion of engineering design and product development knowledge into the curriculum, thereby supporting fulfillment of ABET requirements for student design education.

The vehicle selected for communicating the product development process to students is the "Product Development Guide". A complete prototype version of Product Development Guide has been developed to provide product development information and guidance to undergraduate and graduate engineering students.

Research Sources

Rationale for Case Studies

As the MIT Commission for Industrial Productivity [Dertouzos *et al.*, 1989, p.32] pointed out, there are no national indices of many performance measures, such as quality or product development speed. Even if there were, there is still no assurance that a purely-quantitative set of parameters could be shown to be completely responsible for a nation's performance. The same is true at the firm and at the product level - customers often prefer one product over another for reasons that are not entirely quantitative.

Thus, industrial researchers often turn to case studies when evaluating the tendencies, strategies, and characteristics of various firms and specific groups within those firms. A few of the more widely-known examples of this industrially-focused academic research are studies of the automobile industry [Womack *et al.*, 1990; Clark and Fujimoto, 1991]. Interestingly, most similar work that was found in the university environment originated from the College of Business.

Studies of successful product development cases do reveal common themes that contributed to the superior attributes or performance of that product. Many research efforts have discovered significant differences between successful and mediocre firms. As a sampling, a 1991 McKinsey study indicated that better firms create 2.5 times more new products on average than do less effective firms [*The Economist*, May 11, 1991, p.72]. Kuczmarski [1989] identified some "essential activities" that he found to contribute to the successful development of marketing-oriented products. Dixon [1991a,b] concludes that, "through research and observation of practice, we can discover the knowledge, strategies and principles on which design is based. ... These, then, can be generalized and taught as fundamentals."

The common themes arising from the case studies of superior product development - i.e., the "essential elements" for their success - provide the basis for the Product Development Process that is presented in Chapter 4 and throughout PD Guide.

Case Studies of Innovative Products

This document, a to-be-published book [Wilson, Kennedy, and Trammell, 1994] and the Product Development Guide have all resulted from a six year study of case histories involving the development and manufacture of complex, technologically innovative products, created by leading U.S. firms competing successfully against world-class competitors, particularly those from Japan. These studies span the entire product development process, from product conception through manufacture. In many of these cases, significant technology development was required before the products could be designed and manufactured. Evaluation of these case histories reveals significant changes that have been made in product development and manufacturing processes to improve competitive positions in world markets. Careful review of successful cases reveal common themes that help to account for why those products were successful.

The term, "innovative product", is used to describe a relatively complex product that provides additional customer value when compared to currently available products. The additional value may arise from new technologies, features, better ease of use, lower cost, or other factors deemed important by customers.

While "successful" may be interpreted in several ways, it is used here to contrast these results from those of "failed" cases. "Failed" product cases may occur when the product does not function as intended, cannot be manufactured successfully, costs too much, or cannot be developed on schedule. Many "failures" are never seen, having been abandoned by their developers before the product is completed. Or, the product may be "completed", only to fail in the marketplace either because customers never buy the product or because the purchased product then fails to meet their needs. In other cases, thousands of customers may purchase the product only to find that the product fails after a short period.

Use of U.S. firms. Casual readers of Chapter 2 might conclude that the apparent superiority of Japanese firms should lead this effort towards researching Japanese firms, rather than U.S. ones. Beyond the obvious practical reason that U.S. firms are more accessible, an important aspect of the work is the study of products/firms that are competing successfully against competitors, including those from Japanese firms. In many cases, Japanese firms have been the instigator in provoking the U.S. firm to make necessary improvements; nonetheless, the lessons from these U.S. firms are valid.

Case Study Sources

Case study evidence has been derived from a wide variety of sources, both from within the Superior Engineering Program and from elsewhere.

Internal Sources. Case studies have been performed by a number of persons in the Superior Engineering Design Program. Some materials were gathered personally by the author at industrial sites. The program's principal investigator, Dr. Clement C. Wilson, also has conducted numerous studies, during his tenure both at the University of Tennessee and at the University of Colorado.

The other source of "internal" information is from the graduate engineering course (ME 553), "Development of Superior Products and Processes" [Wilson, 1989; Speckhart and Wilson, 1991]. Much case study data have been compiled by the participating industry engineers or managers themselves and presented to students in class. Students also perform their own case study at the end of the course. Student case studies have been valuable sources of follow-up information (when students are sent after some initial study by others) and as a way to identify projects meriting additional evaluation.

Many types of information may be collected, and it may be collected in a variety of ways. Interviews with participating engineers and managers were conducted in many cases. Industrial participants have been particularly generous in many cases, offering significant time and often allowing investigators (including the author) to review company confidential materials.

External Sources. The research effort also utilized published case or industrial studies, such as those found in *Hewlett-Packard Journal* and in published Harvard

Business School case study materials. (See bibliography for a listing of the many references consulted during the course of this effort).

Firms Studied

A full, complete listing of the products and firms studied is not possible, because some of the participating firms requested confidentiality as a condition for sharing its information and experience. Table 3.1 does provide a partial sample listing. In all, over twenty product development case histories were evaluated (to various extents) by participants within the program. The projects were concerned with a variety of technically innovative products, but a large number were electro-mechanical office-type products, such as desktop printers. Additionally, some other cases were studied indirectly, through use of the "other information sources" described below.

The bibliography lists some of the student case studies that were used, some public lectures/presentations, and other sources related to many of the case studies that were evaluated.

Other Information Sources

The results of other product development process research were reviewed carefully to utilize their conclusions in the development of the product development process and of Product Development Guide.

Corporate Sources. Many of the firms studied during the course of this research have developed (or are developing) their own product development processes or other

Table 3.1: Partial listing of case studies used in research effort.

Participating Firm	Product/Process Studied
Alcoa	Continuous roll mill
Clark Equipment	Equipment handling vehicles
CTI	Positron-Emission Tomography ("PET") scanner
Hewlett-Packard	PaintJet printers
IBM - Boulder, CO	Copiers
IBM - Boulder, CO	Diskette drive
IBM - Charlotte, NC	ProPrinter (dot-matrix printer)
IBM - Lexington, KY (now Lexmark)	Electronic typewriter
Lexmark International	Computer keyboards
Lexmark International	Laser printers
NCR Corporation	Electronic cash registers
Philips	Television manufacturing
Saturn Corporation	Automatic and manual transmission design; component design and manufacturing
Square D - Asheville, NC	Electrical component manufacturing
Storage Technology	Computer tape library retrieval system
Toyota	Toyota Production System; production changeover to new model
Xerox	Copiers

design practices. As one of the first firms to react to the competitive challenge, Xerox has developed a number of documents pertaining to its product development process [Xerox, 1988,1989]. Several firms in case studies provided materials related to their product development process.

Consultant Sources. There are an increasing number of consultants (and consulting firms) who have developed methods for improving their clients' development efforts. Many of these consultants [such as Carter, 1990; Dacey and Lemon, 1990; Bebb, 1991] present their techniques to design and management roundtables.

Published Studies/Results. During the course of this effort, a number of new books on product development have been published, including *Product Development Performance* [Clark and Fujimoto, 1991], *Revolutionizing Product Development* [Wheelwright and Clark, 1993], and several others. Wheelwright and Clark's book is the current textbook for a graduate product development process course taught at The University of Tennessee. A few journal-type publications were also investigated and utilized occasionally, including *Concurrent Engineering*, *Harvard Business Review*, and the *Journal of Innovation Management.* Specific articles in current periodicals such as *Business Week* and *The Economist* occasionally conducted product case histories.

Academic Sources. The use of "traditional" academic research sources was limited, because these sources generally (with some rare exceptions) do not reflect the issues most closely related to product development. The practicing designers in the UK survey reported that they almost never used academic journals as sources for information, and indicated only slightly higher use of other academic and government-based information, other than for obtaining specific standards [Court *et al.*, 1993, p.1712-3]. Engineering Dean John Dixon [1992] concedes that, "most new design developments occur in industry ... ." For this reason, industrial information sources were much more highly used than were academic sources.

One distinct exception to this strategy was the review and use of efforts from Great Britain's SEED program. Pugh's work in particular [Pugh, 1991] was highly used throughout the research effort (this text is also used as a textbook for design courses at The University of Tennessee). It is important to note, however, that this work originated from extensive evaluation of industry design practice.

Research Synthesis

Development Practice Identification

The first major objective was to identify the processes/tasks/practices that should be used in the development of innovative products. Generally, each case study (and external information as well) was assessed to determine what major focus, activities, etc. were used in that project. Items from different cases were often "combined" in an attempt to create a broad picture of the development process.

Given the nature of much of the case study data, a "fixed" or "pre-set" formula could not be used for deciding whether a particular strategy, technique, etc. should be incorporated into the "synthesized" product development process. Instead, a general set of qualitative questions was used to assess the appropriateness and impact of various factors. Techniques, decisions, and tools were assessed against inquiries such as:

- in how many projects was the factor observed?
- for what purposes was the factor used in each project?
- what was the positive impact of that factor on the project effort?
- on what "fundamentals" is the factor based?
- how do the participants assess the factor's importance in their process?

As factors are determined to be significant, this information then had to be "inserted" into the product development structure. The "when" of the factor becomes important at this point. Finally, the question of "how" to address the factor at that point (or multiple points) in the process has to be addressed.

The primary effort was placed on performing case studies on, and evaluating the results from, successful projects. However, some of the external information collected as part of this study profiled "failed" projects (for example, [O'Boyle, 1990]). Generally, problem projects, or problems within an otherwise successful project, were evaluated in terms of what "violations", if any, had occurred in that project versus the product development process model and elements.

Synthesis Results - Output "Types"

The process synthesis activity described above generated several different types of "outputs", the methods by which the critical factors are presented. These outputs include process maps, phase milestones, essential elements, and "critical questions".

(Some of these outputs are presented in Chapter 4; they are shown, in various formats and locations, in the Product Development Guide program).

Process Maps. Process diagrams of major activities, including the overall product development process, provide "road maps" for teaching and executing specific processes. The "process map" of the overall product development process is composite layout of the nine major, "generic" activities for developing a technologically innovative product. Similar maps have been created for each phase of the development process. More-specific maps assist in completing specific tasks.

Milestone Goals. A set of "milestone goals" is defined for each phase to summarize the key objectives that need to be attained in that phase. They provide a broad statement of the knowledge that is to be acquired and/or the tasks to be completed for that development phase.

Essential Elements. The "essential elements" define fundamental concepts, strategies, or activities that the research indicated as most important to completing the development process (or a specific development phase) successfully. They define the key focus items for the process/phase, irrespective of strategy or methods selected for accomplishing those items.

"Critical" Questions. "Critical" questions are used to trigger thinking or action concerning specific issues within the development process. These questions are generally used "within" steps of a process map to help users identify the important factors in their project, address issues that they might otherwise overlook, or to request an important

decision. Other questions provide guidance by "steering" users to a certain decision based on their answers to those questions.

"Product Development Guide" and "PDG Tools"

As the process maps, essential elements, etc. were developed, attention then had to be paid to how what was being learned in the research can/should be communicated to the academic curriculum. This issue is not trivial; Dixon [1992] has lamented that, in the cases where new industrial developments have actually managed to enter the university curriculum, they are generally transferred belatedly.

The method selected for communicating the product development process, essential elements, and other results to students is the "Product Development Guide". A complete prototype version of "PD Guide" (for short) has been developed to communicate product development information and guidance to undergraduate and graduate engineering students. The purpose and structure of this computer-based tutorial is to "guide" (hence the program name) these students through the development process (PD Guide is discussed much more thoroughly in Chapter 5).

The material presentations within Product Development Guide include all of the research "output" types (and more). The development process maps are shown graphically, both at the "general" level and for specific process phases. The milestone goals and essential elements for each phase of the development process are presented, and the concepts contained within used throughout each development phase. "Critical questions" are presented at points in each phase, to call attention to tasks, steps, decisions, etc. important at that point. Other features, such as examples of relevant concepts and some simple "tools" for completing specific design tasks, are also included in PD Guide. (the "tools", which are named "PDG Tools", are discussed in more detail in Chapter 6).

Example Uses of Information in Formulating Process

As noted earlier, it was not possible to define a "procedure" for deciding what (and how) to include the information used to create the development process and Product Development Guide. However, some examples can be presented to illustrate how case study and other information was utilized to yield the end result.

Development of Process Maps. In some cases, development teams created carefully-constructed maps of the development process (or parts thereof) that they used. In other cases, processes were "reconstructed" from other provided information. Similarities/differences in these individual "product development processes" were then used to develop "composite" processes that attempt to take advantage of the relative strengths of the individual processes. Recalling that the resulting process needs to be "generic" for students working on a variety of projects, the "composite" process also that to take account of the nature of the projects used to create that composite. Once major phases/steps were identified, then the major goals, strategies, milestones, etc. could be "mapped" onto those phases/steps.

Use/Adaptation of Existing Tools/Concepts. There already exist many excellent concepts, tools, etc. for pursuing excellence in specific aspects of product development. The primary challenge throughout the product development process "construction effort", then, was not to "invent" entirely new methods, but rather to build on (and improve) the best aspects of already-existing tools and techniques.

Process capability, for example, is a well-established concept for assessing the appropriateness of using a specific manufacturing process for creating a specific design feature (while well-established and effective, it is surprising that it is not used as frequently as it could be). Thus, rather than attempting to "invent" another method for assessing capability, the section was instead constructed by integrating materials from two firms that use (and teach) the technique (Texas Instruments materials and the IBM Process Capability manual).

Similarly, the questions used in PD Guide to ask about "design for assembly" are derived from existing guidelines from Boothroyd [1992], then are supplemented from the lessons derived from case studies of the IBM Proprinter [Galatha, 1988] and diskette drive [Janssen, 1987] projects. Pugh's process [1991] for helping teams to select the "best" machine concepts, the Pugh concept selection process [Pugh, 1991], was implemented as part of PD Guide, based not only on its development by a respected design researcher but also because it was recommended by one of the case study design teams.

Additional Information

PD Guide is explained in more detail in Chapter 5, while the PDG Tools are explained in Chapter 6. The use of PD Guide as an effective communication vehicle to students was evaluated in two ways by two different groups. Students in several courses used PD Guide to evaluate how well it can be used by students (discussed in Chapter 7).

The content of PD Guide, which incorporates the process maps, etc. from the research, was evaluated by a group of industry expert practitioners (Chapter 8).

CHAPTER 4

PRODUCT DEVELOPMENT PROCESS

Chapter Summary

A Product Development Process for an innovative product has been constructed, based on case studies of leading U.S. firms that are competing successfully against worldwide competitors, particularly those from Japan. It is comprehensive, originating with Product Ideas and concluding with Product Manufacture, Delivery, and Use. In this chapter, each of the major phases of this process is introduced to provide an overall vision of this process. Detailed descriptions of each phase is contained within the Product Development Guide software itself, so only an introduction is provided in this document.

The "essential elements" concept is introduced and some overall essential elements for the entire development process are presented. Use of the essential elements throughout the product development process in the studied product development projects helped those teams to produce a superior product containing the appropriate combination of product value, robustness and availability (development speed). Overall, the chapter presents a basic *"product development methodology"* that can be used to structure a product development process for specific products.

Significant portions of this chapter also appear, or are derived from, Chapters 1 and 2 of the upcoming book, *Superior Product Development: Managing the Process for Innovative Products* [Wilson, Kennedy, and Trammell, 1994, upcoming]. The contents

of this chapter and the aforementioned book are based on the processes shown in the Product Development Guide. Other materials are derived from Chapter 18, of *Competing Globally through Customer Value* [Wilson and Kennedy, 1991].

Lessons from "World-Class" Product Development Efforts

As noted in Chapter 2, the first U.S. firms to respond to the product development challenge have generally been those that have faced direct competition from Japanese firms. Some of these responding companies were forced to make radical organizational and management changes to survive. A common response has featured a conscious, intense, and focused effort to improve the firm's product development and manufacturing processes.

More-successful firms generally have well-defined, comprehensive processes for accomplishing this complex effort. The best development processes cover a full spectrum, from the product idea through to customer delivery and product use. They also define a strategic sequence of events, ie. they indicate which tasks should be done and when. Successful firms improve their processes over time as they learn from their experiences, discover new tools, and adopt practices from others. This general flow of activities for the development of an innovative product, the "product development process", is presented momentarily. First, however, review of an example is useful for illustrating the tremendous effect that a firm's product development process can have on that firm's competitiveness.

The Xerox Example

Xerox is a frequently-studied example of a U.S. firm that faced a tremendous competitive attack, lost significant market share, but responded to the challenge by regaining its competitive abilities. The Xerox case is illustrative because it provides several key insights into the critical challenges just now facing many firms today.

Competitive Weaknesses. As the holder of the original photocopying inventions, Xerox introduced copiers to the market, then dominated that market throughout the 1960's and early 70's. As a new technology, the first copiers generally "just worked", and thus required intensive, frequent servicing to operate reliably. At that time, deterioration of copy quality (due to increasing machine contamination over time) was not considered to be a serious problem; many in Xerox actually saw the service business (created when the copiers failed or became contaminated during customer use) to be a source of *extra profit*! [Dertouzos *et al.*, 1989, p.271-273] Xerox also favored the development of ever larger and faster (and thus more expensive) copiers, because these were considered to be more profitable.

With Xerox's rigid profit criteria keeping them out [Hadden, 1986, p.4], Japanese firms targeted the "low-end" segment of the copier market first. The Japanese firms continuously improved their copiers to be more reliable, make better copies, and require less costly service than Xerox offerings. By the late 1970's, Xerox had lost almost one-third of its previous market share [Haavind, 1992, p.39]. Significant declines in Xerox's corporate profits soon followed [Hadden, 1986, p.7,8].

Competitive Assessment. Xerox initiated its response in 1980 by comparing, or "benchmarking", itself against its Japanese affiliate, Fuji Xerox. As other some firms are only now learning, Xerox found that they were grossly uncompetitive. When compared to their Fuji subsidiary, Xerox found that they: [Xerox, 1989, p.2; Hadden, 1986, p.20; Bebb, 1987]

- took twice as long to develop new products as did Fuji, in spite of the fact that Xerox used twice as many people on their development projects as did Fuji;
- produced comparable products at twice the cost of Fuji's products, which meant that Xerox' *production* costs were about as much as Fuji's *selling* costs;
- built products with at least twice as many defects versus Fuji's products (and in some cases 10-30 times as many defects).

Not only was Xerox (US) seriously behind, but it was increasingly behind: its 8% annual productivity improvement rate paled next to Fuji's 14% rate of improvement. Clearly, Xerox needed to improve radically the way it developed its new products.

Problem Diagnosis. Xerox identified many significant problems with its product development process, but found that its most serious problems were based on the way it organized product development projects. The "functional organization" used by Xerox at that time (and still used by a surprisingly large number of firms today) requires that new products move through the separate "functions" of the firm: engineering, marketing, finance, service, etc. To assure that all functional objectives are met, the functional organization often defines specific points during the project where each function must give its approval that a new product meets its functional targets.

In this mode, no entity is responsible for the overall product; functions worry only about their own narrow objectives. Since product development requires an integration of many and sometimes conflicting objectives, functions often "blocked" the product at approval points. Speedy resolution of these conflicts requires good communication among the parties; but since members of each function reported to their own organizations, communication among functions was poor. Lengthy delays often meant that the "new" product was obsolete before it was even introduced to market.

Design and manufacturing functions were inadequate as well. Because these functions reported to separate managers, Xerox product designers often created products requiring more parts than necessary, many of which proved to be difficult to manufacture. Manufacturing used inspection to obtain part quality, rather than improving processes. Indeed, benchmarking of Xerox design and manufacture of plastic parts revealed that both poor parts design and poor manufacturing practices were about equally responsible for problems in quality, cost, and development time. [Bebb, 1991, p.973; Dertouzos *et al.*, 1989, p.272-4; Hadden, 1986, p.13-14]

Targeted Actions. Xerox concluded that a radical dismantling of its functional organization was needed to improve their product development process. To integrate development and production, Xerox created multi-disciplinary "product delivery teams" that were made fully accountable for the total quality, cost, and delivery of the product. Each new product team is led by a "chief engineer", who has broad authority over the new product's development. This chief engineer is provided the full spectrum of resources needed to design, prototype, and manufacture the new product. The team makes its own decisions and controls its own schedule. Because design, manufacturing, and other functions all work on the same team and report to the same "chief", functional specialists communicate frequently and work hard to avoid the delays that are so prevalent in a functional organization.

Xerox also changed how it manages its factory. It substantially slashed the number of suppliers providing parts, and involved the remaining suppliers much earlier in the development process. Xerox also recognized the need to move from quality inspection to quality control. [Hadden, 1986, p.15,16,28; Dertouzos *et al.*, 1989, p.274-5; Xerox, 1988].

Results of Actions. Xerox's efforts to improve its product development and manufacturing processes were very successful. Over the early 1980's, Xerox was able to cut product manufacturing costs by roughly 50% while reducing the number of product defects by 93%. It also was able to reduce manufacturing labor and factory space by 50% each, even while doubling production. By 1985, Xerox had cut its development time for new products by over 50% to pull about even with its Japanese competitors. These design and manufacturing improvements enabled Xerox to halt the decline in its market share, and even regain a substantial part of what they had lost. [Hadden, 1986, p.22,33; Haavind, 1992, p.39; Bebb, 1987]

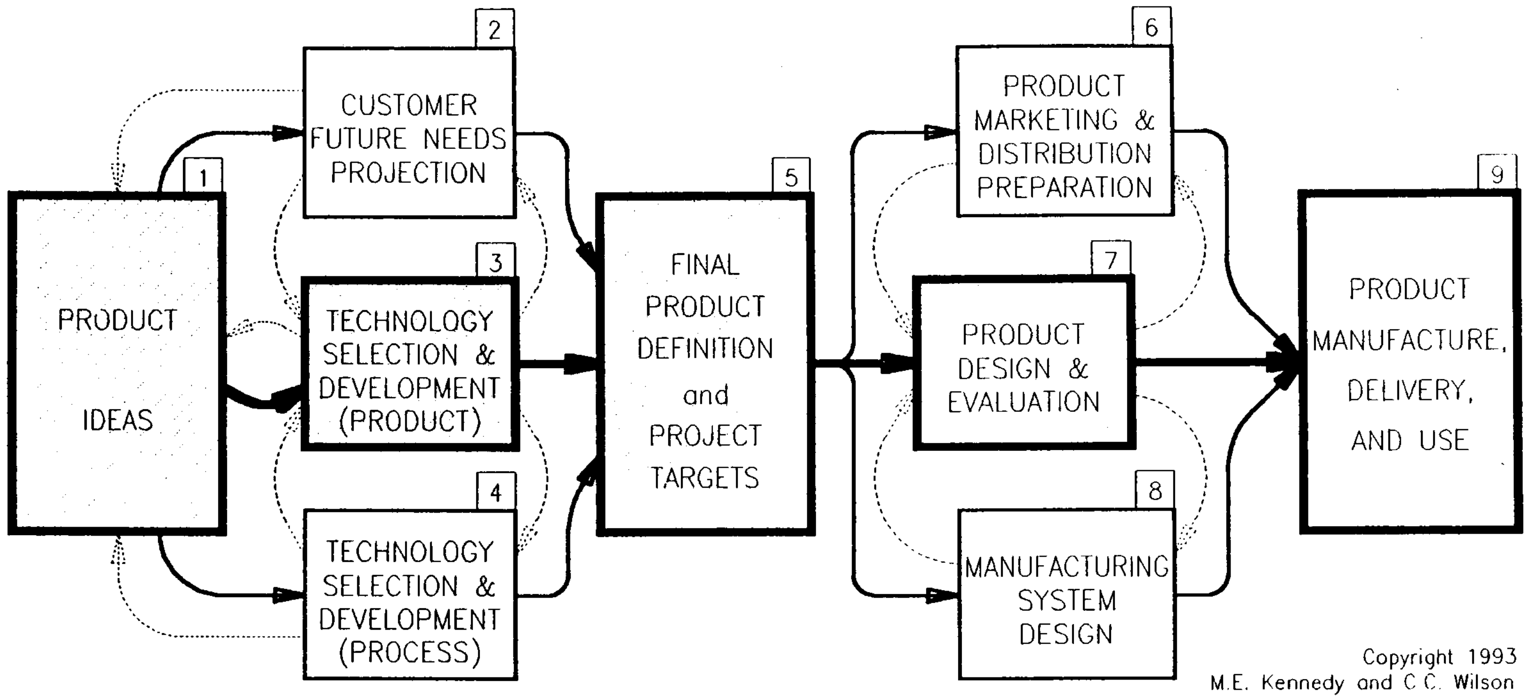
Continuing Effort. As Xerox successfully completed its first major improvement program, it began a new one [Bebb, 1987; Hadden, 1986, p.18]. Continuous efforts in improved Xerox business practices through 1990 yielded even more improvement, including a 92% improvement in product quality, a real reduction in manufacturing costs

(costs unadjusted for inflation), and reductions in development time up to 60% [Allaire, 1990; Kearns, 1990]. These results indicate the tremendous potential that improved processes (including improved product development processes) can have on a firm.

The Product Development Process

A Product Development Process for an innovative product has been constructed in Figure 4.1. This process is based on case studies of leading U.S. firms that are competing successfully against worldwide competitors, particularly those from Japan. It is comprehensive, originating with Product Ideas and concluding with Product Manufacture, Delivery, and Use. Each of the nine major phases in this process has a "milestone goal" that defines what is needed to complete that phase successfully, as indicated by the numbered "flags" and descriptions. Although they appear to be independent, all phases are highly interconnected and interactive in practice.

As has been suggested, the overall objective or "milestone goal" of the product development process is to create a product with a superior combination of value, robustness, and fast availability (ie. development speed). The following sections provide a brief journey through the phases of this product development process (Figure 4.1); detailed explanation of these phases can be found in Product Development Guide (disk in pocket).



DEVELOPMENT PHASE GOALS:

1 Potentially "high value" product concepts, consistent with future customer needs and the firm's goals/strategies.

2 Definition of target customers and their future needs, understanding of competitive offerings ("benchmarking").

3 Appropriate, timely selection and development (as necessary) of robust product technologies.

4 Appropriate, timely selection and development (as necessary) of robust process technologies.

5 "Frozen" final product definition (of "base" product plus derivatives); market, business, and resource targets.

6 Development of marketing/sales, customer support, and distribution systems that reflect customers' value needs.

7 Development of product design specification that addresses customer needs; "design-build-test" of product and its subsystems; verification of product's value and "fitness".

8 Selection and construction of cost-effective, capable processes for parts manufacture and product assembly.

9 Manufacture and assembly of quality product, consistent with customer demand; process control and improvement.

Figure 4.1: A Product Development Process for an innovative product, with milestone goals for each phase.

Product Ideas

A new product generally begins as a new product idea. Product ideas may be generated from many different sources. They may arise from external sources (e.g.,customers, advertising agencies, suppliers) or internal sources (e.g., marketing staff, R&D staff, sales force, corporate planning groups). Ideas may arise from unsolicited suggestions or through planned idea generation activities, such as analyzing customer requests and complaints or looking for uses of manufacturing by-products ("wastes"). Since the firm cannot afford to develop every idea (and because not every idea turns out to be a good one), the product concepts are then evaluated to select the best ones for additional development. Typical evaluation criteria would include assessing how valuable the product would be to customers, whether the firm has the ability/resources to develop the product, and how potentially profitable the product might be. Ideas often arise out of the development process itself - for example, new product ideas may arise as a new technology is developed (indicated by "feedback" arrows on the process diagram).

Regardless of the idea's source, the key objective in this phase is to define the idea sufficiently well so that it can be investigated/evaluated just enough to decide whether to invest in the idea further. If judged to have high enough potential and the firm has the appropriate resources available, then the product idea moves to the next phases.

Customer Future Needs Projection

If/when the Product Idea is deemed worthy, a full assessment of customer future needs is conducted to gain a fundamental understanding of what benefits should be provided in the product, so that the product can provide the maximum possible customer value. The overall objective of this activity is to identify future customer preferences concerning product tradeoffs and preferences, so that an optimal combination can be selected.

During this phase, "target" customers are identified and studied. The needs of these customers are projected into the future, since the product must be superior to the (future) products with which it must compete. (The product must still be developed, and thus will not be available to customers until some time in the future.) Key activities required to make such a projection include assessing market characteristics, "benchmarking" competitive offerings and the capabilities of the competitors themselves, and quantifying customers' definition of product quality.

Product Technology Selection and Development

While customer future needs are assessed, the critical technologies that will be needed to generate the new product's benefits are concurrently evaluated, selected, and developed (particularly if a "new" technology is selected). This Product Technology Selection and Development effort seeks to find/develop the *most appropriate* technical concepts (but not necessarily the newest ones) that deliver the necessary performance reliably and consistently. Selected technologies must meet or exceed customers' performance expectations, but also must be capable of functioning in less than optimal conditions - that is, they must be "robust". Finally, product technologies must be manufacturable with "high yields" so that the manufacturing system can build defect-free products.

The team discovers what critical parameters control the technology's performance, then find a combination of settings for these parameters that enable the technology to work robustly (this concept is described throughout PD Guide as an "operating space"). The investigation also reveals any major limitations to designing, using, or manufacturing the technology. Tests on a functioning prototype confirm that the technology can perform as anticipated. Conclusions from these efforts are summarized in the Technology Feasibility Statement, which provides the key technical and performance information needed to incorporate the technology into a new product.

The newest, latest technologies that could be used are *not* necessarily the "most-appropriate" for a given product. Often, existing more-established ones prove to be the best choice. There are several reasons why existing technologies may be preferred over newer ones: (1) because they already exist, current technologies can be utilized more quickly, providing a development speed benefit; (2) existing technologies will already have a "track record", so that their reliability and manufacturability can be better predicted; and (3) if a specific function is not critical to the product's customer value, it is generally not worthwhile to spend time and money on developing a new technology to accomplish that particular function.

The choice and development of key product technologies is a critical step. Good technology choices can provide a new product with a distinct advantage over other competitive offerings; poor choices lead to defective, poor-quality products. David Kearns, former Xerox CEO, described the use of unstable technology as one of the biggest problems that can arise in the development process [Kearns, 1990]. The probability of making good technology decisions is enhanced by evaluating *multiple* technology candidates versus customer performance requirements, technical barriers, cost, and the ability of the firm to develop and produce them. "Just enough" effort is expended on candidates so that the team can make good technology decisions. "Just enough" is a key: expending more effort than necessary wastes time and resources, while too little work leaves open the possibility of choosing the "wrong" ones.

Process Technology Selection and Development

Not only are the product technologies needed to achieve key product functions considered, but so are any process technologies that are considered critical to successful product manufacture. These Process Technology Selection and Development activities are undertaken to find and develop (if necessary) the critical manufacturing capabilities so that a *high-quality, cost-effective* product can be manufactured.

In many cases, selecting a new *product* technology often necessitates the co-development of new *process* technologies. The ability to use a new product technology often depends on whether new process technologies can be found to enable the economical manufacture of that product technology. Thus, new process technologies are developed concurrently and in conjunction with product technologies.

Process Technology Selection and Development activities parallel the Product Technology and Selection and Development activities described above, and result in a Technology Feasibility Statement for manufacturing process technology.

Final Product Definition and Project Targets

The amassed knowledge of customer needs and technologies, along with the firm's development capabilities and resources, are merged and integrated to form the Final Product Definition and Project Targets.

The Product Definition clarifies the product's primary benefits to the customer, establishes the product's major features and key performance levels, and defines the product "family". The product "family" refers to the concept that a number of related products, called "derivatives", can be created from an original "base" product. The Product Definition is described as "Final" because, once approved, it is unchanged, or "frozen", for the remainder of the development process.

Other key objectives are established in the Marketing Targets, Business Targets, Target Milestones, and Target Resources. The Marketing Targets describe the expected "market" for the product, such as how the product should be marketed to customers, how many are expected to be sold, etc. The Business Targets assess the impact of the new product on the firm in terms how much capital is needed to develop the product and potential profits. Target Milestones define the timetable for key steps needed to introduce the product at a specific target date. Target Resources define assets will be needed to develop the product successfully, such as team members, needed technical expertise, test facilities, etc.

Product Marketing and Distribution Preparation

As the product is being designed and production capabilities are being readied, key tasks involving product marketing and distribution preparation are also completed. The marketing "channels" that will be used to sell the product are decided and prepared for the new product, how the product will be promoted to customers is defined, and pricing strategies are considered.

"After-sale" services can be an important element of customer value; thus, features such as product warranties, customer service support (maintenance service, hotline advice, etc.) are also prepared during this phase.

Product Design and Evaluation

With a Final Product Definition and Project Targets, the team enters the Product Design and Evaluation phase. The team begins by creating a Product Design Specification (PDS), which comprehensively describes the product's major features, uses, and expected environmental conditions. The PDS includes not only all product features and performance items (including the critical items defined in the Final Product Definition), but also addresses many additional, more-subtle issues related to overall customer satisfaction with the product. Because it becomes the set of criteria from which the design is judged, the PDS is completed *before* commencing the detailed product design.

Once the PDS is completed, product design activities begin in earnest. The product's design is created from the "top-down", in that the overall "configuration" (or basic structure) of the product is decided first. The configuration is divided or partitioned into subsystems, or "modules", so that different portions of the product can be designed concurrently (to obtain development speed) and more independently (to make design efforts easier). Product requirements for function, life, etc. are *allocated* to each subsystem so that the product using that subsystem can meet its PDS requirements. Each module is then designed to meet the requirements that have been allocated to it; eventually, the specific parts for each module are selected and/or designed. All potential designs are judged based on their ability to meet all of the requirements as set forth in the PDS.

Several "build, test, and fix" cycles are performed to evaluate parts, subsystems, and the entire product versus their respective requirements. Design prototypes are constructed and tested under both routine and nonroutine conditions. "Tests to failure" are used extensively to find and eliminate problems with the product's design. "Stress tests" are used to evaluate how well the product operates under adverse conditions. Design problems found by this testing are corrected by improving the design, and new prototypes are built and tested. After several carefully-controlled iterations, the design phase is complete.

The resulting product design meets all customer requirements, even when the product is subjected to severe conditions. Critical functional and manufacturing parameters affecting the performance and/or robustness of the product are described clearly in formal product documentation, and are well-understood by all team members.

Manufacturing System Design

As the product is designed, preparations are made to manufacture the product for sale to customers. In the Manufacturing System Design phase, cost-effective, capable processes are selected and constructed to perform needed parts manufacturing and product assembly.

For best results, only processes that are well-understood and controllable are selected for the manufacturing system. Processes found to be critical to the product's ability to deliver its required performance or quality are identified and controlled tightly by the team. A manufacturing readiness review is held as the final step in the phase to confirm that critical manufacturing criteria are met.

Product Manufacture, Delivery, and Use

The primary mission for the Product Manufacture, Delivery and Use phase is to manufacture the "robust" product (that results from the Product Design and Evaluation phase) using cost-effective, capable processes (established in the Manufacturing System Design), and to sell/deliver that product in a way that maximizes the product's value (as determined in the Product Marketing and Distribution Preparation phase).

A Manufacturing "Pilot Run" is performed before full-scale production begins to assure that the manufacturing system is capable of producing high-quality product. Process controls (such as SPC) are utilized to verify the product's critical characteristics, so that only defect-free products are manufactured and delivered to customers. Processes are improved continuously by the manufacturing team. Product support services (such as warranty service, installation, etc.) are also performed.

Key Features within the Product Development Process

Three major viewpoints. The product development process shown in Figure 4.1 provides three imperative viewpoints that must be reflected throughout any product development process: customer, product, and manufacturing process. The customer, or "market", is the primary focus of the "top" one-third of the process (phases #1, 2, 5, 6, and 9 on the figure). The "middle" third of the development process figure (phases #1, 3, 5, 7, and 9) provides needed development focus on the "product" and its design. Manufacturing process considerations are reflected throughout the "lower" one-third of the process (phases #1, 4, 5, 8, and 9 on the figure).

All three viewpoints must be considered *concurrently* throughout the product development process. A vertical line drawn through Figure 4.1 at any given time during the process shows the relevant development phase(s) that address the customer, product, and manufacturing viewpoints at that time. As an example, Customer Future Needs Projection (reflecting the customer viewpoint) is performed at the same time as the Product Technology Selection and Development efforts (addressing the product viewpoint) and the Process Technology Selection and Development program (focusing on the manufacturing viewpoint).

The rationale for the repeated convergence of information during the product's design is stated well by Whitney *et al.* [1988, p.206]:

> "a seemingly minor decision, made to optimize a corner of the company's operations, can have a pervasive effect of how a product is made or how it performs in the field. These decisions can completely defeat the designer's intentions. Management, engineering, purchasing, personnel, and manufacturing can each contribute to making or defeating a product."

Convergence of viewpoints throughout the process. Not only must they be considered concurrently, but all three viewpoints must also be "converged", or integrated, at multiple times throughout the process. Figure 4.1 shows this repeated convergence with the size/shape of the Product Ideas phase (phase #1), Final Product Definition and Project Targets phase (phase #5), and the Product Manufacturing, Delivery, and Use phase (phase #9). In these phases in particular, viewpoints are merged to assure that the development result combines customer, product, and manufacturing considerations and tradeoffs in the best way possible.

"Product" leads the "design" process. While development indeed should be "concurrent" in general terms, product development projects want to avoid the pitfall of allowing other functions to "get ahead of" the product and its design. The need to keep the product "ahead" in the product development process is shown in Figure 4.1 by locating the Product Design phase slightly "ahead" (shown slightly to the left in time) of its two "concurrent" brothers. This offset indicates the continuous need to keep the

product's design "a little bit ahead" of the team's manufacturing and marketing preparation activities.

Essential Elements for Product Development

As introduced in Chapter 3, the term "essential elements" is used to reinforce the idea that there are some fundamental concepts, activities, or approaches ("elements") that are critical ("essential") to the development and manufacture of *superior* new products. The case studies demonstrate that successful product development projects utilize "essential elements" consistently throughout their efforts. While the Product Development Process provides a general framework for accomplishing new product development successfully, the essential elements define the key traits that the process (or a specific phase within that process) needs if it is to be successful.

Essential elements for each specific phase are presented in Product Development Guide, but four essential elements are so fundamental that they affect the entire development process: these are shown in Table 4.1 (as well as in PD Guide). A wide variety of design techniques, management methods, and technical skills can be successfully applied within the essential elements framework; this means that there is no "one, only, best" way to execute successful product development. But even though specific techniques for achieving them may vary significantly, successful product development efforts support the accomplishment of the essential elements.

To most people experienced in product development or manufacturing, the essential elements in Table 4.1 are neither "new" nor "revolutionary"; indeed, they are

Table 4.1: The "essential elements" for the development of an innovative product.

Essential Elements for the Entire Product Development Process
▸ CONTROL BY A SINGLE TEAM
* Team integrates broad skills needed to develop product * Team controls all aspects, from Technology Selection to Manufacturing
▸ CREATION OF A VISION FOR THE FUTURE PRODUCT
* Projection of customers' *future* needs * Team participates directly in future needs projection * Customers provide direct input to team members
▸ INFORMATION CONVERGENCE AT PRODUCT DEFINITION and PROJECT TARGETS PHASE
* Team considers all critical issues early and simultaneously * Team establishes common ("consensus") goals and plans
▸ INFORMATION CONTINUITY FOR CRITICAL PRODUCT CHARACTERISTICS

seemingly so obvious that they tend to be overlooked and thus, poorly executed. Mere awareness of the essential elements is not adequate - rather, success in the product development case studies was predicated on how well essential elements were *implemented* throughout the product development process and in the manufacturing facility.

Control By A Single Team

First among the essential elements for successful product development is to select and utilize a single marketing/engineering/manufacturing team to control the project from technology selection through the first several months of product manufacturing and sales.

The Xerox example presented earlier in this chapter illustrated the power of the single team. The key improvement to Xerox' product development process was to define "Product Delivery Teams" that report to a Chief Engineer [Hadden, 1986]. But Xerox is far from the only firm that has discovered the inherent superiority of teams: when IBM could not produce a personal computer within its "regular" development system, it commissioned an "Independent Business Unit" - a small, completely autonomous team - to develop the original "PC". Hewlett-Packard has used teams to develop its color "Paintjet" printers [Baker *et al.*, 1988]. Chrysler built a new multi-million dollar development center specifically to support its (new) integrated development teams.

These firms found that their functional organizations could not be competitive versus Japanese team-based systems. Xerox's Lyndon Hadden [1986] has described the functional organization as a "system created to prevent errors ... but (instead) almost prevented product delivery." Glenn Gardner, Chrysler's top development engineer, says that the traditional functional organization is inherently inferior because the functions inherently "drive decisions without regard for the customer" [White, 1992, p.A1].

The most effective teams are directed by a single leader, who is provided authority over *all* project aspects, including product definition, project schedule, and team resources. Because the team is responsible for the entire product, the team itself needs an appropriate skills mix to accomplish its mission, including the design, marketing, testing, manufacturing, and other skills. The team itself develops and executes its own plans (product definition, schedule, etc.) and monitors its own progress against those plans using team-based measures.

A full discussion of industrial organization is beyond the scope of this document; but, in general, use of half measures such as product "coordinators" are inadequate. Using a single team may be the single most positive step that a firm can take to improve their product development abilities; thus, it may be the most essential of the essential elements for superior product development.

The single team concept applies not only to the product development process, but extends to manufacturing as well. One division of Texas Instruments found that converting their factory from "functional shops" into "focused factories" led to an "amazing ... 2X, 3X improvement in every category we can measure." [Randall, 1989] Indeed, a key feature of the "lean manufacturing" approach is have functionally-integrated teams manage workcells that make entire parts/assemblies.

Vision of the Future Product

The second essential element affecting the entire development process is the creation of a product "vision" describing how the product will meet customers' future needs. This guiding vision creates an enthusiasm and dedication that contributes immeasurably to achieving product objectives by sustaining the team's momentum throughout the project. This product vision is created largely during the Customer Future Needs Projection phase, and provides the team with its "window to the future" throughout the project. The window is opened by projecting the customers' future needs, having the team participate directly in the needs determination process, and assuring that customer inputs are provided directly to the development team.

The key word in the vision statement is "future". Figure 4.2 illustrates how customer needs might be projected in a situation where competitive products currently have superior capability (as determined from product benchmarking activities) and the firm needs to develop an improved product to catch up. If only "today's" competitive information is considered, one might be led to believe that only relatively small product improvements are required to regain competitive position in this market.

The shortcoming to this approach (indeed the problem of only using "benchmarking" or being "market driven") is that the new product is not available today; it must be developed. Once development time, market life, and future improvements in competitors' products are considered, the product enhancement really needed may be much larger than what "today's" information would indicate, as shown in Figure 4.3.

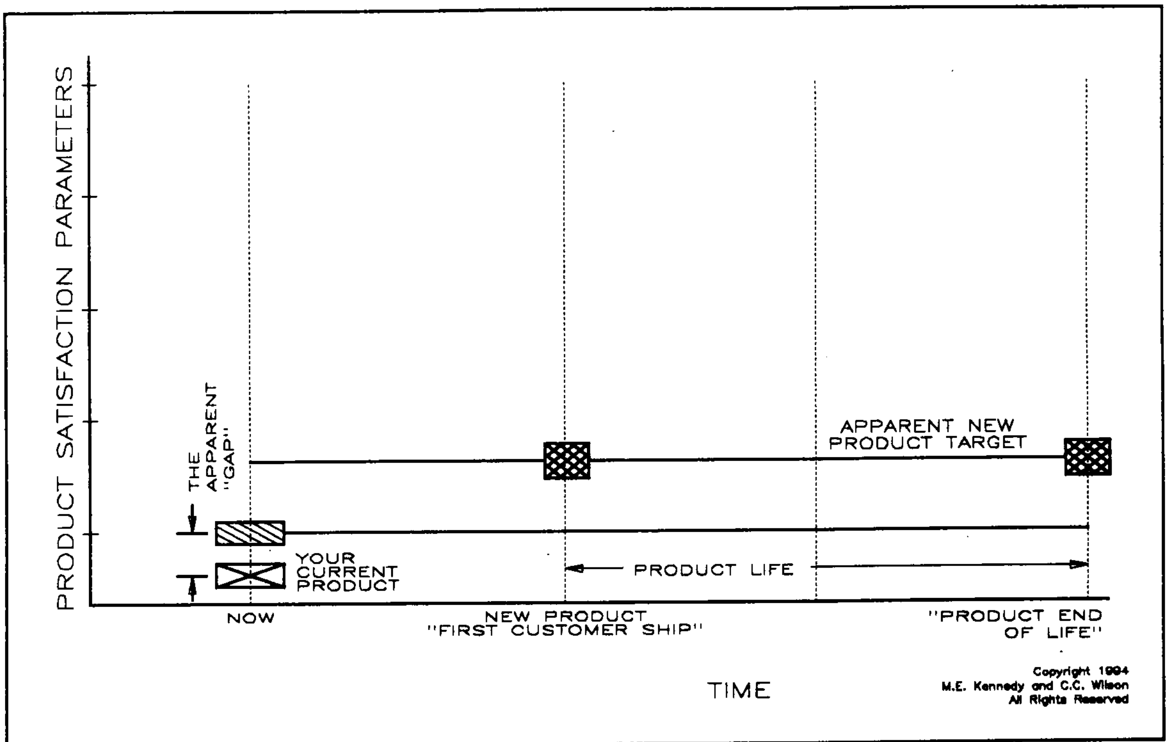


Figure 4.2: Product development goals based on "today's" competition and customer needs.

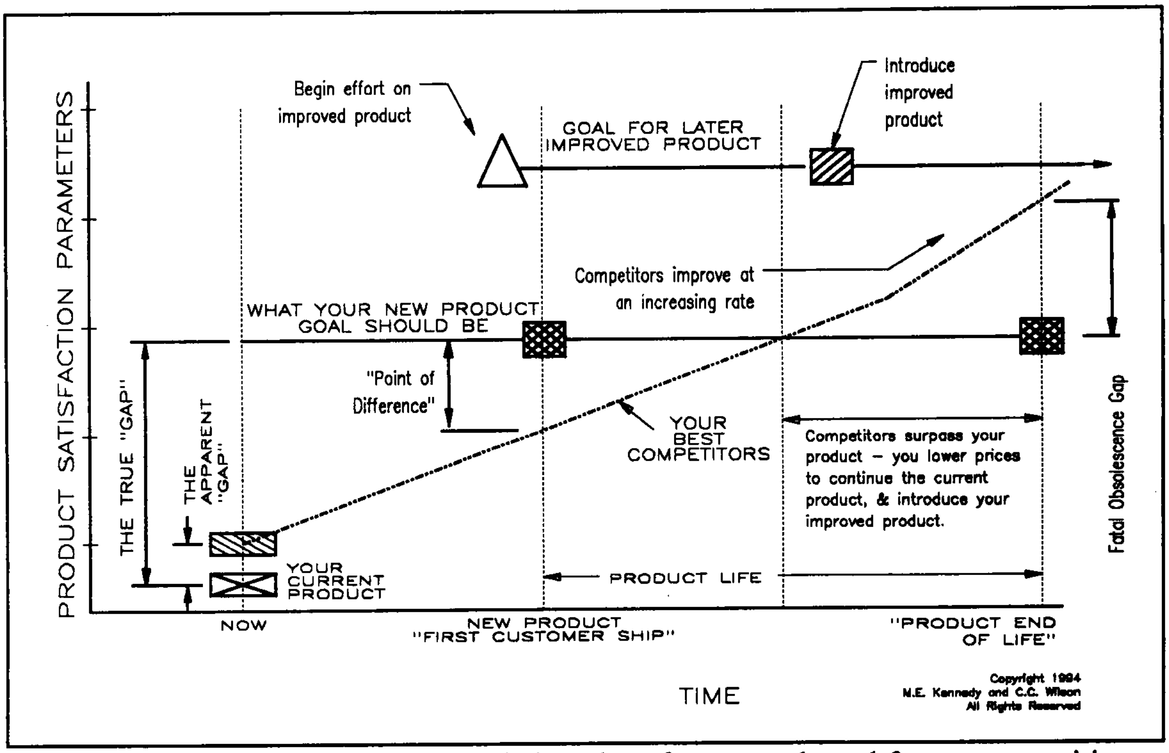


Figure 4.3: Product development goals based on future needs and future competition.

Consequently, development teams must think beyond today's needs, and forecast *future* customer needs to assure that the new product will have adequate value.

A new product's "value" must always be higher than the one it replaces, but this does not necessarily call for an "across-the-board" increase in every product performance parameter. Indeed, this "laundry list" approach to new products is impractical. Thus, one objective in defining the product vision is to identify those factors (and improvement levels) that will most greatly improve the product's overall customer value. The vertical axis shown in Figure 4.2 and Figure 4.3 is named "product satisfaction" to indicate that the product's overall value must increase, not necessarily each specific parameter.

A narrow focus on only existing products may unnecessarily limit the team's vision to defining improved versions of those products. Most "innovative" new products do not yet exist as the needs analysis is performed, so that direct comparisons to existing products cannot always be made. Additionally, customers tend to express their needs in terms of their experience with existing products - typically they cannot express their needs in terms of a radically new product. Thus, expressed customer needs must be properly interpreted to find their real needs, so that new, innovative products can be defined from those real needs.

Direct team participation in the focus groups, customer interviews, and other activities used to determine customer needs help team members to "see" opportunities that they will not see by merely reading a report from a distant analysis group. Then, the team maintains its contacts with customers throughout the development process. Some firms establish customer advisory boards to provide direct customer involvement during the product design effort [Abbott, 1988; Xerox, 1989]. These boards are generally composed of technically astute customers, who evaluate new product designs throughout the development process. Direct, ongoing interaction between team members and customers is an essential element in successful development of innovative products, particularly for those firms that historically have not been very successful at developing new products to meet customer needs [AQF, 1992].

Convergence of Information from Marketing, Engineering, and Manufacturing

The importance of the three major viewpoints (customer, product, and manufacture) was introduced with the product development process. Indeed, the "convergence", or integration, of these viewpoints is an essential element of the product development process. While consultation is ongoing throughout the development process, explicit and formal "convergence" of marketing, engineering, and manufacturing occurs twice in the process (Figure 4.1): at the Final Product Definition and Project Targets phase, and at the Product Manufacturing, Delivery, and Use phase.

A key "concurrent integration" point occurs at the Final Product Definition and Project Targets. Here, the three viewpoints must be combined to create a meaningful (and somewhat "circular") whole. The product's market needs and opportunities must be reflected accurately in the product definition; product design needs must be supported by appropriate manufacturing process technologies; and selection of appropriate manufacturing processes is, in part, dependent on the quantity of product that the market is projected to demand. Final convergence of marketing, engineering, and manufacturing information at the start of the Product Manufacture phase confirms that plans were executed as intended, that projections are still valid, and that all systems are ready for product launch. Specific confirmation is needed that the product-as-designed meets the criteria for the product-as-specified, and that the product-as-manufactured matches the product-as-designed.

Continuity of Information about Critical Product Characteristics

Measuring Critical Characteristics. A recurring problem throughout the development process is to assess how well the product delivers the desired customer benefits. Thus, the development team needs to ask two critical questions: "How can (at least some of) product benefits be measured, to know that the product meets or exceeds customer expectations? What values or limits on these measures are needed so that the product meets or exceeds these expectations?"

Since product characteristics vary widely, measurement criteria and techniques will also differ. However, superior product characteristic measures clearly distinguish themselves from other, less effective measures. The "essential elements" of these measures are summarized in Table 4.2.

The most useful measures for assessing critical product characteristics are developed at the start of the product development process and used throughout the process for product quality "scorekeeping." Measurements that accurately reflect customers' value/quality impressions are particularly useful for assessing the performance of potential product technologies. In a laser printer development project, measurements for the

Table 4.2: Essential Elements for Effective Measurement of Product Characteristics

Essential Elements for the Characteristics of Superior Product Measures
▸ Measures are Customer-Oriented:
* Measures are characteristics that are important to customers * Quantified limits are derived from customer participation
▸ Measures are Developed at Start of Process through a Planned Activity
▸ Measures are Simple and Easy-to-Use
▸ Measures have Multiple Uses throughout Development Process
* Used for product quality "scorekeeping" * Used to measure/assess development progress

subjective characteristic of "print quality" were developed. Customer survey results established print quality requirements for the product. The development team used the print quality measures to assess how well they were doing throughout the entire product development process: to verify technology feasibility, to define product design targets and specifications, and to set production quality requirements.

The best product measures are customer-oriented in at least two ways: the measures quantify characteristics that are important to customers, and acceptable values are based on direct customer input. Even subjective characteristics are measured, as necessary (and possible), if important to the customer. The most effective measures are simple, effective, and easy to use.

The selection, development, and successful use of suitable measurements for critical product characteristics is difficult, and, as such, must be a planned, deliberate activity within the product development process.

Tracking and Converting Critical Characteristics. The organizational structure of many firms makes it difficult to assure that critical product information is transferred to, and understood by, the manufacturing organization. The single team product organization is superior in this respect, since the team is responsible for manufacturing system design and pilot manufacturing. Thus, the team itself carries the critical information into the manufacturing phase. Nonetheless, product responsibility does indeed change over time, as the product is finally transferred to the manufacturing arm of the firm, or simply as team members join or leave the team itself.

In one case study, the development team defined a specific approach for transferring critical product characteristic information to the manufacturing process. This transfer formally connected the product's development to the manufacturing process, and thus serves as an outstanding example of how teams can assure product quality (value and robustness) by ensuring the continuity of critical product information throughout the development process. This example is described below and is illustrated in Figure 4.4.

Keyboard "touch" is an important product feature for a typewriter or computer keyboard, and is often the deciding factor as to which one a customer purchases. Since the force-deflection curve for the keys is the primary determinant of the keyboard's "touch," the features of this curve are critical product characteristics for the keyboard design. Steps 1 through 3 of Figure 4.4 illustrate how the characteristic is identified, quantified, and targeted. First, customers are questioned, measured, tested, etc. to determine what characteristics are important (in this case, the "touch"). In step 2, measurements of these critical characteristics are developed (in this case, a force-displacement curve), and customers are again assessed to learn which target values for these measurements they prefer (in this case, the shape and values on the curve). The characteristic and target values are documented in the product engineering specification as a "Critical-To-Function" parameter (CTF) that must be controlled (Step 4 of Figure 4.4). Dimensions and features that affect the critical-to-function parameters subsequently are identified in step 5 as Process Control Dimensions (PCDs) to be used for manufacturing process control. The PCD's are put under process control in manufacturing (Step 6) to assure that the process is stable and produces a product that

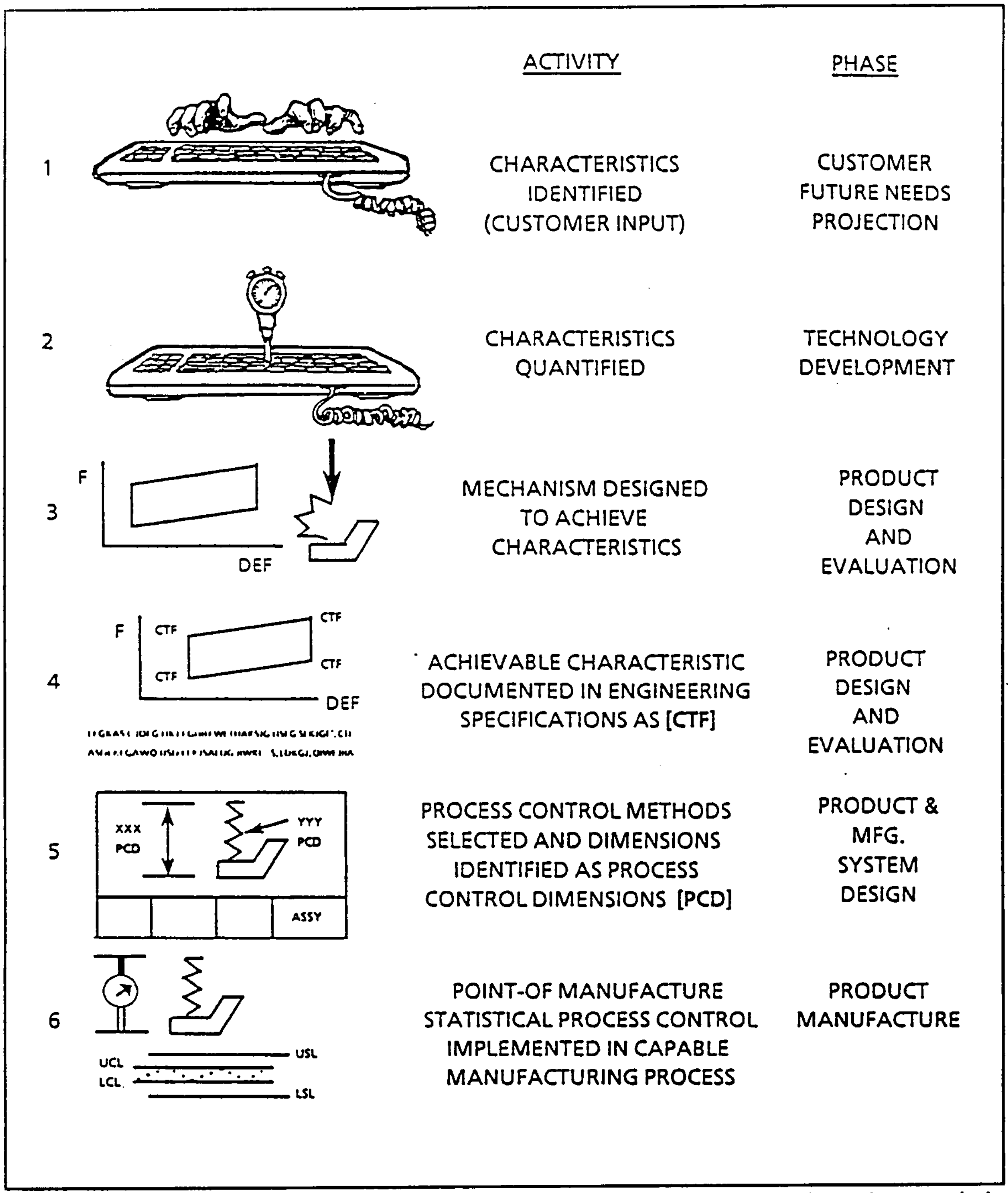


Figure 4.4: Illustration of a formal method for transferring critical product characteristic information into the manufacturing process.

Source: Originally published in "Some Essential Elements for Superior Product Manufacturing", *Proceedings of Manufacturing International '90 (Vol. V)*, by Clement C. Wilson and Michael E. Kennedy, Atlanta, GA, March 1990.

meets all specification requirements (and, thus, customer "touch" needs). Additionally, to eliminate any urge within manufacturing to compromise these critical engineering specifications, any off-specification permit for any CTF dimension requires the written, signed approval of the third-level manufacturing manager.

Converting critical customer characteristics into critical-to-function (CTF) parameters and then into manufacturing process control dimensions (PCDs) for controlling processes is a powerful technique. It provides a simple method for formally documenting critical information so that critical product characteristics are controlled properly throughout the entire product development effort and in manufacturing processes.

Product Development in Practice

Several key challenges pervade the Product Development Process and its successful use within the firm.

"Balance" in Product Development

A key issue is one of "balance". Typical approaches to product development that are observed in firms that are not effective in developing new products include:

- "no" process, which results in missing product features, erratic product performance and organizational uncertainty;
- a "rigid" process, which uses complex, inflexible procedures that delay projects and costly, time-consuming enforcement mechanisms that force workers to oppose each other rather than work together;

- a "function-dominated" process, where marketing, R&D, manufacturing, or other function is stronger than the other functions and dominates decision-making.

To avoid the problems of "no" process, a process is needed, but the organization must be careful to not let its "process" become so rigid that it becomes a "procedure". Thus, a "balance" in the extent a process is procribed and used must be struck.

Additionally, all factors related to a new product's success need to play roles in that product's development, but must avoid dominating the development process to the detriment of the other factors. This "functional balance" is needed to derive the "best" combination of decisions to meet the wide ranging needs to be met. The product development process proposed in this chapter achieves this balance through its customer orientation and its cross-functional integration. Customer orientation is maintained through use of two essential elements: a vision of a product that will meet customers' future needs, and customer-oriented measures of product quality that are tracked throughout product development. Cross-functional integration is achieved through two other essential elements: control of the project by a single team, and explicit convergence of marketing, engineering, and manufacturing information in the process.

Focus on People and Processes

Just as managers will not solve their manufacturing problems solely by buying automated equipment, a managerial decree to use a new process will not solve their product development problems. As in manufacturing, management attention must be paid to the people who will be expected to use those processes if they are to be successful.

It is the focus on processes and the people that perform those processes that generally distinguishes successful from unsuccessful firms. A successful manufacturing improvement program at AT&T-Oklahoma City attributed their success to teamwork and quality management, above all other factors. [Seifert, 1988, p.29] Dr. Barry Bebb [1987] of Xerox attributes much of Xerox' resurgence to "people motivation, people-oriented processes, management principles, and communication." Japanese auto firms have demonstrated that their success stems from their management processes (particularly their product management processes) and not just their Japanese "culture": many of these firms now both develop and manufacture new products in the U.S.! That Japanese firms conform to U.S. domestic constraints (labor force, laws, etc.), yet still succeed, demonstrates that a major difference is *how* these firms work, not simply *where* they work.

Continuous, Sustained Effort

U.S. firms have not just suddenly lost their competitiveness; the decline has been gradual and sustained, even if a particular firm's realization of its decline is remarkable and sudden. The GE facility making the uncompetitive compressors was known as "a loud, dirty operation built with 1950's technology" that scrapped 30% of its output [Magaziner and Patinkin, 1989]. In many firms, products and the manufacturing facility used to make them have been neglected for many years; decades of neglect cannot be made up easily over a short time. Firms that expect simple, quick, huge leaps to regain competitive position may be in for expensive disappointments.

Still unbeknownst to many U.S. industries, Japanese firms have undertaken programs to improve their product development and manufacturing capabilities for several decades. The successful U.S. firms that we have studied have all committed themselves to a long-term, continuous investments to improve how they develop new products and processes. Indeed, the recent resurgence of the U.S. auto firms Ford and Chrysler are a direct result of their 5+ year efforts to improve the way that they develop and manufacture their new car models.

Use of Process Model

The process introduced in this chapter and detailed throughout PD Guide attempts to provide a balanced methodology for developing new products. Functions are balanced by making the product the centerpiece of all activities; functions must act in the interest of the product. The process provides the structure necessary to direct the team toward a successful effort, avoiding problems that result from having "no" process. Specific methods and procedures are left to the team, so long as they meet the objective of the milestone goals and the essential elements.

The structure of the product development process and the essential element of "control by a single development/manufacturing team" link the developing product to both customer needs and manufacturing process requirements. Use of the single team enables the continuous cross-functional integration throughout the product development that is needed so that the product reflects the overall, balanced needs of customers rather than just those of functional specialties within the firm.

This chapter provides only a brief introduction to a very complex process. The "top-level" essential elements for successful use of the Product Development Process discussed in this chapter are "necessary, but not sufficient" to achieve superior product development.

CHAPTER 5

THE PRODUCT DEVELOPMENT GUIDE

Chapter Summary

A computer-based learning tool, named "Product Development Guide" ("PD Guide"), has been developed based on the product development research and process described in earlier chapters. The primary objective for PD Guide is to help senior and graduate engineering students learn competitive product development practices and processes. PD Guide provides the student with a comprehensive view of the product development process. It serves as a mentor by providing structure, asking critical questions, and recommending useful tasks/tools at appropriate points during the product development process. Although PD Guide may assist, ***the student engineer is always responsible*** for assuring that their efforts meet customer requirements. Since PD Guide is to be used in various (and unknown) design projects, it has been made to be "generic", to address a broad scope of problems.

Before discussing PD Guide itself, some improvements in design education are described to derive the potential role(s) that PD Guide can/should play in the educational process. The structure, display format, and information access method used to create PD Guide is then discussed. Several types of information are presented in PD Guide: a description and example of these types is presented.

The contents of this chapter are partially extracted from the papers, "Enhancing Product Development Teaching With A Computer-Aided Product Development Guide" in the *ASME International Computers in Engineering Conference Proceedings* [Wilson and Kennedy, 1992], and "A Product Development Guide for Students," from the *Advances in Capstone Education* conference proceedings [Wilson and Kennedy, 1994].

Improvement Efforts in Education

If PD Guide is to be an effective communications vehicle for industrial practices to enter academic curricula, it should be adaptable to that academic environment. Thus, it is useful to consider some improvements that are taking place in design education, in order to understand what role(s) PD Guide can play in the design education process.

Sampling of University Efforts

Some U.S. universities are increasing their emphasis of product development in their engineering and business curricula. A new course at Stanford University was featured in a 1994 *New York Times* article [Holusha, 1994]. This graduate course, named "Design for Manufacturing and Marketability", combines engineering and MBA students, "to develop in MBA's an appreciation for the process of design and manufacture and to develop in engineers an appreciation of the constraints placed on design and manufacture by a competitive context." [Prof. William Lovejoy, by Holusha, 1994]

At Purdue, Allen's "phase-zero" course has students work in four-person teams to complete structured product definition activities for a small product, such as a kitchen appliance. Tasks include detailing background information on the project, creating a product line recommendation, and developing a business plan. The emphasis in the course is the process of developing this information, and not as much on the accuracy of the information itself. [Allen, 1993, p.100]

As one of the early colleges to change its design course, Santa Clara University was cited in a *Managing Automation* article in 1988 for integrating manufacturing with the traditional capstone design course. In that course, students are provided a problem from which they are expected to develop a product specification, then "design, build, and test the solution" [Metz, 1988]. Interest in improving the senior "capstone design" course has grown enough that a conference was organized in August 1994 to discuss that specific topic. The focus of "Advances in Capstone Education Conference", held at Brigham Young University, was to discuss ways in which the design curriculum can be improved. Additionally, The American Society of Mechanical Engineers was recently awarded a $40,000 grant from the National Science Foundation to evaluate improvements in engineering design [Wesner, 1994]. The study is being conducted in two "tracks": (1) to evaluate how design is taught now; and (2) to determine what industrial "best practices" should be introduced into the curriculum.

Example: The UT Superior Engineering Design Program

In response to the need to improve U.S. product development competitiveness and education, the Superior Engineering Design Program (SEDP) was established in the University of Tennessee's College of Engineering in 1987. The objective of SEDP is to improve the teaching and practice of product development so that its graduates "can lead and participate significantly in design efforts to build world class products" [Speckhart and Wilson, 1991, 1993].

Senior Design Courses. At UTK, this two-semester "capstone design" sequence consists of ME 455, "Introduction to Design" and ME 469, the capstone design project. The course pair is taught as a "guided problem-based learning experience" [Speckhart and Wilson, 1991]. The key feature of this sequence is that students working in small teams develop a small commercial product, subsystem of a larger product, or industrial process equipment. Students generally not only perform product design, but also assemble and evaluate prototype hardware.

Before beginning the project, students are introduced in ME 455 to a wide spectrum of relevant design/development issues, such as an introduction to the product development process, product liability, patents, and engineering economy. Late in the term, project problems are presented, and each student individually develops and presents a conceptual solution to one of the problems at the end of the term (as a final exam).

At the start of spring semester (in ME 469), students are grouped into 2-3 person teams and charged with designing, building, and testing a prototype hardware solution to their problem. Teams use concepts generated during the previous term to begin their concept selection process, then complete a detailed design of their selected option. The team constructs and evaluates a prototype to complete the effort. Teams present their solutions to industry sponsors at midterm and at the end of the semester.

Product and Process Development Course. The product and process development course, entitled "Development of Superior Products and Processes" (ME 553), is a joint graduate-undergraduate offering that presents case study examples of outstanding product development [Wilson, 1988].

In the ME 553 course, students first receive an overall introduction to the development process for an innovative product (like that shown in Chapter 4). Next, product development practitioners from industry present lessons from their own firm's efforts in developing products. These presentations are wide ranging, and usually cover parts of the entire product development process. Towards the end of the course, students conduct their own case studies of product development projects. (Both the presentations and the student case studies from this course have been used in developing the product-development process and the Product Development Guide.)

Graduate Projects and Research. The MIT study agreed with the SEDP's premise that "university engineering schools have contributed little to the engineering of industrial-production processes" [Dertouzos *et al.*, 1989, p.78]. Thus, within the SEDP is a significant research effort to examine the best engineering design, evaluation, and manufacturing methods that are being used by competitive U.S. firms. In this area, the SEDP started ahead of the recommendations made by Dixon [1992] and the National Research Council study [1991] for improving graduate engineering education: to pursue study and use of "design methodology stressing industrial best practices and the intellectual fundamentals underlying these practices".

M.S. theses in the SEDP are not the usual efforts in a narrow scientific discipline but instead are generally comprehensive product or process development projects. M.S. program students often create and evaluate "production-ready" designs. Other thesis topics include the development of methods and tools to enhance the learning of modern engineering practice [Walker, 1991].

This dissertation and Product Development Guide are part of the result from these efforts- other Ph.D. level results include Lenoir [1994] and Harrison [1994].

Need for PD Guide

The educational issues discussed in the previous section and in Chapters 2 and 3 attest to the need for, and greater interest in, improving design education. PD Guide, if it is to be a successful communicator, needs to support educational objectives in design, such as the ones noted above. For illustrating the general needs for PD Guide in engineering design education, it is useful to discuss them in the context of the SEDP courses described in the previous section.

Senior Design Teaching Needs

The key issue in the capstone design course is that seniors are generally inexperienced in product design and development. Thus, they are likely to require frequent counsel throughout the course of their project. Particularly when the project is a "design, build, and test" effort, student teams need to be kept "on track" to assure that they can complete their project within the semester.

Since students experience only a portion of the product development process during their capstone design experience, they need perspective as to where their tasks fit in within the overall development process. Some *"industrial best practices"* can be introduced in conjunction with project activities; but, once the capstone project is assigned, subjects need to be generally related to the students' projects, since students need most of their time to complete their design, build, and test effort.

Most ABET-accredited engineering programs utilize a "capstone design" course sequence for their students. Some variations in the above-described program can be observed, both in different sections of the UTK mechanical design sequence and across universities. Some larger, more comprehensive projects are started sooner in the fall term, and continue through most of the academic year. Larger, expensive projects may be designed, but not constructed (because of the large cost involved or of limited time).

Graduate Needs

Students in the graduate course are introduced to the product development process at the start of the course. As case studies are presented by practitioners, students assess the role of these lessons in the development process. Topics are wide-ranging. In their case studies, students are expected to compare the activities of their case to the development process described in the class.

In contrast to the capstone design sequence, a course like ME 553 is relatively rare throughout both undergraduate and graduate education. While using different approaches, the undergraduate "product definition" course taught by Dr. Wes Allen at Purdue [Allen, 1993] and the joint engineering-business course at Stanford [Holuska, 1994] are generally intended to meet the same general educational objectives, that of broadening the role of engineering design to include business, market, and other issues that are also integral to the successful development of new products.

Need for a Design Resource

Some engineering educators have complained that they have "found it difficult to find a single textbook that covered the structured design process .... ." [Todd *et al.*, 1992, p.1771] Purdue's Allen [1993, p.99] has said that a difficulty in teaching the non-analytical aspects of engineering is that "the backbone of the college course - an appropriate textbook - does not exist." Clearly, if constructed appropriately, PD Guide can fill an existing need in the design curricula.

Need to Overcome Obstacles

Dr. Allen [1993, p.99] suggests that faculty generally lack interest in teaching courses that cover the broader aspects of the design process, due in part to their lack of industrial experience and to a lack of research funding for these topics. Dixon says that what few industry best practices do get incorporated into the curriculum that they arrive belatedly. Part of the reason, he suggests, is that the creation of new design courses is more time-consuming and more difficult than defining courses in traditional engineering science [Dixon, 1992]. Thus, another important role for PD Guide is to collect and process this industrial experience, then to facilitate its transfer so that its use in courses is not as difficult.

Objectives for PD Guide

The fundamental objective for PD Guide is to help students understand how competitive products can be developed successfully. Based on the general structure of the courses, and accounting for other desirable objectives related to introducing product development into the curriculum, some overall objectives for PD Guide were derived:

- *Be Applicable to a Range of Problems*: Since the specific project assignments in the capstone project are different each year (and are current problems), PD Guide must be "generic" enough to assist with a reasonably broad scope of products and potential design tasks.

- *Do not make decisions, but rather be a "consultant"*: It was considered important for learning that the student teams remain responsible for all decisions regarding their project/product. Thus, PD Guide should *not* be an "artificial intelligence" system that attempts to replace student thinking and decision-making.

- *Stimulate student thought*: As a consultant, PD Guide should recommend structured approaches, ask questions, present crucial development issues (at the "right" time during the process), and prompt students to assure the "completeness" of their efforts.

- *Be broad in scope*: To meet the needs of the product development graduate course, PD Guide should cover the entire product development spectrum, from product ideas through manufacture. (This objective also matches the earlier stated needs for engineers with interdisciplinary skills, broad view of design, etc.).

- *Provide specific assistance where appropriate*: While not making decisions, it was desirable to help students make their decisions. This could be achieved either by making specific recommendations, or by providing tools (including PDG Tools, discussed in Chapter 6) to help students perform the necessary evaluation.

- *Be easily used and operated*: The primary use requirement is that the student must be able to access and use PD Guide with minimum instruction. Operation on a simple system was also considered important so that PD Guide's use could be extended to other institutions, if desired.

Information Flows

Figure 5.1 shows the primary information flows during the development of PD Guide. As described in Chapter 3, the prime source of information for this project is the industrial "best-practices" that have been extracted from the SEDP's industry partners and case studies of their projects. Knowledge of these practices is utilized in creating the product development process model, its sub-processes (such as process flows for a phase or specific task), and tools. Additionally, industry partners often present this information directly to students in the product and process development course. The product development model and associated information, in turn, is incorporated into PD Guide. As will be described later in the chapter, PD Guide is then used in the product and process development course (ME 553) and in the senior capstone design course (ME 469).

The information flow during PD Guide development has not been one-way, however; there have been extensive "feedback" loops to and from PD Guide, as shown in Figure 5.2. Student users have provided significant comments on PD Guide's ease-of-use and value (described in Chapter 7). Additionally, PD Guide was submitted to a group

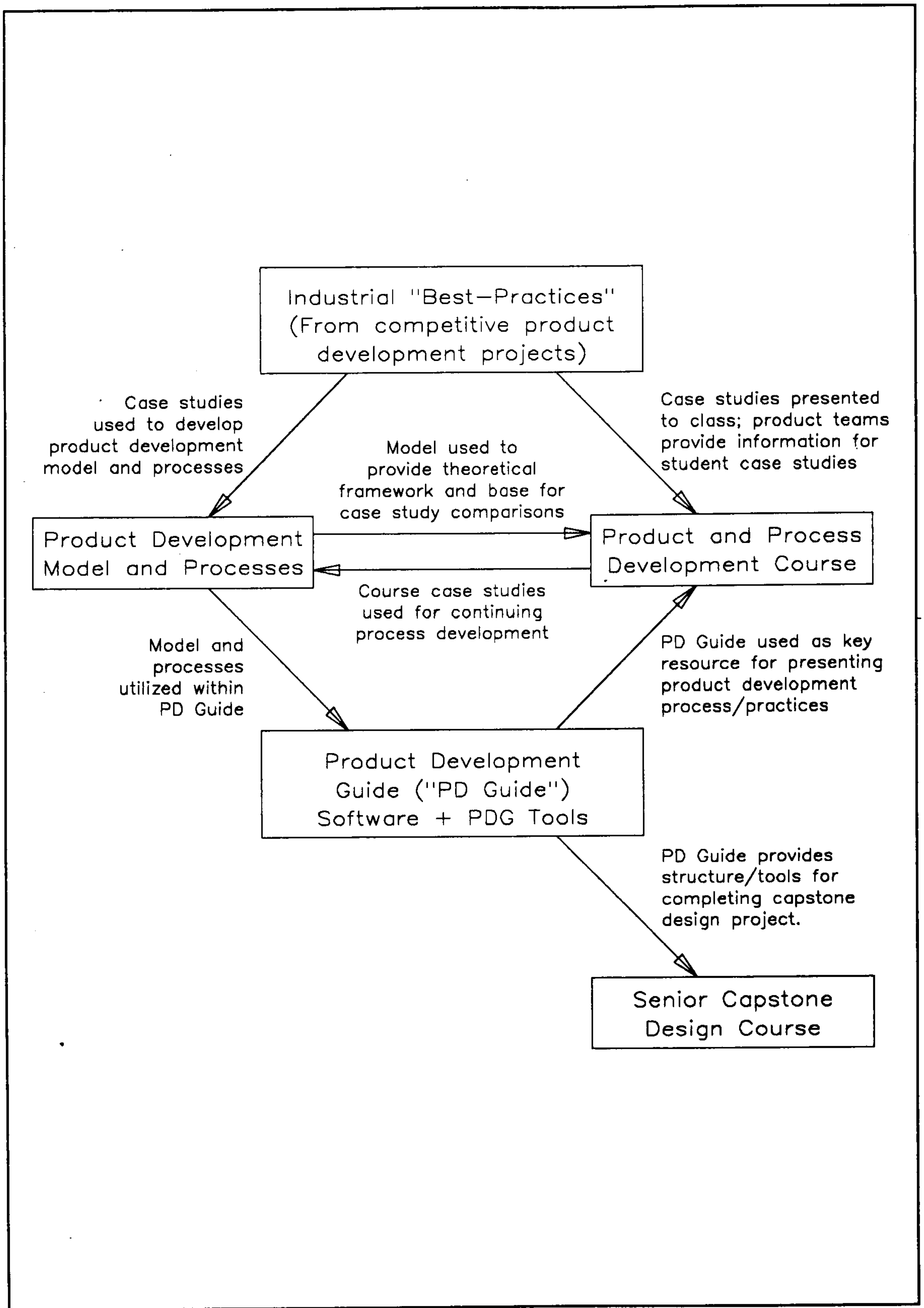


Figure 5.1: Primary information flows during the creation of Product Development Guide.

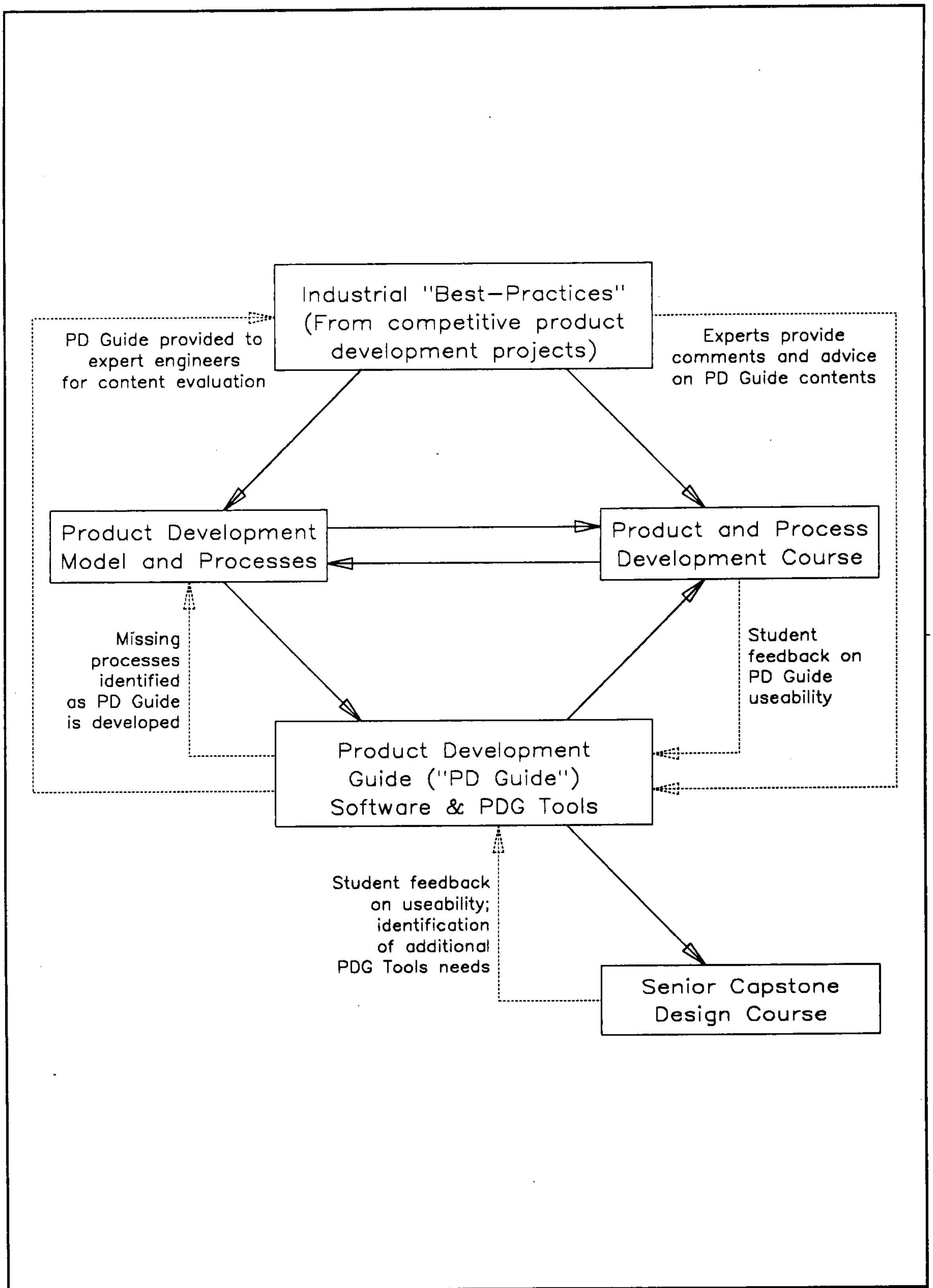


Figure 5.2: "Feedback" information flows during the creation of Product Development Guide.

of expert industry practitioners, who reviewed the contents for adequacy and made improvement suggestions (detailed in Chapter 8).

Although their respective developments are discussed separately (here and in Chapter 3), in actuality the development of the product development process and PD Guide were largely concurrent. While the results of formulating the product development model and processes are used in PD Guide, the development of PD Guide had the beneficial effect of pointing out clearly what sections were still missing or inadequate.

Description of Product Development Guide

Basic Characteristics

As currently developed, PD Guide is primarily targeted to support the activities of seniors in a capstone design course. However, it has been made expansive enough to be applied also to a graduate-level product development course. PD Guide's information is "generic", to support the development of a wide range of products (and senior design projects). The broad perspective in PD Guide covers the wide spectrum of considerations that need to be addressed during product development.

PD Guide's easy-to-use menu structure (described below) lets new users begin learning with minimal or no instruction. It runs on IBM-compatible personal computers, so that it can be used by many students and universities. Other than preferring a color monitor (which is now standard on most computers), expensive computers and support equipment (high-speed processing, sound board, etc.) are not needed.

PD Guide provides the student with a broad view of the product development process, from product ideas through to manufacture and customer use. PD Guide serves as a mentor to students by providing structure, asking critical questions, and recommending useful tasks/tools at appropriate points during the product development process. Use of PD Guide brings industrial product development knowledge and practices into the engineering curriculum. It is an assistant; *the student engineer is always responsible* for assuring that their efforts meet requirements.

Contents Source

The key to success for PD Guide, of course, is for the information and development structure presented to the student to be reliable and "correct". PD Guide's contents are derived from the case study assessments and product development process creation effort that is described in Chapter 3. PD Guide thus incorporates product development strategies and techniques that are practiced by some of industry's most competitive product development teams. (PD Guide was also reviewed by 14 product development experts to verify its contents - Chapter 8).

Standard Display Format

Figure 5.3 shows a sample information display from PD Guide (this particular display is adapted from one shown in PD Guide's tutorial). The "box" containing the major title and sub-title, along with the specific topic line, provide quick-reference information as to the contents of that display. PD Guide (and its modules) contain many

```
                    SAMPLE MAJOR TITLE LINE
                    Sample Sub-Title Line

                  Sample Content Title Line

> INFORMATION ZONE:   What types?

     + Process Maps or Diagrams

     + "Critical Questions"                  (SAMPLE CONTENTS)

     + Menu Option Descriptions
       (for 0-9, "S", and "E" keys)

     + Advice or Recommendations

     + Examples or Data

     + "How To" Information

Press (key to access more-detailed data) or press ... ("F" keys to "go back")
```

Figure 5.3: Display from Product Development Guide Tutorial, showing sample screen and listing the types of information in PD Guide.

different information types; these information types are listed in the "information zone" of the display.

PD Guide is controlled by pressing specific keys on the keyboard, depending on which operation is desired. Typically used keys include the "F" or "function" keys, numbers, letters, and the Page Up/Down keys. When more data on a topic in the information zone is available, it is "marked" with a number or letter key; pressing the key shown accesses the data. What options are available at any given point are explained on the "user option" line, located across the bottom of the display. The PD Guide Tutorial contains complete information on how specific key commands are defined and used.

Structure and Information Access

Figure 5.4 shows the "home" menu for PD Guide, which matches the product development process for an innovative product described in Chapter 4. This menu provides the "global" road map to access more-specific information, since additional material about each specific phase can be obtained by pressing the number key associated with the particular box on the display. The actual PD Guide display shows the product development process in three color "bands", one each for the customer-focused, product-focused, and manufacturing-focused phases.

The "home" menu provides a broad, overall framework for teams (particularly the senior design course student teams) as they progress through the development process (or portions thereof). The "top-down" structure associates specific, detailed development tasks and activities to the overall development process. This approach helps the design student to understand how specific tasks contribute to the completion of an overall product development project.

Each development phase that can be selected from the home menu is also shown as a sequence of more-specific tasks, from which even more-detailed information can be accessed. In many cases, the additional information extends several levels deep, so that very detailed information can be accessed easily. Most flow paths terminate with either questions, references to design tools, or recommendations to consult other resources (these information "types" are discussed in a section below).

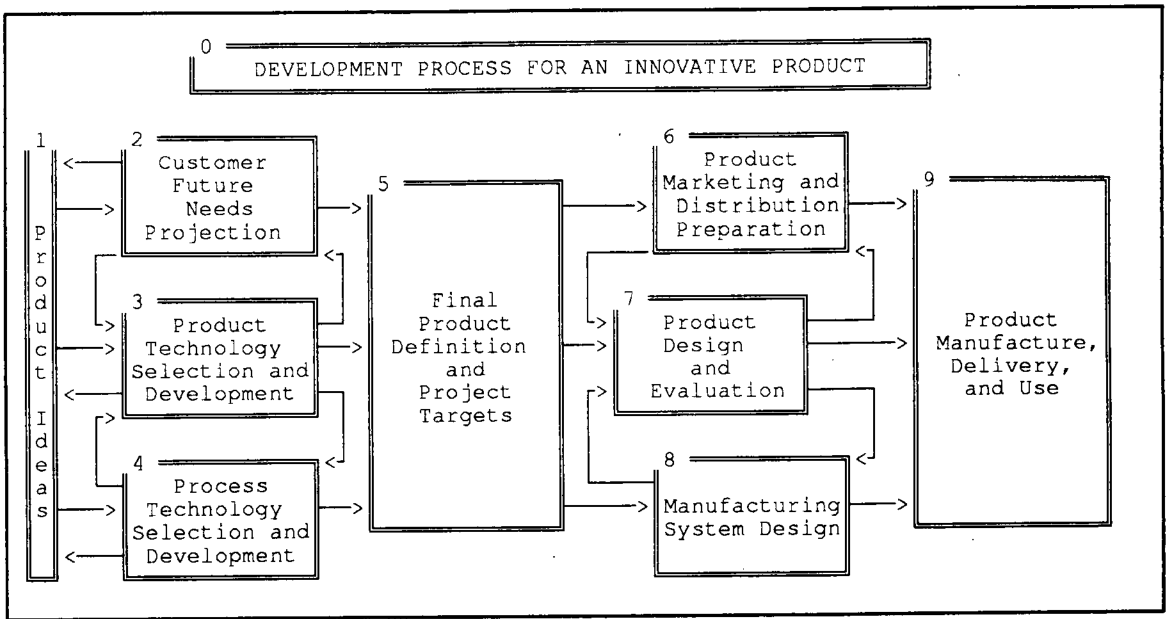


Figure 5.4: The "home" menu for Product Development Guide. The menu matches the development process for an innovative product (Figure 4.1), shown in Chapter 4.

PD Guide Tutorial

PD Guide includes a full introductory tutorial to help students (and their professors). The tutorial contains sections on how PD Guide is operated and organized, as well as presenting an introduction to the product development process and a description of available PDG Tools. The introduction is similar (but much shorter) than the description of the product development process provided in Chapter 4.

An example display from the "introduction to the product development process" portion of the tutorial is shown in Figure 5.5. It has been suggested that a professor could use this introduction section as an illustrated lecture, by using a personal computer display system.

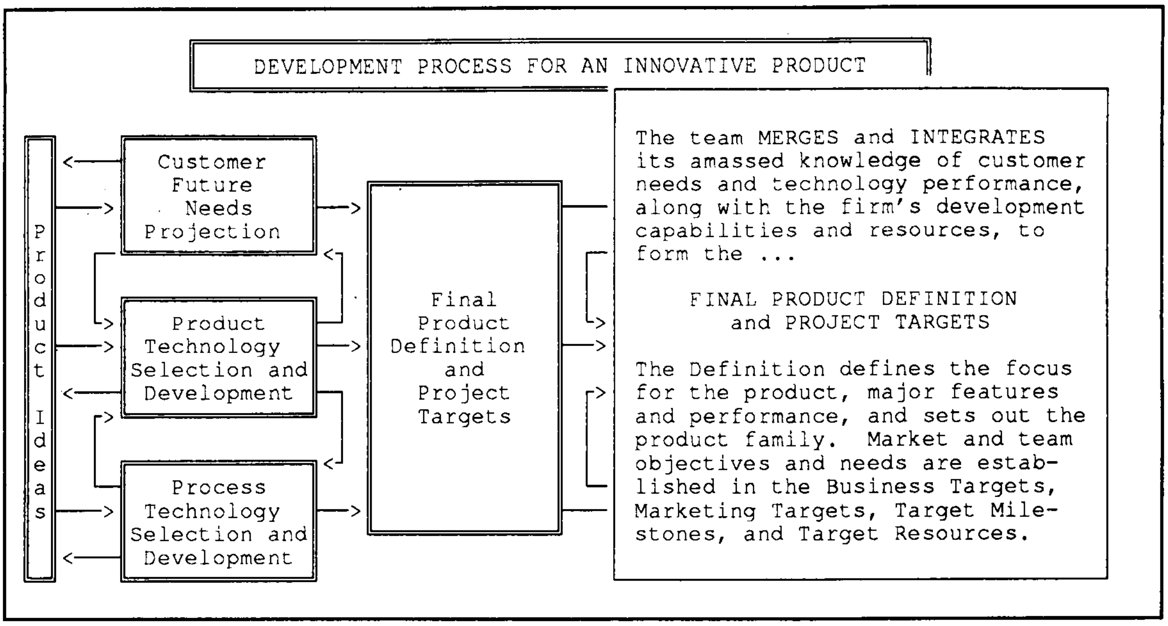


Figure 5.5: Sample display from the PD Guide Tutorial.

PD Guide Module: PDG-PDS

As PD Guide became larger, it was thought desirable to divide portions of PD Guide into separate, self-contained "modules" that could be used in conjunction with, but discretely from, PD Guide itself. To test the desirability of this approach, the portion of PD Guide that assists students in writing the Product Design Specification (or "PDS") was extracted from PD Guide and made a separate program, named "PDG-PDS" (short for "PD Guide - Product Design Specification"). At the point in the product development process where a PDS should be written, PD Guide refers the user to the PDG-PDS module. Since PDG-PDS runs independently of PD Guide, PDG-PDS can be used either with PD Guide, or by itself.

Technical Features/Description

"Engine". PD Guide uses a 1987 program called AutoMentor™ to control the selection and display of its information screens. AutoMentor (from Software Recording Corporation, Dallas, TX) was designed specifically for creating computer-based tutorials.

Use of AutoMentor enables PD Guide (and its modules) to run on the Intel 80386™ based computers in the SEDP's Engineering Design Center, which is used for the senior design course. While reasonably priced (for tutorial engines offered at the time of purchase in 1991), its limitations did become a factor later during PD Guide's development (these problems are discussed in Chapter 9).

Additional information on the operation, format, size, and architecture of PD Guide can be found in Appendix B (user instructions, including hardware requirements) and in Appendix S (file locations and structure).

Size / Growth of PD Guide. Figure 5.6 shows the growth of PD Guide throughout the development effort, which began in the summer of 1991. The first "complete" PD Guide package (provided "in pocket"), including the PDG-PDS module, contains about 1400 different information displays.

Types of Information in PD Guide

The information shown on any specific PD Guide (or PDG-PDS) display may be one or a combination of several various types, as was shown in Figure 5.3.

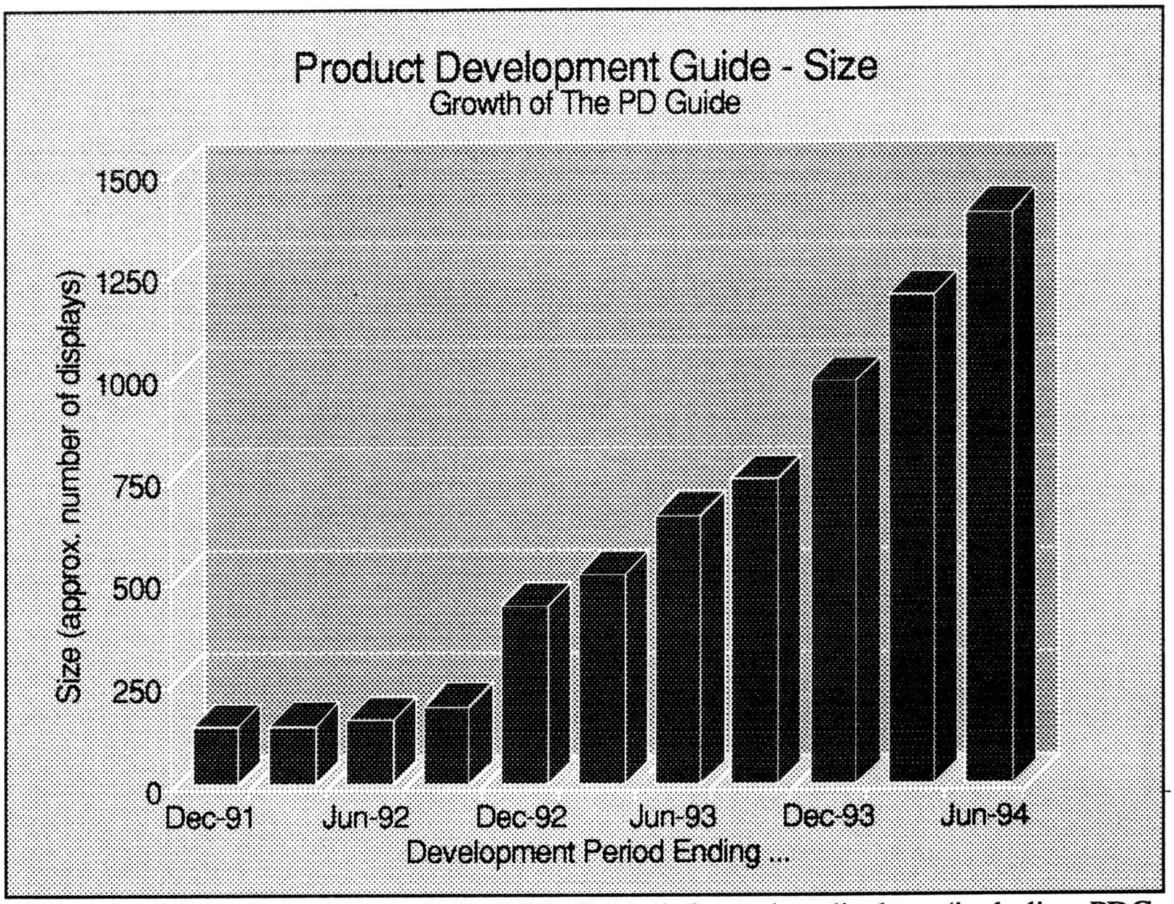


Figure 5.6: Growth in the number of PD Guide information displays (including PDG-PDS) over the development effort.

Process Maps

Process maps or diagrams are used to illustrate the nature and order of tasks. The PD Guide's own "home" menu shows the product development process as a flowchart of phases from Product Ideas to Product Manufacture, Delivery, and Use. Maps are also used to show the steps needed to complete specific phases of the product development process and of some tasks. An process map example, drawn from the Product Design and Evaluation phase, is shown in Figure 5.7. It is important to note the iterative "loops" in many of the process maps (including Figure 5.7). These loops repeatedly illustrate to the student the highly interactive, iterative nature of the product development process.

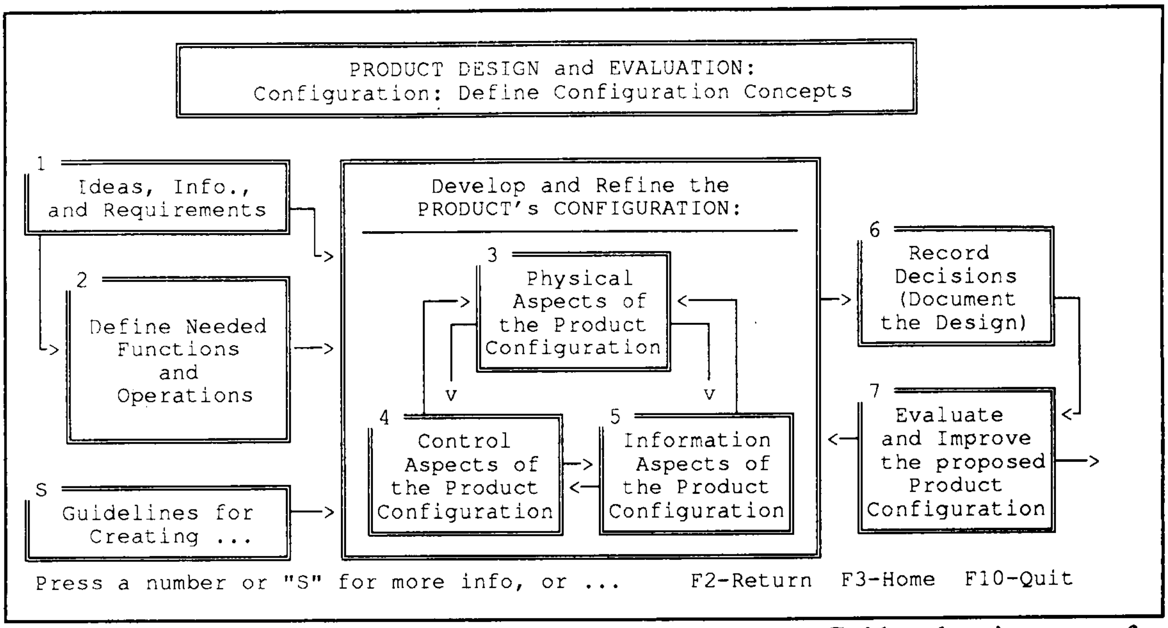


Figure 5.7: Information display from Product Development Guide, showing use of a process map or "flowchart".

"Critical Questions"

"Critical questions" are asked to initiate consideration or encourage resolution of issues to be addressed at that specific point in the development process. The goal of these "critical questions" is to alert students as to "what is most important", to prompt teams to pursue the most urgent ("critical") activities first. An example of a PD Guide display that asks questions is shown in Figure 5.8.

Critical questions are asked throughout the process, and may direct the senior design student toward specific activities, information, or tasks. Some questions may be resolved in team discussion, while others may require significant additional efforts. For students in the graduate course, the questions raise crucial product development issues which can serve as starting points for the student's case study. Because PD Guide is intended to be "generic", not all questions will necessarily apply to a particular project.

```
PRODUCT DESIGN and EVALUATION:                          Page 1
Configuration Design: Evaluate Product Complexity       of 3

Product Complexity: Assess machine to reduce product complexity

>  How can the product's complexity be reduced?

   + How can the number of steps, parts, subsystems, etc. needed to
       provide each function be minimized?

   + How has the configuration been reviewed to assure that it is
       no more complex than necessary to perform the function reliably?

   + How are critical tolerances minimized through the skillful
       definition of subsystems and interfaces?

   + How have system operating parameters been selected to minimize
       the need for active control or adjustment of the product?

                    --- CONTINUED on the next page ---
Press PgDn-Next Page or press ...          F2-Return   F3-Home   F10-Quit
```

Figure 5.8: Information display from Product Development Guide, showing use of "critical questions".

The sample display (Figure 5.8) also illustrates a key feature of the questions presented in PD Guide - they are probing, investigative questions. Yes/no questions were intentionally avoided whenever it was possible to do so. In this way, PD Guide functions as more than a checklist. Often, suggestions or recommendations may be implied as part of a question, but this was considered to be part of the "guided discovery" process.

Menu Option Selections

Information displays containing "menu options" offer the user an opportunity to obtain more information about topics. Menu options may be available from process map boxes (such as from home menu, Figure 5.4, or process map example, Figure 5.7), critical questions, or other statements. These options are indicated by specific screen markers or labels which indicate when additional information is available on a particular topic.

```
                    PRODUCT DESIGN and EVALUATION:
            Configuration: Define/Derive Technical Requirements

              Develop and/or Convert Technical Requirements

At this step, the team develops and/or converts multiple technical require-
ments for the product system (and subsystems) from many sources, including:
    > the Product Definition          > Configuration Concept Decisions
    > the PDS                         > Module / Subsystem Decisions

 >>>>> Technical requirements are defined in CONJUNCTION and INTERACTIVELY
       with the creation and evaluation of Product Configuration Concepts!

 1   Convert Product Def'n and PDS        3   Convert any manufacturing needs
      into technical requirements.             into design requirements.

 2   Evaluate common sources of           4   Assess need and desirability
      technical requirements.                  of product adjustments.

 5   Evaluate feasibility of requirements and Create Requirements list.

Press a number for more info, or press ...      F2-Return  F3-Home  F10-Quit
```

Figure 5.9: Information display from Product Development Guide, showing some menu options available from a display which offers recommendations.

Pressing the number/letter key associated with process box, question, or advice provides access to more specific information about that topic. Figure 5.9 shows a menu option display that provides access to more-detailed information about recommended tasks or activities.

Recommendations / Advice

Advice, instructions, or recommendations may be provided when the research indicates an action or decision has been useful in other successful projects. However, it is pointed out that the user/team is *always* responsible for *all* decisions that pertain their new product.

"How to" information is provided in many instances to help teams complete certain tasks within the development process. This "how to" information provides critical

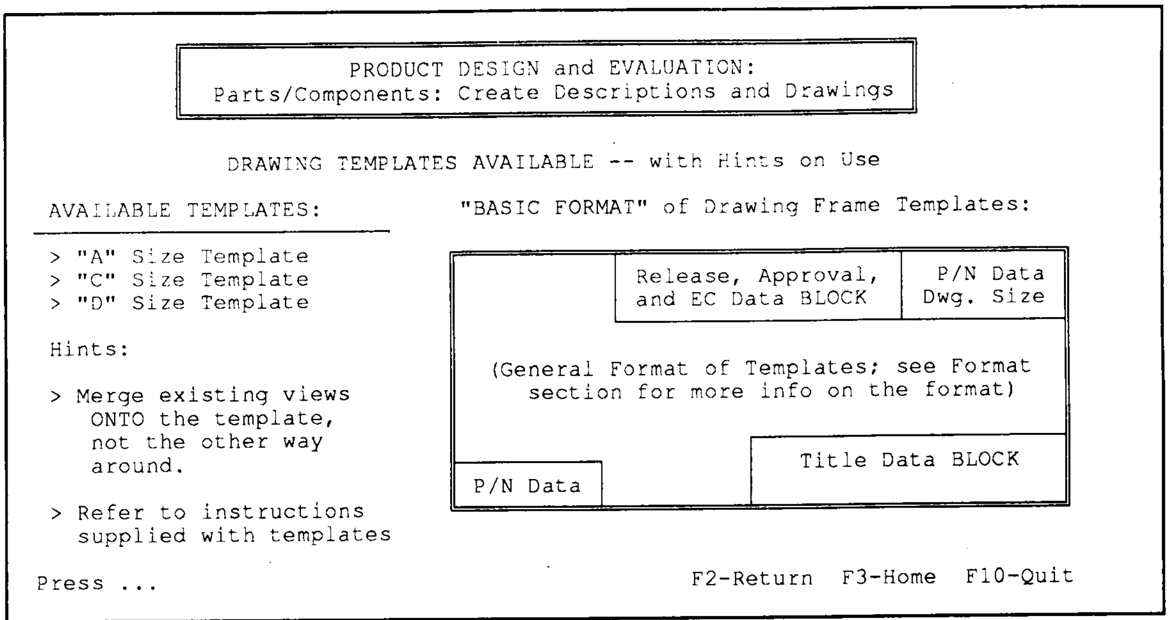


Figure 5.10: Information Display from Product Development Guide, showing advice about the use of a PDG Tool.

information that the team may need to complete this process successfully. Figure 5.9, which shows the example menu option display, also shows one method by which PD Guide provides recommendations. In this case, steps for defining the product's configuration requirements are recommended.

Other "recommendation" displays provide advice about how to use a Product Development Guide Tool (PDG Tools are discussed in Chapter 6). Figure 5.10 shows one display from a section that explains the layout of the PDG Tool "part drawing templates".

Examples

Examples are shown throughout PD Guide to illustrate concepts. The intent of the examples is to show how a given issue/question applies in a certain case, and to stimulate

```
PRODUCT DESIGN and EVALUATION:
Configuration: PDS to Technical Requirements

Convert PDS performance requirements into relevant system and/or
sub-system requirements:

PDS performance requirements are written in "customer" terms; these
customer requirements must be converted into technical machine
requirements, based on the proposed product configuration.

Example: Convert PDS requirements of x pages printed per minute
         to a y in/sec paper feed requirement, z MB/sec data
         processing requirement, etc.

Example: Convert fluid volume holding capacity requirement into
         the amount of weight that must be supported.

Example: Convert payload acceleration and capacity requirements
         into minimum power requirements.

Press ...                                F2-Return   F3-Home   F10-Quit
```

Figure 5.11: Information display from Product Development Guide, showing examples.

team thinking about how that issue might apply for its product. Data are sometimes offered to reinforce the importance of specific factors/issues. Figure 5.11 shows a sample display that presents examples to the student; in this case, how to convert one set of requirements to another related set is shown. Students can draw analogies from the examples as to how the issue applies to their specific project.

References to Other Resources

PDG Tools. PDG Tools are identified throughout PD Guide to direct students to provided aids for specific tasks (PDG Tools are discussed in Chapter 6). Some of these sections are "matched to" its corresponding PDG Tool, so that students get concurrent advice on the method and use of the tool. For example, the part drawing section of PD Guide (Figure 5.10) is constructed to match the layout shown in the PDG Tool for part drawings. The Product Profit Analysis (or "Business Plan") and the student design schedule spreadsheet are two other specific tools that are matched to corresponding sections in PD Guide.

Other referrals. When appropriate, PD Guide refers to additional "outside" information sources that may be available. For example, the process capability section of PD Guide refers students to the IBM *Process Control, Capability and Improvement* manual. Students also can be referred to videotapes in the SEDP's tape library; the library has tapes covering several important topics, such as Design-for-Assembly techniques. Case study presentations from the graduate Product and Process development course (ME 553) are also referenced.

Some PD Guide topics support or reinforce contents of instructional "skill modules" that are also being developed within the SEDP [Kennedy *et al.*, 1993]; [Lenoir, 1994]. As for PD Guide, the main objective of these modules is to integrate industrial best engineering practices into the curriculum at appropriate times. Key areas in common include referrals or tutorials on "design of experiments" and "process capability".

Essential Elements

While not listed specifically as an information "type", PD Guide also contains the "essential elements" for each development phase. These essential elements, identified as part of the product development process model discussed in Chapter 4, define some "critical few" factors within each phase that most affect the probability of success. With these displays, the student hopefully becomes aware that there are "essentials" to superior product development. An example display of essential elements is shown in Figure 5.12.

MANUFACTURING SYSTEM DESIGN

Essential Elements

> Processes selected for the system are restricted to those that are well-defined and characterized. Standard, well-established processes are used whenever possible in the manufacturing system.

> Automation is attempted only after the process to be automated has been proven "stable" and has been simplified as much as possible. Except for when a process cannot be performed manually, automation feasibility is generally demonstrated using a manual procedure first.

> Critical processes are performed/controlled internally. Processes that affect critical technology/design parameters are maintained by the firm itself, or perhaps controlled VERY closely along with "best" suppliers.

> Processes and equipment detect errors automatically, or, even better, have "designed in" features that prohibit errors from occurring.

Press ... F2-Return F3-Home F10-Quit

Figure 5.12: Information display from Product Development Guide, showing presentation of some "essential elements" for product development.

Current Uses

PD Guide (and the corresponding PDG Tools described in Chapter 6) have been used in the year-long capstone design experience and in a graduate product development course at the University of Tennessee for the last two years. The evaluation resulting from this use is described in Chapter 7. PD Guide has also been evaluated by 14 industry expert practitioners; the results from this review are presented in Chapter 8. These evaluations were used to evaluate the "correctness" of the information, to determine areas requiring additional information, and to identify additional development tools.

Issues related to the typical/potential use of PD Guide in academic settings are discussed in Chapter 9, Conclusions and Recommendations.

CHAPTER 6

PRODUCT DEVELOPMENT GUIDE TOOLS

Chapter Summary

While the process maps and questions in PD Guide help students in deciding *what* to do, PDG Tools have been created help in *doing* specific tasks. Easy-to-use worksheets, tables, templates, or programs are provided for typical product development tasks. For example, a simple project scheduling template helps project teams define and schedule major project activities.

PD Guide and the PDG Tools are "generic", to support the development of a wide range of products. The PDG Tools are designed for use with the commercially-available programs Lotus® 1-2-3®, WordPerfect®, and IBMCAD.

Significant portions of this chapter are adapted from the paper, "A Product Development Guide for Students", from the *Advances in Capstone Education* conference proceedings [Wilson and Kennedy, 1994].

Goals of PDG Tools

The maps and questions within PD Guide are supposed to assist students in deciding what tasks are the most important to accomplish. The PDG Tools provide aid in completing specific tasks. That is, while the questions help in deciding *what* to do, the design tools help in *doing*. In many cases, the tools are quite simple, consisting of easy-to-use worksheets or tables.

The Product Development Guide Tools (PDG Tools) are introduced primarily for use with the students' design project and are designed to help students directly accomplish project tasks. For example, the Product Design Specification and the Project Schedule tools (discussed below) are directly related to tasks that students perform as part of their capstone design project.

Some advanced tools, such as a Design of Experiments program and a worksheet for performing Failure Mode and Effects Analysis, are also referenced within PD Guide [Walker *et al.*, 1991], but are not discussed here.

Requirements for Running PDG Tools

The PDG Tools diskette (contained "in pocket") contains files that are to be used with the commercial programs WordPerfect 5.1, Lotus 1-2-3, and IBMCAD. Which files operate with which program are ascertained from the suffix of the filename. The PDG Tools are loaded into its corresponding program just as any other document, worksheet, or CAD file.

In general, users need an IBM or IBM-compatible personal computer running DOS 3.3 or higher, Lotus® 1-2-3®, WordPerfect® 5.1, or IBM CAD. Other commercial programs, such as Borland's Quattro Pro®, can be used when they are capable of reading Lotus, WordPerfect, or IBM CAD files. Appendix A and Appendices C-M contain more information on the use and operation of PDG Tools.

Computer-Aided Drawing (CAD) Tools

Table 6.1 lists the PDG Tools that are available to assist with computer-aided drawing ("CAD") activities. These files can be divided into two basic items, drawing templates and a "critical item" designation system. These tools, based on the IBM CAD™ drawing program, provide standard drawing formats and assist students in following good engineering drawing practice.

CAD Drawing Templates

The drawing templates provide common, professional formats onto which students place their part and assembly drawings. They include many of the engineering drawing features and controls that students will likely experience in industry. Use of the template requires students to supply pertinent information to specify and manufacture the part fully: material specification, tolerances, surface finish, corner treatment, etc. Students can reference a section within PD Guide that explains the meaning of the template's features.

The common drawing formats/features provided by the templates accomplish several desirable objectives within the capstone design course:

- they reinforce good parts/assembly drawing practice and control;
- they save time for students, by eliminating the task of generating a drawing format for themselves; and
- the common format makes it convenient for instructors to ensure that drawings have required information.

Table 6.1: The IBM CAD based PDG Tools.

File Name	Tool Name	Tool Description, Information
AFRAME.cad	"A" size Frame (drawing file)	Standard drawing frame for "A" size (8.5"x11") paper. Includes blocks for "assembly release" and engineering change control.
CTEMPLAT.cad COVERLAY.cad	"C" size Frame (drawing files)	Same as "A" frame, but sized for "C" size (22"x17") paper.
DTEMPLAT.cad DOVERLAY.cad	"D" size Frame (drawing files)	Same as "A" frame, but sized for "D" size (34"x22") paper.
CRITICAL.sym	"Critical" Symbols (ibmcad symbol file)	Symbols for designating dimensions as critical to function, assembly, and manufacture. Used in Product Design and Evaluation phase.

A sample of one of the templates is shown in Appendix M. Formats are provided for "A", "C", or "D" size drawings. For users without IBM CAD, the DXF formatted versions of these files can be used in many generic drawing programs. Appendix M also contains more-specific information on equipment and software needs.

"Critical To" Indicators

The "Critical Symbols" file is used on engineering drawings to designate the following critical conditions:

<CTF> identifies dimension/s as critical-to-function;

<CTM> identifies dimension/s as critical-to-manufacture;

<CTA> identifies dimension/s as critical-to-assembly.

This designation system was developed to "fill a hole" in standard industry documentation, which normally does not provide for the identification of critical dimensions. The case study research revealed that some industry product engineering groups use this or a similar approach to assure the performance and quality of their products.

PD Guide contains a section that explains the meaning and use of these symbols on engineering drawings (an illustration of these symbols is also shown in Appendix M). A key benefit arising from student use of this tool is that they must evaluate exactly how the assembly or part contributes to the desired characteristic/function in order to mark the dimensions properly.

WordPerfect® Based Tools

Many of the WordPerfect®-based tools provide standardized formats or "templates" for the documentation activities that are performed as part of the Product Development Process. These common formats can be particularly useful for professors that must evaluate and compare the efforts of multiple design teams. Table 6.2 lists these WordPerfect® Based Tools.

Reporting Aids

Many of the word processing based PDG Tools are designed to help students fulfill the reporting requirements in the capstone design course.

Table 6.2: The WordPerfect based PDG Tools.

File Name	Tool Name	Tool Description, Information
PDG-NTRO.wp	Introduction to PD Guide	Questions about the product development process, answers to which can be found in the PD Guide. Can be used as student exercise to introduce PD Guide.
PDSFORM.wp	Product Design Specification (PDS) Template	"Starter" document for the PDS, which is the first step of the Product Design and Evaluation phase. Use with PDG module, "PDG-PDS", a guide to creating a PDS.
PRCE2MFR.wp	Price Conversion Worksheet	Used to convert the "value-based" customer price target for the product to the actual price received by the manufacturer.
RPORTFOR.wp	Guidelines for Technical Reports	Guidelines and format to use when writing technical reports. Useful both for technical reports during product development and for academic "final design reports".
RPTSTRTR.wp	Report "Starter" Format	A "nearly-blank" report containing the generic title page, table of contents, and header features that are specified in the Guidelines for Technical Reports. Retrieve and edit this file when starting a new report.
WRKRPT-I.wp	Design Project Progress Report, Individual	Progress report format for individual design team members. Useful for student reporting of individual efforts to their professors.
WRKRPT-T.wp	Design Project Progress Report, Team	Progress report format for design team to their superiors. Useful for periodic student team reporting of efforts to their professors.

Guidelines for Technical Reports. This Tool describes a structured format for the design report. This format requires a short background statement of the problem, followed immediately by conclusions and recommended actions, so that readers can quickly understand the problem and recommended actions by reading only the first section. Appendix F shows the contents of this Tool.

The guideline is adapted from one originally developed at one of the SEDP's industry partners. They developed the guideline because most of their new engineers (ones newly-graduated from college) were writing reports chronologically from the writer's point of view, rather than for the reader's point of view. With this guideline format, students must "get to the point" immediately. While requiring students to organize their communication more carefully, the capstone design professor also benefits from having a common format for every report.

Report "Starter" Format. The report starter format Tool provides a "blank" document that corresponds directly to the format requirements specified in the Guidelines for Technical Reports. The contents of this "template" document is shown in Appendix G. It has sample names, section headers, etc., which are already set and located in the appropriate format. Students thus get a quick start on any report since the starter document has the appropriate format built-in.

Sample headings and appendix titles included in the starter document provide a list of items that are often included in design reports. Students evaluate the content needs for their particular report by using/deleting the provided headings as needed.

Design Project Progress Reports. These two progress report Tools, for the individual and for the team itself, provide a format that has been used in some of the capstone design classes at The University of Tennessee (these Tools are shown in Appendix E). Again, student use of these starter documents assure that reports begin in a common format for the professor.

Word Processing Based Project Aids

Two of the word processing based PDG Tools are designed to help students fulfill specific tasks related to their capstone project assignments.

Product Design Specification (PDS) Template. This tool is used in concert with the PDG-PDS module of Product Development Guide to prepare a PDS (contents of this Tool are shown in Appendix D). In the introduction to design course, student teams prepare PDS's for an example product. In the capstone design course, student teams prepare PDS's for their "design, build and test" projects. The PDS is the critical document that describes the product design requirements and the environment in which it must operate. The use of a standard format for the PDS facilitates the understanding of the students in preparing the document and of the professor in reading it. As with the PDG-PDS module, the template is generally extracted from Pugh's approach [1991].

Price Conversion Table. This very-simple Tool communicates the need to develop products from a customer value and price ("price minus") approach, rather than from a firm's cost ("cost plus") viewpoint. The worksheet helps students to determine the "allowable manufacturer's price" of a new product from the estimated price that the team believes customers will pay. Then, from the manufacturer's price, the product's cost target can be determined. The Business Targets section within PD Guide provides background information and guidance to use the table effectively. A copy of the table is shown in Appendix L.

Introductory Exercise

The "Introduction to PD Guide" Tool provides a self-teaching method for introducing students to the product development process and the Product Development Guide. Small teams answer the questions in the Introduction exercise, which can be answered by reviewing the PD Guide. The team's answers can be written directly into the starter document under each specific question. With this approach, learning occurs through team discussion rather than by a class lecture. Some instructors may wish to have teams present results in class to reinforce the exercise. This Tool is shown in Appendix C.

An answer key to the Introduction to PD Guide exercise has been created and can be made available to course instructors. (It is not included on the PDG Tools diskette).

Lotus® 1-2-3® Based Tools

A listing of the Lotus® 1-2-3® Based Tools, along with a summary description of their contents, is shown in Table 6.3. These spreadsheets are designed to help teams schedule their efforts, assess financial costs/returns, or define project lists. As partially-automated worksheets, many of these tools can speed certain tasks within the product

Table 6.3: The Lotus 1-2-3 based PDG Tools.

File Name	Tool Name	Tool Description, Information
BUSPLAN.wk1	Product Profitability Analysis	Helps teams determine potential financial returns from a product development effort. Used with the "Business Targets" section within the "Final Product Definition and Project Targets" phase.
MILESTON.wk1	Project Milestones Chart / Utility	Helps teams establish the "Project Milestones", using the milestones defined within the "Final Product Definition and Project Targets" phase. Teams enter dates, spreadsheet creates bar or "Gantt" chart automatically.
DESSCHED.wk1	Design and Evaluation Phase Schedule / Chart	Helps teams create their Design and Evaluation activity schedule; used with the "Planning and Scheduling" step in the "Product Design and Evaluation" phase. Teams enter dates, spreadsheet creates bar or "Gantt" chart automatically. Schedule items match the steps shown within the Design and Evaluation phase.
CLASSCHD.wk1	Design Course Project Schedule	A derivative of the Design and Evaluation phase schedule, customized to meet specific needs of academic "design-build-test" projects. Schedule items tied to relevant "blocks" in the PD Guide often addressed in academic projects.
PARTCOST.wk1	Parts Cost Calculation Worksheet	Computes "per part" costs of product components, based on setup, processing, and tooling needs. Provides options for "batch" processes and different process costs.
PARTLIST.wk1	Bill of Material Format	Provides layout and short example for a product's Bill of Material.

development process. The common formats provided by these worksheets can be particularly useful to professors that must evaluate and compare the efforts of multiple design teams.

Scheduling Chart Spreadsheets

These spreadsheet utilities helps students to create Gantt-type charts for various efforts within the product development process. Students/users enter start and end dates for the activities, while the spreadsheet creates the timelines automatically. Printouts of sample schedules are shown in Appendix J.

Project Milestones Chart. This spreadsheet lists key project milestone dates. The "milestones" are keyed to the phases defined within PD Guide, where key questions are asked about planning the product development process. A section in the Final Product Definition phase explains the schedule entries.

Design and Evaluation Schedule/Chart. This schedule is an "industrial strength" level schedule that covers the full Product Design and Evaluation phase. A section in Design and Evaluation phase defines the entries for this chart and asks questions to help users schedule tasks appropriately. Since most academic projects are limited to but a portion of Design phase, capstone design students use the Design Course Project Schedule instead.

Design Course Project Schedule/Chart. This schedule is a derivative of the "regular" Design and Evaluation schedule, but is tailored to the specific needs of an academically and time limited design-build-test project. It includes much more specific entries to help design student teams execute their projects effectively. Entries are also tied to relevant sections within PD Guide. A section in the Planning and Scheduling portion of the Design and Evaluation explains the entries in this schedule.

Financial Cost/Returns Spreadsheets

Two spreadsheet tools introduce design students to the financial aspects of the product development effort.

Product Profitability Analysis. This "Business Plan" tool gives students the opportunity to learn how financial returns from a product development effort are estimated. Engineers are often ignorant of what information goes into this plan, even though the resulting conclusions often determine whether a project effort continues and what direction it takes.

A key part of the value from using this tool is that the engineering student gets an opportunity to examine the effects of price and cost variables on the profitability of a project. Allen [1993, p.99] points to the topic of economic considerations, such as the business plan, as becoming increasingly important to "enhanc(ing) the student's ability to apply their technical education in today's competitive environment."

A printout of part of the Business Plan is presented in Appendix H. As shown, the tool comes preloaded with a sample case (eg. sample sales projections, market price, etc.), so that students can review an example before beginning their own case. The Business Targets section of PD Guide contains the background information and questions needed to help students through the Business Plan effort. The basic format and structure is modified from a useful approach explained in *Developing Product in Half the Time*, by Smith and Reinertsen [1991]. One enhancement versus many other traditional profit analyses is that "overhead costs" are split both by activity and into two components: an overhead as a percentage of sales (most often used in most traditional analyses) and fixed overhead costs that are incurred regardless of the level of sales (often neglected in traditional analyses).

Parts Cost Calculation Worksheet. This Tool (shown in Appendix I) provides the student with exposure to the various cost "components" that combine to create the "cost" of a part. It also gives students a relatively simple and fast way to generate a fairly comprehensive parts cost estimate.

The Tool is best used to estimate the cost of simple, machined parts; this parts type was selected because these are often used to build prototypes of the student designs. Students using this tool learn about different types of costs, which are based somewhat on Activity Based Costing techniques. The Tool includes the effects of two types of setup costs (initial and repeated) and of tooling consumption. It also allows for two different processes and two cost rates, to account for cost differences across processes and personnel.

The worksheet was first developed and used on the author's master thesis project, to estimate costs of machined parts for a low-cost industrial robot [Kennedy, 1991].

Project Listings

Bill of Material Format. A Bill of Material ("BOM") or "parts list" starter format (shown in Appendix K) requires that teams track and list all materials that are to be used in their product. The format is a simplified version of the typical material control structures that are used by many firms to control parts and assemblies. Some sample items are entered into the worksheet to give students some examples as to how the BOM actually works.

CHAPTER 7

STUDENT USE AND EVALUATION OF PD GUIDE

Chapter Summary

This chapter describes the use and evaluation of Product Development Guide ("PD Guide") and PDG Tools by various groups over a two-year period. Several prototype "levels" of PD Guide have been used in senior-level mechanical engineering design courses and in a graduate engineering course covering new product development. Use of PD Guide as a one-half day professional development course exercise is also discussed.

Many student users responded to structured surveys and/or provided written comments about their use of PD Guide and PDG Tools. User responses were analyzed to ascertain perceptions about PD Guide's ease of use, usefulness, and other factors.

In general, the presentation of PD Guide has been well received. Students generally said that PD Guide easy to use and a worthwhile experience. Students must be encouraged (or required) to use PD Guide in their design project to achieve PD Guide's maximum usefulness. Responses suggest that students find value in PD Guide and PDG Tools, once they can be convinced to use them. The capstone design class said that working in teams is a critical part of their learning, and that the capstone experience increases their interest in pursuing a career in design / product development.

Objectives, Use, and Information Collection

Use and Evaluation Objectives

Since PD Guide is intended as a learning tool for students, it was considered important to have students influence its development. Thus, several different student groups have been assigned to use and evaluate various prototype versions of PD Guide and PDG Tools throughout their development. Primarily, the objectives of these student uses and evaluations were to assess student perceptions of:

- advantages/problems with using PD Guide as part of a class assignment;
- PD Guide's "ease of use";
- their learning from PD Guide;
- relative effectiveness of PD Guide versus or as a supplement to alternative approaches, such as in-class lectures and textbooks;
- needed PD Guide improvements.

The versions of PD Guide evaluated by these classes were all incomplete to different levels, based on what was available at the time of the assignments. The continuing goal has been to use all feedback to improve PD Guide and its use in design and product development courses.

Survey Structure and Analysis

When used, structured surveys generally consisted of 10-15 "agree-disagree" questions, followed by several short-answer questions. One survey asked students to report the extent of their use of specific PDG Tools and their perceptions of the Tool's value. As more was learned about PD Guide and use of the surveys, questions were added, changed or deleted as needed. The surveys were constructed primarily to identify use, ease-of-use, and improvement needs, and specifically was *not* constructed to prove formally the educational efficacy of PD Guide. Nonetheless, student views were usually solicited concerning the relative effectiveness of PD Guide as a supplement or replacement to regular instruction and textbooks.

The "agree-disagree" questions provided a statement, then asked students to agree or disagree with the statement on a "seven point" scale of -3 to +3. Statistical tests were used to decide when student opinion was sufficiently strong from a neutral opinion. Student opinions and differences in response between different groups (such as between two classes) were evaluated by computing a 95% confidence interval for the difference between the two groups' means, using an alpha of 0.05. Opinions or differences between groups were deemed significant when the confidence interval did not include "0", or "no difference". This procedure is equivalent to a one-sided t-test, using an alpha of 0.025. A small alpha was used to be conservative in making conclusions about PD Guide.

The "open-ended" comments section solicited student opinions regarding topics such as presentation/layout, contents, how they might envision their use of PD Guide, and needed improvements. Comments were compiled and grouped by subject. These results were used to gain additional insight into the conclusions derived from the numerical analysis and to gather ideas for improvements.

Classes Involved in Evaluation

PD Guide was utilized in several courses taught in the mechanical engineering curriculum at The University of Tennessee. Table 7.1 shows the courses (and the specific semester) in which the PD Guide, PDG Tools, or a combination were used as part of that class. The professional education course listed in Table 7.1 is discussed separately.

The basic purpose of the Mechanical Engineering 455 (ME 455) course is to prepare students for their comprehensive design project the following semester. This project, also known as the "capstone" design effort, is performed in the ME 469 course and involves at least the design of a significant device or product. Often, ME 469 students are required to not only design a solution, but also to build and evaluate a working prototype of that solution. Many projects are derived directly from industry; others address a recognized customer need.

The ME 553 course, entitled "Development of Superior Products and Processes", enables students to examine the best engineering design, evaluation, and manufacturing methods used by competitive U.S. firms. Engineers and managers of product development efforts personally present key concepts to the class. Students conduct their own case studies of product development projects as part of the course.

Table 7.1: Courses in which PD Guide was used/evaluated.

Date	Course	Use/Assignment	Number of Participants
APR 1992	ME 553, Development of Superior Product and Processes	Trial use, provide free-form written comments on PD Guide concept	11
SEP 1992	ME 455, Introduction to Design	Introduction exercise, PDS for sample product	27
FEB 1993	ME 553, Development of Superior Product and Processes	General reference for course lectures and case study	20
MAR 1993	UT Management Development Center (professional course)	Develop Product Concept and PDS for specific product idea	20
SEP 1993	ME 455, Introduction to Design	Introduction exercise, PDS for sample product	24
MAY 1994	ME 469, "Capstone Design Course"	Support capstone design project activities	32 (two sections)

Course Assignments

Students in the listed courses completed various assignments and were asked to provide feedback in different ways. A short description of each assignment and how data was collected is provided below.

ME 553 Course, Spring 1992. PD Guide was first used by students in the Spring 1992 version of the ME 553 course. These 11 students were asked to review PD Guide and to provide written comments of their impressions. Later, students were asked to make an attempt to use PD Guide as a reference in their case study assignment, then provide any additional comments that they had. A structured survey was not administered to this class.

ME 455 Course, Fall 1992. Twenty-seven (27) students in the fall 1992 ME 455 course used PD Guide to complete two assignments. All students in the class were mechanical engineering seniors. Students first were asked to identify some key elements for the successful development of an innovative product, which are shown within PD Guide. Next, students working in teams were asked to create a Product Design Specification for a proposed product.

After the assignments, they completed a structured survey to record their impressions of PD Guide and its use. (The report of findings from this survey is in Appendix N). Comments were solicited on PD Guide's operation, format, layout, and ease of use. Students were also asked what should be covered in a PD Guide tutorial, which at the time had not yet been developed.

ME 553 Course, Spring 1993. Nineteen (19) students in the Spring 1993 version of ME 553 completed an assignment and survey involving PD Guide; one additional student provided only comments. Fifteen (15) of the 19 students were graduate students in engineering. Four undergraduate senior students taking the course were generally considered to be above-average undergraduates. (The analysis report of this survey is provided in Appendix O). Students were asked to compare concepts shown in PD Guide to key lecture points from two or three previous class sessions dealing with Technology Selection and Development. They also were encouraged to think of PD Guide as a reference "text" throughout the semester and for their case study.

ME 455 Course, Fall 1993. The 24 senior mechanical engineering students in this class completed two assignments similar to those in the Fall 1992 version of this course. Students in this 1993 class used a later, more complete version of PD Guide than did the 1992 students. Students were grouped into 3 person teams and asked 14 questions related to the product development process, answers to which could be found within PD Guide. Next, the teams used PD Guide to create a Product Design Specification for a proposed product. Students generally were given little instruction on use of PD Guide - teams were expected to determine what was needed. After the exercises, students answered a structured survey (The analysis report of this survey is provided in Appendix P).

ME 469 Course, Spring 1994. Thirty-two (32) of the 36 senior mechanical engineering students in two separate sections of the "capstone" design course ME 469 (spring semester 1994) returned a survey concerning their use and impressions of PD Guide and "PDG Tools" after they completed the course. The survey was conducted primarily to assess student use and value perceptions of PD Guide and PDG Tools within the capstone design course and to identify desirable improvements (the analysis report of this survey is provided in Appendix Q).

Student Reported Use and Value of PD Guide

Use and usefulness results from the capstone design course, as well as the observations of the author and the course instructors, indicate that students must be encouraged (or required) to use PD Guide in their design project to achieve PD Guide's maximum usefulness. Students' relative value rankings of PD Guide and specific PDG Tools were higher than their use ratings, which suggests that students find value in PD Guide and PDG Tools, once they can be convinced to use them.

Student-Reported Use of PD Guide

Student use of PD Guide. Student use of PD Guide during the capstone design project might best be described as "moderate". The significant difference in reported use between course sections suggests that students must be encouraged to use PD Guide in their design project.

Student use of PDG Tools. Student-reported use of PDG Tools in the capstone class varied dramatically, depending on the tool. The most-highly used tools were the part drawing templates and the design project schedule worksheet. The product design specification (PDS) module and its associated "starter" document were the next-highest used tools.

The Product Profitability Analysis, or "Business Plan", was reported to be the least-frequently used tool. The Parts Cost worksheet and the Parts List worksheet also were not used much by students.

Student-Perceived Value from PD Guide

Students in the capstone course rated the usefulness of Product Development Guide as moderate. Some PDG Tools, such as the final design report template and the CAD drawing frame, achieved very-high usefulness mean scores.

Communication. Students across surveys generally said that PD Guide is a good method for communicating the material contained within it.

Importance. Students across the surveys indicated that they thought using PD Guide had been a worthwhile experience. As shown in Figure 7.1, students consistently believe that they learned something important about product development from their PD Guide experience. (The "ticks" represent the mean response of the class, while the vertical lines represent the span of the 95% confidence interval for the mean.)

It is interesting to note a significant decline in reported learning for the capstone design course (Figure 7.1, May 1994 entry). Comments from students in that class who said that PD Guide was not useful or worthwhile suggest that these students perceived PD Guide as "extra tasks" requiring more time, rather than as "an project assistant".

Recognition of Potential Use. Students in the ME 455 Introduction to Design class quickly recognized the rationale for the "critical questions" used in PD Guide. Students repeatedly commented that the questions were asked to assure that their designs

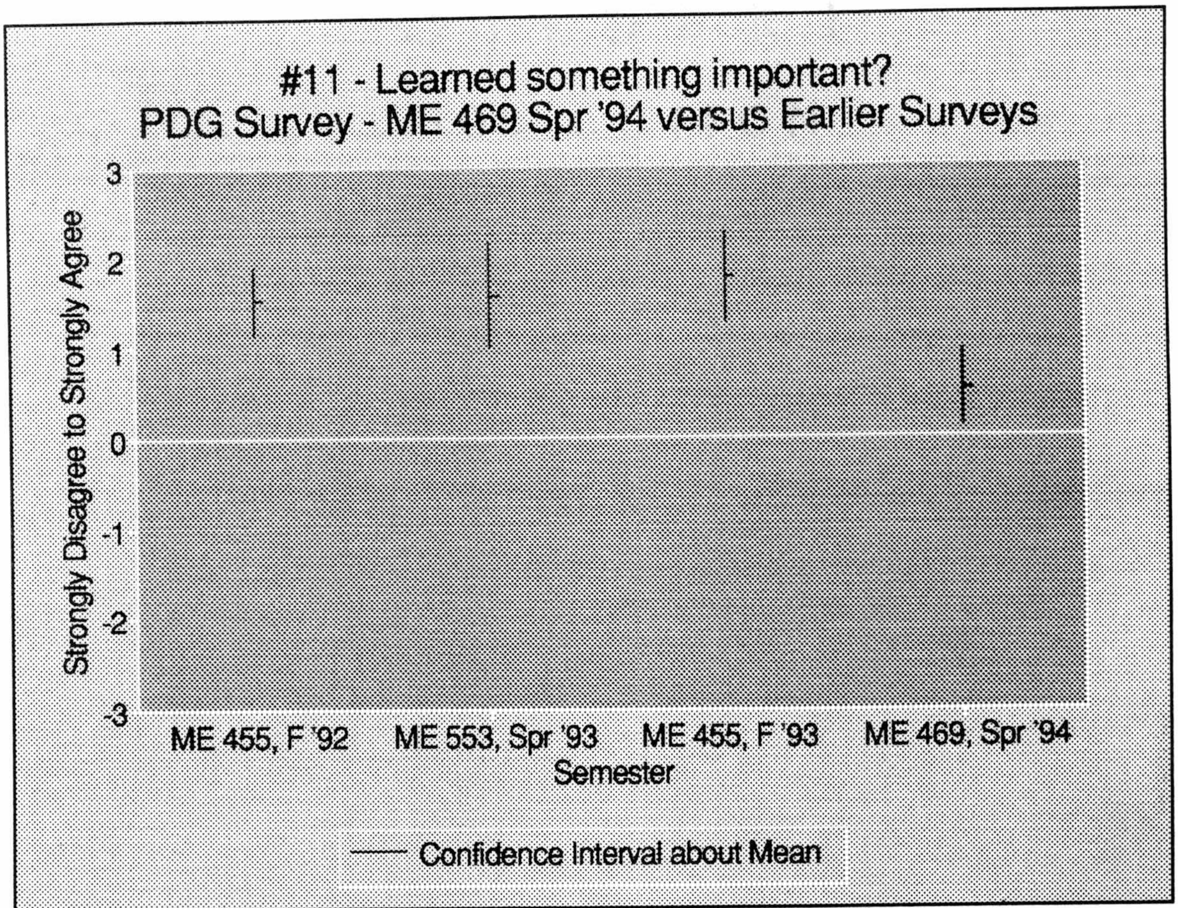


Figure 7.1: Comparison of mean student response (with confidence interval) across several surveys to a question asking students if they "learned something important from using PD Guide". (question #11 on ME 469 survey, spring 1994)

are complete and do not overlook important factors. Significant majorities indicated that they could see how PD Guide is intended to assist them with their design project.

In the graduate course, students indicated that they believed that PD Guide would prove useful in helping them complete their case studies and could even be useful to them beyond the confines of the course.

Impact on Design Projects. Disappointingly, students in the capstone design class were neutral concerning whether PD Guide and PDG Tools had affected their design project. They did indicate, however, that PD Guide *can* be used successfully to help student teams complete their design projects.

Analysis of Student Responses

This section summarizes key student reactions to their use of PD Guide throughout the PD Guide development effort. Full reports pertaining to classes that completed structured surveys are presented in Appendices. Additional student response distributions, relevant statistics, graphs, and compiled comments are maintained in research files.

Overall Presentation

In general, the presentation of PD Guide was well received. Students overall said that PD Guide is relatively "user friendly" and easy to navigate.

Ease-of-Use. Students in surveyed classes indicated that PD Guide is easy to use, as shown in the response distribution graph, Figure 7.2. Students in the early classes reported strongly that PD Guide is easy to use; students in the later Fall 1993 class reported a statistically significant lower level of satisfaction. Students in the capstone design class reported some difficulty with using the PDG Tools, but part of this difficulty is believed to be due to the lack of instructions on those Tools at the time of their use.

Completeness. Students throughout the evaluations reported observing a "completeness" or "depth" to PD Guide. One senior student remarked that PD Guide had two seemingly contradictory qualities: "It was to the point but in depth." Several ME 553 students perceived that course contents were covered more comprehensively in PD Guide

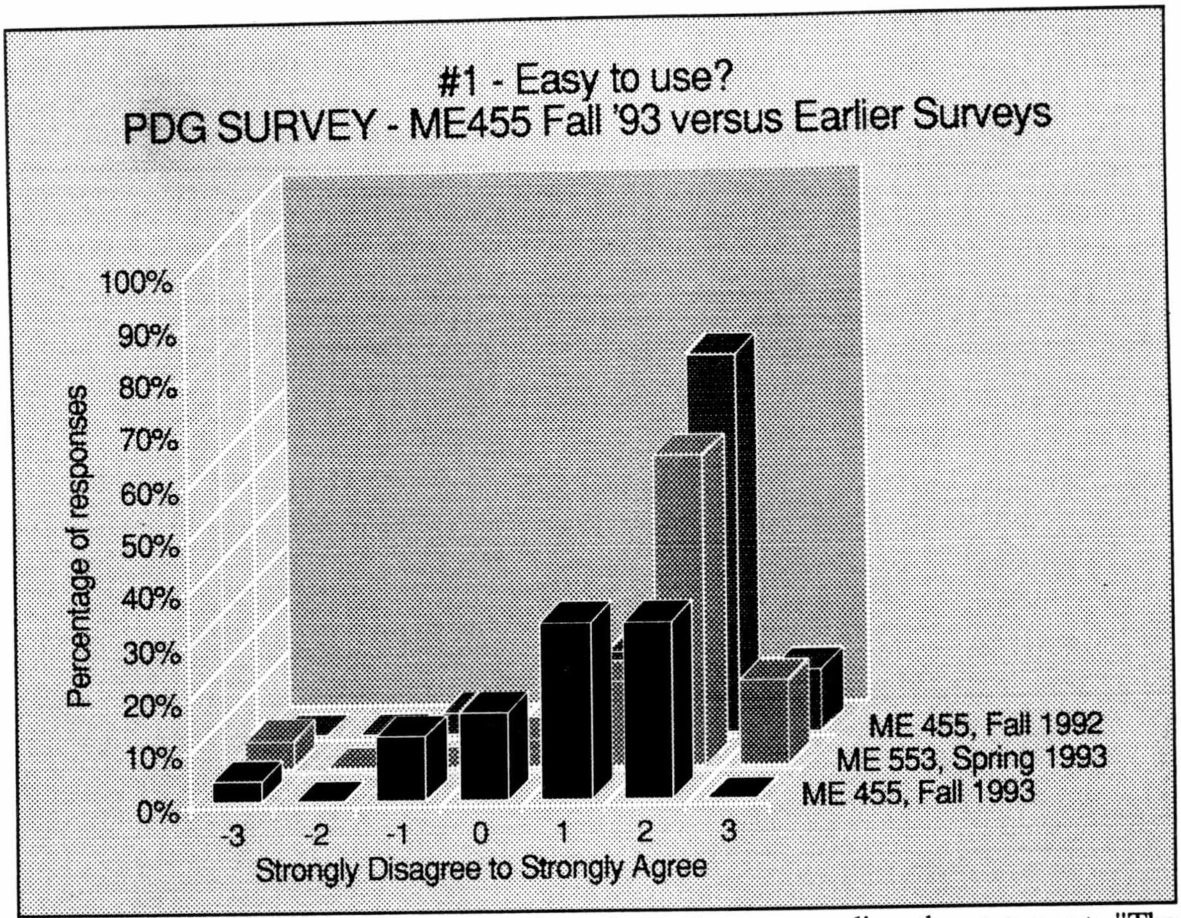


Figure 7.2: Comparison of responses from three classes regarding the statement, "The Guide was easy to use, even without a tutorial or previous training." (question #1 for all three surveys shown)

than they were (or could be) in class lectures; "in this way," one student noted, "it is a helpful supplement to the class."

When students have registered complaints about PD Guide contents or completeness, they generally claim that PD Guide is "too advanced" or "complex". A few students speculated that PD Guide information applied more to firms than to students in a design course.

Information density. Comments by students on the amount of information and how it is presented described PD Guide as "detailed", "concentrated", and sometimes "overwhelming". In the graduate course, students who eventually earned "A's" in the course reported PD Guide to be much less intimidating than did those who did not.

Other students claimed that displays are too busy and carry too much information; some suggested that these be "broken down" into less-dense multiple screens. On the other hand, some students complained that there were too many sub-menus available.

Ability to Locate Contents. Several students noted that they sometimes had difficulty figuring out "where they were" within PD Guide when they "descended" to detailed levels. Student reports of trouble finding material or identifying location have gradually increased over time, corresponding with the increasing number of available PD Guide information displays.

Adequacy of Instructions. Students adapted very well to PD Guide's operation. Results of the first two surveys clearly reported that PD Guide's instructions (even as incomplete as they were at that time) were adequate to utilize PD Guide effectively and that they had no trouble navigating through the PD Guide menus. Mean response and student comments were consistent enough that the question was not asked in later surveys.

Colors. Student users of early-developed sections of PD Guide complained about the "vast use of unpleasant colors" in those sections.

Comparison to Lecture and Text Resources

Although the surveys were not intended as proof of the educational efficacy of PD Guide, student views have often been solicited concerning the potential effectiveness of PD Guide as a supplement or replacement to regular instruction and textbooks.

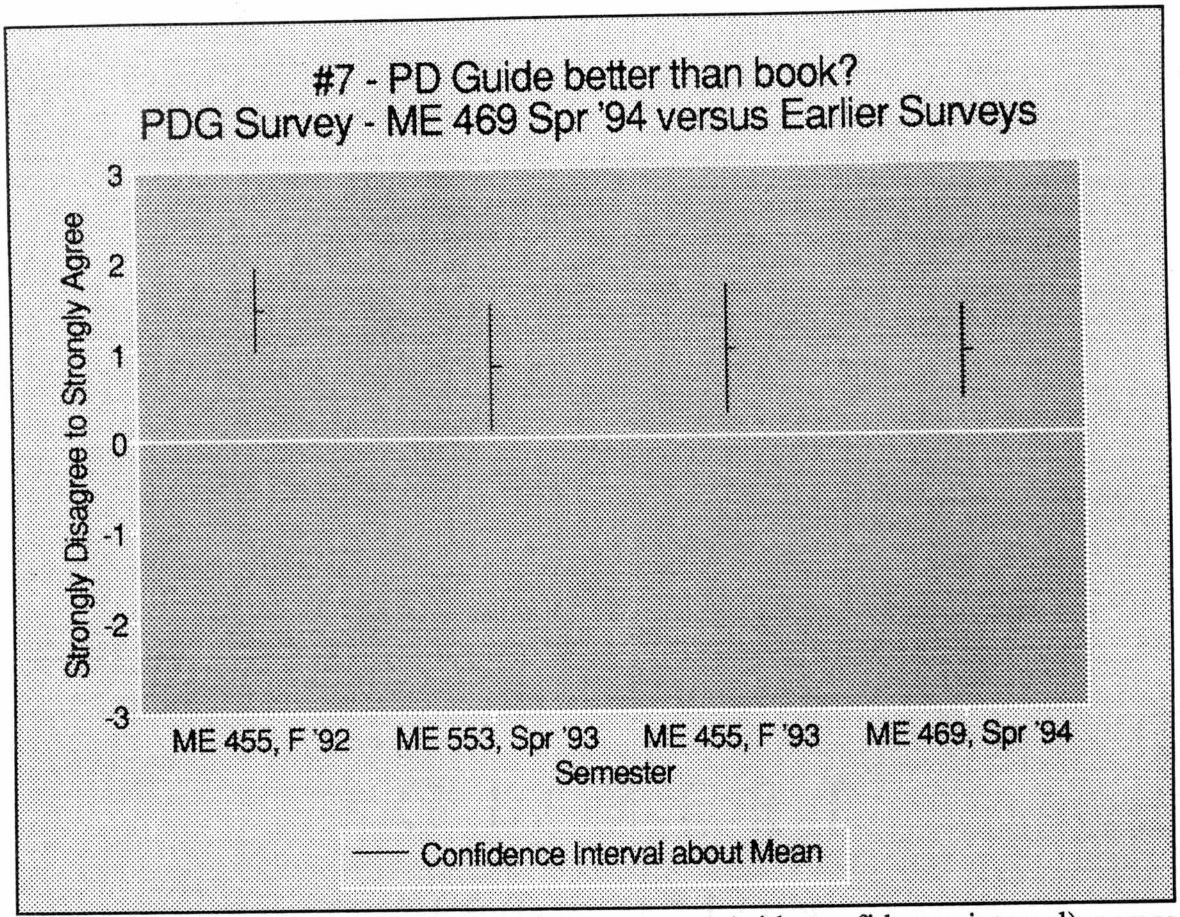


Figure 7.3: Comparison of mean student response (with confidence interval) across several surveys to a question asking students if they believe that PD Guide is better than a book. (question #7 on ME 469 survey, spring 1994)

PD Guide versus Textbook. Students have generally concluded that using PD Guide is better than finding/reading equivalent material from a book, although the strength of this opinion has changed somewhat over time, as shown in Figure 7.3. Comparison among the four classes show that the Fall 1992 response was significantly higher than those that have occurred since.

When citing PD Guide's advantages over a text, students typically comment that they see PD Guide as providing faster information access, or that PD Guide is "laid out better" than their textbook. Some students who prefer a textbook format suggested that PD Guide's contents be converted into a handbook.

Net student reaction was generally neutral to the possibility of having a software program like the PD Guide replace a textbook, although more supported the idea than opposed it. Interestingly, student response did not depend on whether the student had a computer at home. Students who preferred PD Guide to a textbook were more likely to accept its use in place of a course textbook.

PD Guide versus Lecture. When asked to compare PD Guide to equivalent class lectures on the same topic, student opinion has varied. Figure 7.4 shows the mean responses (and confidence intervals for the means) across the different classes. The first undergraduate class survey (ME 455, fall '92) indicated that students actually preferred PD Guide to a lecture, but the subsequent graduate ME 553 class came just short of being statistically in favor of the lecture. A later class was neutral.

Classes also have been generally neutral regarding which is more effective, except for the graduate course, which said that lectures are more effective. However, "A" students in that course were more likely to find PD Guide more effective than did non-A students. Part of the poor comparison of PD Guide in that course may be due more to the unique ME 553 course lectures than from any specific PD Guide inadequacy.

Use of PD Guide in Courses

Need for resource. Students in the capstone course solidly expressed a need for some type of resource to support the execution of their design project. The different

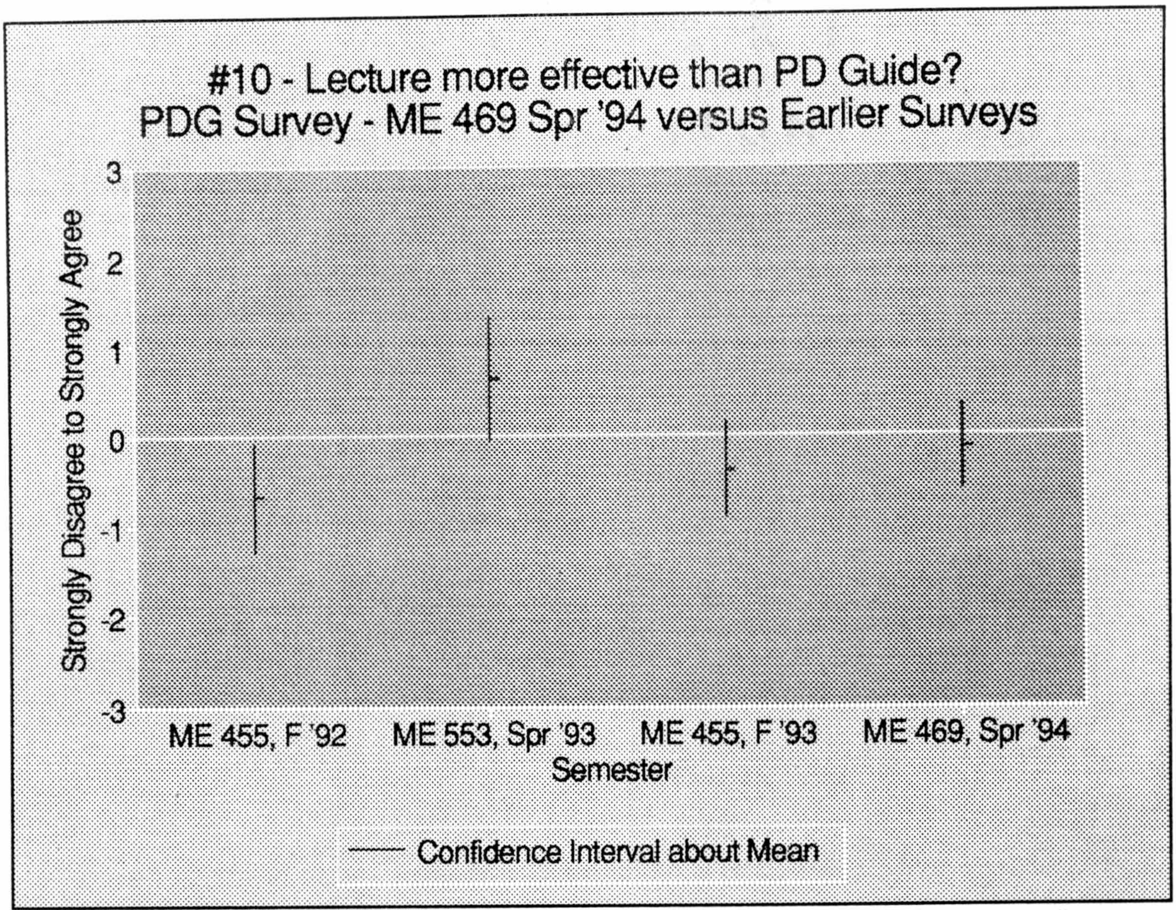


Figure 7.4: Comparison of mean student response (with confidence interval) across several surveys to a question asking students if they believe that lectures are better than using PD Guide. (question #10 on ME 469 survey, spring 1994)

reaction across course sections suggests that students' perceived need for a resource is inversely proportional to the extent of instructor interaction with the design teams.

Need for PD Guide Tutorial. Student responses were repeatedly split as to whether students should complete a tutorial before using PD Guide. Students in all sections were generally able to complete their PD Guide assignments without a tutorial, as the tutorial was completed late in the program and was not available to most students.

However, since about one-half indicated some need, an introductory tutorial section was created and is now available within PD Guide. It is believed that this tutorial should eliminate most need for an introductory lecture to PD Guide itself. However, students still appear to require some guidance from the instructor as to what the expectations are for completing various assignments.

Need for Introductory Discussion. Student response across classes has varied as to whether an introductory lecture on how to use PD Guide is needed. The first ME 455 class (fall 1992) rather indicated that one was not needed, but the subsequent graduate course said that one was indeed needed. The later ME 455 class was essentially neutral.

Role of Problem Assignments. Classes repeatedly said that completing specific problem assignments was important to their use and learning from PD Guide. How PD Guide is used in a class has a significant effect on how students perceive it. Students who completed more structured assignments tended to respond more positively to PD Guide than did students who were expected to use PD Guide as a general reference over a longer period. Students completing more-general assignments appeared more likely to need an introductory lecture, perhaps to gain a better understanding of the assignment.

Interestingly, a couple of capstone design students said that use of PD Guide and Tools in that course should be required, and not just available. At the minimum, it appears to be important to prompt students about specific PD Guide and PDG Tools capabilities at specific points throughout the term to maximize their use.

Scope/focus of use. Related to the role of problem assignments, several students also said that PD Guide was too large or "too involved" for students to use effectively, and that its size/complexity was "intimidating" and discourages its use. In response, students suggested that they would prefer that use be focused on the sections most directly related to their design project, such as the PDS and conceptual development parts.

Need for Awareness and Initial Use Before Capstone Design Course. Many students in the capstone design class said that they were unaware of many features and Tools related to PD Guide, and thus did not use them. Students also indicated that their earlier use of PD Guide and Tools in the predecessor course ME 455, "Introduction to Design", was not a large factor in their design project.

This response suggests that the introductory course has not been used as effectively as it could be to introduce PD Guide and PDG Tools. Capstone design students suggested that they had not had enough time in the capstone course to consider use of PD Guide or Tools, and would have preferred to already know how to use them before they were assigned their design project. Others saw PD Guide and PDG Tools as extra tasks for which they did not have time to consider.

Other Lessons

Importance of teams. Students in the fall 1993 and spring 1994 classes emphatically stated working in teams was important to their learning, yielding one of the highest mean scores observed in any of the surveys. Almost two-thirds of the capstone course students indicated the maximum score, and none was negative. Thus, not only have professors observed increased productivity from students working in teams, but students perceive the method as superior for learning.

Student interest in design / product development. Students enthusiastically reported that they have a much *stronger* interest in pursuing a career in design or product development than they did before taking the capstone design course. Almost half of respondents scored the question with the highest possible response; no student reported that the course had decreased his or her interest. Clearly the capstone design course is serving to increase student interest in design and product development.

Use in Professional Development Course Setting

PD Guide was used as the basis for a half-day exercise in a professional development course taught at the University of Tennessee's Management Development Center in March 1993. The 21 participants were all Brazilian professionals, whose backgrounds were roughly one-third each from industry, academia, and government. The session was led by the author.

Assignment

Participants were grouped into teams of three persons, consisting of one each from industry, academia, and government. The PD Guide was introduced and its operation explained. A product development scenario was presented: "a potential opportunity has been identified to develop a product to help persons stand after using the toilet."

Each team was commissioned to consider questions presented in the Product Ideas phase of the PD Guide and to create a "Product Concept Description" for the proposed item. Teams then briefly presented their results. Part 2 of the assignment had the teams define customer's needs and the market environment more precisely by considering factors presented in the Customer Future Need Projection phase of PD Guide. Short presentations and discussions followed. Finally, teams were asked to create an abbreviated Product Design Specification for their product using the questions shown in PD Guide. After short presentations and discussion, photographs of a working prototype product were shown and discussed.

Participant Response

Twenty (20) students provided comments about the product development exercise and PD Guide, but only 15 of those also answered the structured "poor-to-excellent" questions that were asked. (One key lesson from this experience was that questions should not be put front-back on a single page survey.)

Overall, session participants were quite enthusiastic about their experience, as shown in Table 7.2. Of the 15 participants answering the structured questions, 13 (87%) rated the effectiveness of PD Guide as either "good" or "excellent". Two-thirds (67%) ranked the value of PD Guide session as either "high" or "very high". No one in the session ranked the experience negatively.

Participants were asked to describe the most/least beneficial aspects of the exercise, and to suggest improvements. For benefits, participants noted that PD Guide and the exercise showed the wide range of considerations that must be considered in new product development. Others saw PD Guide as a "checklist" to provide structure and to assure that relevant criteria are considered. Several others said that they appreciated the

Table 7.2: Survey results from professional education session, March 1993.

Rating Item	Very Poor	Poor	Fair	Good	Excellent
Effectiveness of instructor	0	0	0	12	3
Effectiveness of PD Guide	0	0	2	11	2
Session's value to personal education	0	0	5	9	1
Overall ranking of session	0	0	3	11	1

process of considering customer needs.

The most-frequent problem noted and improvement recommendations made concerned the time allotted to complete the exercise, with most suggesting that the allotted time was inadequate and that a one-day period would be more appropriate. Other noted (correctly) that customers had never been consulted during the process and that decisions had been made without required data. Issues pertaining to PD Guide suggested that some screen displays contained too much information, and that some questions were unclear. Two participants said specifically that there was *no* "least beneficial" aspect to the exercise and the PD Guide.

CHAPTER 8

EXPERT PRACTITIONER EVALUATION OF PD GUIDE

Chapter Summary

Fourteen (14) expert industry practitioners evaluated the contents of Product Development Guide ("PD Guide"). The purpose of this evaluation was to assess the "correctness" of PD Guide's contents. Evaluators were asked to assess how well the process maps, milestone goals, and essential elements shown in PD Guide were reflective of sound product development practices. In addition to an overall assessment of PD Guide, reviewers were asked to identify concepts, items, etc. that they believed were missing and to suggest improvements.

PD Guide was well received by the reviewers, who were unanimous in recommending that PD Guide be accepted as a valid result from the product development research described in this document. Evaluators indicated that PD Guide overall was reflective of sound development practice, and represented a comprehensive effort for describing/aiding the development of a new product.

Reviewers did offer constructive criticism about PD Guide, ranging from suggested enhancements/alterations in high-level strategic focus to adding specific questions to particular information displays. The most important reviewer comments related to how important the development team is to successful product development. Along this line, reviewers recommended that the future PD Guide include additional discussion on, and guidance for, choosing and managing the development team.

PD Guide Evaluation Structure

Reviewer Qualifications/Experience

The author was fortunate to recruit a group of industrial reviewers with a wide-range of traits and experience. A combined profile of reviewer traits and experience is shown in Table 8.1.

The group includes a president of a small technology firm, a Malcolm Baldridge quality award examiner, a chief engineer for a laser printer project, an ASME Fellow, manufacturing plant manager, and many other varied and distinguished qualifications and achievements. The average experience of these reviewers exceeds 25 years. Three respondents also have significant university teaching experience, which was considered useful since PD Guide has been primarily created for use in engineering design courses. As with PD Guide, the experiences of these reviewers extend from the product idea through to manufacture, product delivery, and use by the customer. Table 8.2 provides abbreviated general profiles of these PD Guide reviewers.

PD Guide Evaluation Process

Each reviewer was sent a "PD Guide review package" from which to conduct the review. The package consisted of PD Guide materials, PDG Tools materials, and

Table 8.1: Combined Characteristics of PD Guide Reviewers.

Characteristic	Quantity (and/or Percent)
Total number of reviewers:	13*
Professional Experience (average)	27.4 yrs
Of above, Industrial Experience (avg, and % of average total)	24.2 yrs (88%)
Number holding P.E.	6 (46%)
Academic Degrees Attained:	
BS - Engineering	13 (100%)
MS - Engineering	9 (69%)
Ph.D. - Engineering	5 (38%)
MBA	1 (7%)
Other	2 (15%)

* One additional reviewer performed a special assessment of one PD Guide section.

Table 8.2: Abbreviated profiles of PD Guide expert reviewers.

Reviewer Name and Experience (total/industry)	Expertise / Career Highlights
Thomas D. Abbott (30/30 yrs)	BS, MS (ME); Director, StorageTek Card Operations; 20 years in product management, including printer, optical disk, data storage; manufacturing.
C. Wesley Allen (36/29 yrs)	BS, MS, PhD (ME); P.E.; Concurrent engineering consultant; visiting professor in design; former manager of technical education at IBM.
Jerry Beck (21/21 yrs)	BS (IE); Plant Manager at Square D, Asheville; former plant manager at Raleigh; manufacturing, product and industrial engineering experience.
Robert L. Burdick (32/32 yrs)	BS, MS (ME); Senior Technical Member, Lexmark Int'l; chief engineer for Lexmark 4037 laser printer; copier, printer, and typewriter development.
Rudolph J. Eggert (24/18 yrs)	BA, MBA; BS, MS, and PhD (ME); P.E.; Design project professor at Union College; formerly project engineer/manager at GE, NYS Energy & others.
Steven Foster (17/17 yrs)	BS (ME); Mechanical design leader for Lexmark laser printer development; conceptual design/test for typewriters, ATM's, and desktop printers.
Rod Heard (34/27 yrs)	BA, BS, MS (EE); P.E.; U. of Kentucky extension engineer, helps KY firms with manufacturing; former product manager for IBM office products.
H. Lee Martin (15/15 yrs)	BS, MS, PhD (ME); P.E.; President of an electronics, robotics & software firm; NSPE Young Engineer of Year (1988).
Ron Randall (23/23 yrs)	BS (ME); P.E.; Texas Instruments Defense Systems Total Quality Management Team member; Baldrige examiner, Certified Quality Engineer.
Ronald L. Roof (27/27 yrs)	BS (EE); Now manager of electronics advanced manufacturing, design-mfg. transition, process technology at Square D; circuit design, program mgmt., and operations.
E. Dawson Ward (26/17 yrs)	BS, MS, PhD (ME); Senior engineer for print technology at Lexmark; team leader for printer subsystems; technology manager for numerous projects.
John W. Wesner (36/29 yrs)	BS, MS, PhD (ME); P.E.; Technical manager, Design Quality R&D, for AT&T; product design manager, ASME Fellow, former chair of ASME Design division.
Al Wittwer (35/28 yrs)	BS, MS (ME); U. of Kentucky extension engineer for "lean manufacturing", coordinates UK student design projects; IBM office product automation/production development.

NOTE: David A. Walker (BS, MS), reliability engineer for JBF Associates, Inc., performed a special assessment of the Failure Mode and Effects Analysis section.

survey/response materials. The PD Guide materials consisted of the PD Guide software diskette and operating instructions for its use. The PDG Tools materials consisted of not only the diskette containing the tools, but also of an assembly of "printouts" that result from using these tools. The printouts were included because it was recognized that many reviewers might not have the software needed (or enough time) to run the PDG Tools, but would want to review their contents.

The review-related materials consisted of a cover letter, general review instructions, specific "focus area" instructions, and a survey. The cover letter explained the objectives of the review, namely that of verifying the appropriateness of PD Guide contents and its applicability to design education.

The "general" instructions asked all reviewers to review some general features of PD Guide, including the tutorial, the overall product development process, and the "top-level" items for each individual phase (process maps, milestone goals, and essential elements.) The objective of this part of the review was to have the reviewers assess the broad results/conclusions from the research, as reflected in PD Guide. It also serves to acquaint the reviewers with PD Guide's broad spectrum of contents.

As noted in Chapter 5, PD Guide is quite large, containing about 1400 information displays. Thus, it was not feasible to have reviewers evaluate the entire contents of PD Guide. Instead, reviewers were asked to assess an "area of focus" in more detail. These "focus areas" were different for each reviewer, to attain the widest possible review of PD Guide contents and to take advantage of the varied experiences of the reviewers.

PD Guide Review Survey

After their review, evaluators answered a structured survey regarding their impressions of what they had observed in PD Guide. The five-page document asked reviewers a variety of questions pertaining to their review, and included both "scaled" questions and short-answer inquiries.

The critical portion of this survey was the "comments" section, which is shown in Figure 8.1. These inquiries were structured to prompt reviewers to address what was considered to be the key items for assessment: PD Guide's "match" with "good" product development fundamentals, an overall evaluation of PD Guide in terms of its reflection of good practice (and as an accurate result of this research program), identification of key problems, and suggestions for improvement.

Evaluator's Response to Survey

A side effect of choosing excellent reviewers is that they are in "high demand" - that is, they draw significant, time-consuming assignments in their jobs. Understanding that reviewer's time is at a premium, the reviewers were given wide discretion as to how they approached the review.

As a result, there was some variation in the responses received, which make it more difficult to present a uniform survey result, although the variety of approaches taken may indeed have strengthened the quality of the evaluation itself. For example, some reviewers took a broad approach with their review and comments, looking for and evaluating certain overall themes throughout PD Guide. Others evaluated their sections

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<u>**Overall Assessment/Comments:**</u> Please provide your overall opinion of PD Guide. Responses may address both/either the overall layout of PD Guide and/or the specific sections that you reviewed, as appropriate.

Please use a separate sheet for your responses.

1. **Product Development Fundamentals:** Assess the "match" (or lack of it) between the contents of PD Guide and what you believe are the major tenets for achieving successful product development. Does PD Guide contain what engineering students most need to know about product development?

2. **KEY Problems:** Describe any important criticisms that you have of PD Guide, including:

   - Major Disagreements - any area in which you have serious philosophical, operational, or tactical disagreement with what is presented in PD Guide (please try to be specific);
   - Missing or poor development of critical concepts, inadequate coverage of topic, etc.;
   - Errors (misunderstood questions, operational errors, etc.)

3. **OVERALL Assessment:** Describe your overall "grade" of PD Guide, in terms of :

   - it being reflective of, and consistent with, competitive product development practices;
   - using the contents of PD Guide to teach product development to engineering students (undergraduate, graduate, and/or professional development);
   - whether my dissertation committee should (or should not) approve PD Guide as a valid result from my research in competitive product development.

4. **Improvements/Suggestions:** Please provide any input that you have regarding:

   - ways to increase the "match" between PD Guide and most-competitive practices;
   - incorporating any "new" product development issues that are becoming increasingly important to the competitiveness of your firm;

Figure 8.1: Comments portion of Industry Expert Review Survey.

to great detail, going so far as to making comments on "print screen" copies of the information displays.

As a result of this variation, however, not all reviewers completed the "general review" portion in the same way. Because of this, some reviewers did not (could not) answer all of the agree-disagree questions and the questions pertaining to the milestone goals and essential elements. Thus, conclusions made from these statistics do not always reflect the views of the entire reviewer panel (obviously, it can only include the opinions of those that answered the given questions). This is not meant to suggest, however, that results are any less valid; indeed, the biggest ramification of this event is just that response statistics do not always add up to the total number of reviewers.

Overall Assessment

As is shown in Figure 8.1, reviewers were asked to provide comments regarding significant aspects of PD Guide. This section summarizes those comments; a more-extensive sampling of industry reviewer response is provided in Appendix R.

Reflective of Competitive Practices

- *PD Guide "matches" major tenets.* Reviewers generally found PD Guide to be well matched with what they believe to be the major tenets of product development. Comments among those reviewers who explained their view included:

> "The guide is comprehensive and thorough, very well done. All the major elements of product development are adequately covered. There are no major omissions that I could see." [Abbott]
>
> "An excellent comprehensive piece of work - a massive effort. ... An excellent compilation of what it takes to develop/deliver an outstanding product." [Ward]

Consistent with existing, competitive practices. Reviewers were asked to "grade" PD Guide in terms of it being consistent with competitive, industrial practices, such as those used in their firm or with others of which they were aware. Overall, reviewers concluded that PD Guide ...

- "embodies much of the current practices of leading product developers" [Foster]
- "is consistent with and ahead (of competitive practice) in many areas" [Burdick]
- "captures well (overall) the processes needed to develop competitive products" [Heard]
- "(is) consistent with modern design practice at (his firm)." [Randall]

Reviewer Abbott noted that he has found "the overall quality of the guide to be excellent." Reviewer Wittwer suggested that one reason why PD Guide is consistent with competitive practice is that it "contains the bulk of the essential elements related to being competitive." Reviewer Eggert expanded on this aspect of PD Guide:

"(PD Guide) is the most comprehensive and real-life tool for product development that I have *ever* seen. Many texts or articles describe specific phases well. But none tie together the whole process with a unified language and methodology like (PD Guide). (PD Guide) is a contribution to the state of knowledge because it unifies, and interrelates the development process in a comprehensive and user-friendly fashion."

Dissertation accuracy assessment. One role of the expert review was to assess the quality and accuracy of the results presented in terms of its use in this graduate research effort. Since product development is performed in industry by industrial practitioners, it was considered desirable to have an "outside review" (that is, outside of, and in addition to, the traditional academic review). Reviewers were unanimous in saying that they believed PD Guide's contents are valid as dissertation-level material (it should be noted that 5 of the reviewers have engineering Ph.D.'s - reviewers Allen, Eggert, Martin, Ward, Wesner). Reviewer Heard's comments captures the general consensus of the group very well: "Overall, I believe the guide to be a valid research result which will be useful for a variety of teaching and reference purposes."

Consistent/Appropriate for Education

Contents appropriate/accurate for teaching product development. PD Guide contents were described as accurate and appropriate for use in design education:

- "... is an excellent teaching tool for students of product design and development." [Foster]

- "... should be an excellent teaching tool" [Burdick]
- "the level of detail is well suited for an engineering student, or for students in other fields as well" [Abbott]

Reviewer Eggert, who currently teaches design courses at Union College, concludes that:

> "Pedagogically, PDG will make a *major contribution* to undergraduate and graduate engineering education. Its multiple menus can be explored individually or comprehensively as in a specific product development assignment, required in a course." [Eggert]

Factors Affecting Use in Education. Two reviewers noted factors that they believe are important for PD Guide to be used the most effectively in education:

> "I believe that the most effective use of the guide is in a teaching environment where the pace can be controlled to focus on individual sections and where additional materials (such as case studies and class discussion) can be introduced to support it. It is well suited for this purpose. The structure does not lend itself well to a "cover-to-cover" read ..." [Heard]

> "(PD Guide) needs to be taught with case studies, and there are many that could be used to bring out the points in the guide. And hands-on simulation, and real industry student project work." [Wittwer]

Reviewer Wittwer, who now works with senior design projects at the University of Kentucky, also noted that the mind often works in parallel, meaning that many different aspects of a problem are considered in an "intuitive process." He sees PD

Guide's role as one for bringing "to light the critical processes or problems in short order," to shorten the "apprenticeship" period that students need to understand the process.

Limitations / Cautions. Reviewer Ward suggests that PD Guide is so thorough that it could "overwhelm" students if it is not used somewhat carefully. He also cautioned that experienced reviewers in general, and himself in particular, may not be the best persons to assess how well PD Guide can help a novice student because it is difficult to recognize how much one has learned that a novice does not know. On the other end of the spectrum, while assessing PD Guide as good for university educational purposes, reviewer Martin suggests that it "needs more concrete direction to be useful for professionals." Dr. Martin also suggested that PD Guide may impart "a bit too much of a scientific feel", which discounts the amount of intuition and risk involved in the development process.

Numerical Response Assessment

The compiled reviewer response to the agree-disagree questions that were asked about the general features of PD Guide are shown in Table 8.3. As noted earlier, not all reviewers answered all questions, so that the total response does not necessarily add up to the total number of reviewers. The questions were presented in terms of statements, with which reviewers indicated various levels of agreement or disagreement on a -3 (strongly disagree) to +3 (strongly agree) scale. As per good survey practice, some statements were phrased negatively, so that "plus" numbers are not always better.

Table 8.3: Industry expert assessment of "general" features of PD Guide.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Frequency Summary of Responses						
	-3	-2	-1	0	+1	+2	+3
1. PD Guide's "home" menu and "top-level" process maps provide an appropriate framework for explaining the product development process.	0	0	0	0	1	6	4
2. The PD Guide "top-level" charts provide an *accurate* description of the product development process.	0	0	0	0	1	8	2
3. In the tutorial, the item order should be "reversed", so that the "viewpoints" (the three-color tracks) are explained before describing the contents of each phase.	1	1	0	3	1	2	2
4. The PD Guide tutorial *fails* to provide an *adequate* summary of the product development process.	4	6	0	0	0	0	0

Consistent with their written comments, reviewers' numerical scores for the "general features" of PD Guide indicate that PD Guide does provide an appropriate and accurate framework for the product development process (questions #1 and #2 in Table 8.3). After reviewing their specific "areas of focus", reviewers again were asked for their (now more-detailed) assessment of PD Guide's contents (Table 8.4). In general, reviewers concluded that their sections identify the critical tasks involved in that section and present sound approaches for completing those sections. Reviewers also said that the "quality" of the sections that they reviewed are of the same comparable level.

Reviewers were also asked to assess how well the Milestone Goals and Essential Elements for each phase capture the key objectives and "critical few" factors most affecting success for that phase. These results are shown in Table 8.5, and indicate overall that the reviewers find these items good for summarizing the critical factors affecting the development of a new product.

Tutorial

As indicated by the reviewer composite response (question #4, Table 8.3), reviewers also concluded that the PD Guide Tutorial provides an adequate summary of the overall product development process. Reviewers were essentially split in their opinion about the order of items in the tutorial, although more believed that the overall "viewpoint" should be presented before the description of each phase (question #3, Table 8.3).

Table 8.5: Expert reviewer assessment of phase Milestone Goals and Essential Elements.

NUMBERS AT RIGHT: (0 = Key Objectives *Not* Captured) to (+4 = *Well* Captured) PHASE	Milestone Goals					Essential Elements				
	0	1	2	3	4	0	1	2	3	4
PDG "Home Menu"/Elements	1	0	2	3	2	0	0	0	5	3
Product Ideas	0	0	0	3	4	0	0	0	5	2
Customer Future Needs Projection	0	0	0	1	6	0	0	2	2	3
Technology Selection and Development	0	0	0	4	4	0	0	1	1	6
Final Product Definition and Project Targets	0	0	1	2	4	0	0	1	2	4
Marketing and Distribution Preparation	0	0	0	5	2	-	-	-	-	-
Product Design and Evaluation	0	0	0	3	4	0	0	1	1	5
Manufacturing System Design	0	0	1	4	2	0	0	1	3	3
Manufacturing, Delivery and Use	0	0	0	3	4	0	0	1	2	4

After completing the tutorial, reviewers were asked if any concepts were lacking in the tutorial that they believed were needed. In general, reviewers rated the tutorial as relatively complete, with one reviewer commenting that there were no omissions [Randall] and another describing the tutorial as "painfully complete" [Ward].

The most significant omission mentioned by reviewers was neglecting to discuss the importance of the team and building team relations as part of the process [Beck, Wittwer] (this topic is discussed additionally in "Areas of Criticism", below). Two other suggestions were to mention the importance of design reviews [Eggert] and to note the increasing need to consider the environment when designing manufacturing systems [Wittwer]. A suggestion for the tutorial was to provide a method for experienced users to "skip" or to complete an abbreviated version of the tutorial [Ward].

Areas of Criticism

While the industrial reviewers found PD Guide to be generally reflective of good product development practice, reviewers provided significant constructive criticism as to what they saw as current problems in PD Guide and also offered advice as to how to make PD Guide better.

In general, reviewers noted that their criticisms were made in the spirit of "continuous improvement", and were not meant to suggest that the overall contents of PD Guide were seriously inadequate. Several commented specifically that they had found no section to be "poor". The comments made by Mr. Abbott and Mr. Burdick are reflective of this position:

> "The overall thoroughness of the guide is outstanding. My critical comments are meant to serve as minor observations, not major problems." [Abbott]

> "I did not find any areas I would rate poor. My feedback is, in general, not in disagreement with the PD Guide but in most cases additional building on what was already there." [Burdick]

Teams and Team Management

The most mentioned and most significant issue is a need to incorporate more information and advice on creating and managing the development team. This issue is indeed very important, for the case study research indicates that the single development team may be the most important "essential element" in product development. Other writings arising from this research reflect this position [for example: Wilson, Kennedy, and Trammell, 1994; Wilson and Kennedy, 1989a]. The single team is defined on the "essential elements display" for the overall process. The reviewers also noted the team's importance; for example ...

> "But to be successful, the "softer" side of teams, team development, common goal, common purpose are critical. The answers to the questions and criteria (in PD Guide) are a function of who answers them." [Randall]

The problem is not that a team is recommended, but rather that very little guidance has been provided to create and manage the team itself. The team is so important to the process that, in retrospect, it indeed has in part been "assumed" throughout the process, without much explicit attention. While saying that he thought the coverage of teams in PD Guide "is more than adequate for students," Mr. Abbott does state that:

> "My most significant observation relates to the treatment of team formation and performance. ... successful teams share many common characteristics, and that the formation and nurturing of these teams is a critical success factor. Many of the individual factors are covered in the guide. Overall treatment of the subject is missing."

According to the reviewers, important topics to cover in this respect would include: selection of team members [Wittwer]; learning to build team consensus [Randall]; interpersonal team relations and how to deal with conflicts [Beck]; employee education and training [Wittwer]; and allocating time for team-related training [Beck].

Converting Customer Needs into Specifications

Another general area for comment relates to the process of taking "customer needs" and converting them into "target values" and/or "functional specifications". Reviewers Ward and Mason made comments suggesting that there is a need to provide a more specific approach for converting identified needs into target values, such as the use of Quality Function Deployment ("QFD") or other mechanism.

The concept of QFD is mentioned in the Customer Future Needs Projection (CFNP) phase, but Dr. Ward suggests that its function/method should be more highly emphasized in general and also noted in more locations throughout that phase. Reviewer Mason suggests that the "voice of the customer" and the QFD tools need mention further back in the process, in the Product Ideas phase [Mason - phone conversation]. Dr.

Wesner suggested that the QFD results should then "tie in" to the Product Design Specification section in the Product Design and Evaluation phase.

Dr. Ward also noted an inconsistency within the CFNP phase, in that PD Guide is "not consistent in stating whether the customer *can or can not* give a detailed target value for product characteristics. I would argue that they cannot." He proposes that the more-consistent approach is to:

> "'soft gather' customer needs (why they need this) rather than have engineers speculate and ask specific questions. Warn your students (that) "you do *not* think like your customer." Seek to understand your customer, then translate their personal needs into benefits your product can deliver. Finally test those benefits with target customers." [Ward]

"Fundamental Function" Design

Reviewers Burdick and Foster identified a need for additional emphasis on the creation/use of "fundamental function" layouts and machine/subsystem/part datums. Mr. Burdick states,

> "The areas I have most interest in is the introduction of fundamental function and datum dimensioning thinking. These topics are referenced in the PD Guide, but I would like to see them given more emphasis since I believe they can have a *major* impact on arriving at a 'world class' design process." [Burdick]

While the details of these concepts are beyond the scope of this discussion, it is noteworthy that these reviewers both drafted significant letters on these subjects for additional explanation. They also made handwritten comments on information display "printouts" where they believed that the concepts could/should be invoked.

The use of machine and parts datums is highly related to the "functional layout" concept. Mr. Foster addressed the topic of adding emphasis on the use of datums in the design:

> "I believe that much more emphasis on the establishment and use of datum systems is warranted in the parts design section. ... This provides a geometric framework on which truly superior designs can be built. Although it takes significant work to create this framework, the robustness and reduction in variability more than justify the effort. I do not consider this section 'poor' - I just believe it would be improved by adding more emphasis as described above." [Foster]

References to Standard Tools, "Outside" Sources, and "How To" Help

Several reviewers noted that, while PD Guide generally presented the "right questions" for consideration at various points in the process, it did not always provide enough to determine the answers [Martin, Randall, Abbott]. One good way to provide this information would be to increase the use of "calls" to standard references and tools. For a technique, a book or other reference could be suggested for advice on performing it; for tools, PD Guide could discuss the use of "standard" tools, such as project management software [Beck, Roof].

Economics / Costs Focus

Several reviewers made comments regarding the "economics" part of product development. Dr. Martin, for example, sees an objective to "broaden, awaken more business reality in the engineer" as a major role for PD Guide. Mr. Heard, whose "focus assignment" was to review the Business Targets section in the Final Product Definition phase, identified a number of potential improvements for that section. Mr. Roof evaluated many of the financial PDG Tools and made several suggestions for improving them.

The most significant items noted by these reviewers are targeted to completing the overall financial picture for the product. In addition to the tool for parts cost, an additional tool was suggested for assessing overall product cost. Mr. Roof made some suggestions regarding the parts costs and profit worksheet to add some additional "fixed" costs categories. Mr. Heard identified a "timing" problem regarding the use of product cost estimating, and suggested its repeated use throughout several phases of development, instead of the one location at present. Mr. Roof noted that, while one PDG Tool translates the proposed product price to the manufacturer's price, it needs to go further and translate the manufacturer's price into target costs. Dr. Wesner described the price-price table as "clever", and noted that this step is often hidden from engineers because it has already been done (by marketing) by the time the engineer obtains the cost target.

Among the numerous other specific recommendations by Mr. Heard include a more explicit treatment of ROI and ROA, possible addition of cash analysis ("out-of-pocket" analysis) to the financial evaluations, and some discussion of how to evaluate the impact of a new product on existing products. Finally, Mr. Heard indicated that PD Guide needs to reemphasize the point that ...

> "there are some things that *must* be done in order to stay in business. An example might be modernizing an obsolete production facility, even though the quantifiable benefits over the evaluation period may not show positive returns. This is a risk that *must* be taken anyway." [Heard]

Other Overall Concepts

Building on Existing Knowledge/Designs. Reviewers Burdick and Martin both commented on the need to emphasize (repeatedly) the usefulness of selecting existing technologies, modules, components, etc. Mr. Burdick provided comments on several screen printouts in the Design phase suggesting locations where the concept might deserve mention. Dr. Martin noted that use of existing knowledge through subcontracting choices can be both useful and economical, so long as the core capabilities for the product are retained.

Large firm orientation. Mr. Heard noted that portions of PD Guide are oriented towards the perspective of larger firms with multiple product lines, and that those contents are not generally applicable to a small firm (and, by extension, to a student design team). However, it is these firms which are most likely to have their own defined processes, so that the utility of PD Guide in these cases would be limited to that of supplemental checklist or reference.

PDG Tools Evaluation

Reviewers Beck and Roof evaluated many of the PDG Tools and provided useful comments regarding their format and structure. One of their more global suggestions is that commercially-available project management software would be a better choice than the use of the Lotus spreadsheet currently used. They suggested that the "project management" features of the commercial software are important aspects of making/altering a project schedule.

Along with Mr. Heard, Mr. Beck and Mr. Roof suggested several alterations to the financial tools (some of these are discussed in the "Economics" section above).

Dr. Ward reported (an already realized) problem with the currently provided PDG Tools - he did not have access to the commercial software packages needed to run them. Along this line, Mr. Abbott suggested that these tools need to be made available for Microsoft applications.

Problems in Operation/Presentation

In addition to his efforts in the Business Targets section, Mr. Heard also carefully considered the operation/presentation of PD Guide itself. He noted problems in 3 basic areas: (1) problems in identifying priorities; (2) "vision" of a section; and (3) lack of "navigation aids".

The priority problem occurs because of the way items are presented; particularly when there are a large number of items, each appear to be of equal importance. Need for navigation aids arise "to avoid getting lost and to help access a specific area." The desire to observe an entire subsection at once led Mr. Heard to run multiple copies of PD Guide through the MS Windows operating system.

Specific Criticisms/Errata

Reviewers of specific sections often contributed suggestions about how to improve that section. In the Manufacturing System Design phase, for example, Mr. Wittwer suggested that some areas for future incorporation would include addressing environmental needs in manufacturing (such as state permits/approvals), scale up plans for production, and the request for specific backup plan for critical components. Many reviewers offered comments of a similar type about issues related to their specific sections.

Reviewers also indicated a few problems with selections failing to function (number selection fails to call next display), spotted some spelling and duplicate word errors, and made suggestions for improving some specific display text. These comments are useful for improving PD Guide's operation and readability, but do not merit detailed description here.

Future Areas for Improvement

As Mr. Wittwer indicated, "There's always room for improvement." Many of the suggested improvements correlate with reducing or eliminating the weaknesses or discrepancies described above. However, reviewers also provided some ideas for some other areas of focus and tools that may well deserve attention in future improvements to the product development process and the PD Guide.

Mr. Abbott called attention to an effort that his firm is pursuing called "process train engineering," which is targeted to reducing cycle time to market. He and others also noted significant efforts to understand the phenomenon of team building and team management.

Mr. Randall noted that his firm is now assessing "manufacturability prior to production in a quantitative way." The technique combines information on process capability, part requirements, and system performance variation to estimate the defect rate in manufacturing. He suggests that the underlying principles of the approach could be presented to students with a spreadsheet that listed requirements, capabilities, and summed failure probabilities to get the expected number of defects per unit.

Dr. Eggert suggested that sections could include the increasingly important issue of "green" design. The environment, energy, hazard materials, and scarce resources are being factored into more and more product designs.

CHAPTER 9

CONCLUSIONS AND FUTURE DIRECTIONS

Chapter Summary

Product Development Guide was well received both by students and by a distinguished group of industrial reviewers. The industrial reviewers were unanimous in recommending PD Guide as a valid result from product development research. Students indicated that PD Guide is generally easy to use, and that it helped them learn about product development. PD Guide provides a resource for the senior capstone design, an expressed need of both students and of design course professors.

As would be expected for any undertaking, some "continuous improvements" have been identified for enhancing the presentation, usefulness, and quality of PD Guide. Improvements to PD Guide content, information display layouts, and access features are proposed. Implementation of these improvements in future versions would enhance PD Guide's utility.

Overall Achievements versus Objectives

As described in Chapter 3, the basic goals for this effort can be divided into two major areas: objectives for the development process and objectives for communicating the process. The objectives set out in that chapter have been largely met.

Development Process

The first major objective was to identify industry-based processes/tasks/practices used in the development of innovative products, then to utilize this information to create/provide a product development structure that establishes a consistent and professional product engineering framework. This process is communicated through the use of PD Guide.

The author was fortunate to recruit a distinguished group of industrial reviewers to evaluate the contents of PD Guide. PD Guide was well received by these reviewers, who were unanimous in recommending that PD Guide be accepted as a valid result from the product development research. Evaluators indicated that the contents overall were reflective of sound practice, and represented a comprehensive effort for describing/aiding the development of a new product. Per objectives, the process is also interdisciplinary, reflecting product, manufacturing, and customer viewpoints. Both industry and student reviews suggest that the product development process (as shown in PD Guide) meet most, if not all, of the SEED criteria for a design process listed in Chapter 5.

Vehicle - "Product Development Guide"

The second "half" of the project objective is to provide a "vehicle" for communicating the product development process principles - in this case, the "Product Development Guide". As noted above, the expert reviewers agreed that PD Guide does provide a broad interdisciplinary perspective to students, and successfully introduces some industry "best practices" into the traditional academic program.

In general, students generally found PD Guide easy to use and to be a worthwhile experience. Responses suggest that students find value in PD Guide and PDG Tools, once they can be convinced to use them. Students generally said that PD Guide is a good method for communicating the material contained within it and did indicate that they thought that PD Guide *can* be used successfully to help student teams complete their design projects.

PD Guide serves as an "always-available" resource for teaching the overall development process. The PDG Tools, in particular, have been useful in enhancing the ability of students to perform product development activities. Students learn through actual product development experiences how to apply the methods presented in design courses and in PD Guide, thus supporting ABET objectives for students to have a significant design experience.

Key Benefits Achieved

Resource for Design Courses

Need for resource. Students in the capstone course solidly expressed a need for some type of resource to support the execution of their design project. As noted in Chapter 5, design faculty in their writings have expressed interest in finding an appropriate reference for use in their capstone design courses. The experience at The University of Tennessee suggests that PD Guide is a viable candidate for meeting this need.

PD Guide versus Textbook and Lecture. Students have generally concluded that using PD Guide is better than finding/reading equivalent material from a book, although the strength of this opinion has varied. Students cite PD Guide's advantages as providing faster information access, or being "laid out better" than their textbook. Some students who prefer a textbook format suggested that PD Guide's contents be converted into book (contents of PD Guide have been adapted in the upcoming book by Wilson, Kennedy and Trammell, [1994]). Students were generally neutral when asked if PD Guide could replace a textbook, although more supported the idea than opposed it. When comparing PD Guide to equivalent class lectures on the same topic, students have been generally (although somewhat erratically) neutral.

Professional Structure Successfully Provided

In addition to specific process maps, PD Guide uses other characteristics to help students structure their design effort. Firstly, PD Guide's format itself provides scheduling guidance, by suggesting (through order of presentation, when questions are asked, etc.) what activities need to be completed first. Secondly, the "critical questions" and "essential elements" promote order by invoking significant development concepts, such as freezing the product definition before beginning detailed design activities.

Product Development Guide provides students with a broad perspective of the entire product development process, and helps students understand how specific design techniques and activities "fit in" within that process. Structure extends to the design tools, called PDG Tools, which incorporate professional practice and helps students achieve more consistent results. These also help the design course professor by providing common formats for simpler review.

Detailed Platform for Discussion

One unanticipated benefit of PD Guide that was only realized during analysis of the expert practitioner review is that the significant detail within PD Guide facilitated a very-precise discussion about product development. For example, reviews by Burdick and Foster (see Chapter 8) triggered a significant discussion about the role of functional layouts and datums throughout the design process. In their assessment, they actually made printouts of specific information displays and wrote comments where they believed attention needed to be paid to these concepts. These very-precise comments (precise in both detail of task and in its timing) might not have been extracted as easily from "normal" case study interviews.

In this way, PD Guide appears to be a good method for extracting details concerning the actual *implementation* of important concepts, in addition to the concepts themselves. In some cases, the information extracted from the review is more focused than the information extracted in the case studies. One unintended use of PD Guide may be as another tool to collect case study information and expert opinion about specific aspects of the product development process.

Comparison to Other Models and Research Results

Formation of the product development process model described in Chapter 4 and in PD Guide began in 1988, and has resulted in the publication of several papers, the first of which was presented in December 1989 [Wilson and Kennedy, 1989a,b]. Information gathering and assessment continued repeatedly throughout the completion of Product Development Guide in May 1994. During this development period, other research organizations have reported their findings concerning the product development process [NRC, 1991; Dertouzos *et al.*, 1989; etc.].

As these other studies reported, their results were compared to the product development model presented in this work, to evaluate their common features, to look for useful additions or detail in both the product development model and PD Guide. These assessments were done because one fundamental premise of this work has been that product development processes should take advantage of lessons/shortcomings identified from other research efforts and to utilize their solutions whenever possible. In terms of the current research effort, the problems/results from these other studies have been used both as an information source for creating the process model and as a "benchmark" for assessing the "goodness" of the process model.

Table 9.1 has been constructed to illustrate a "post-development" comparison of the product development model shown in the PD Guide versus key criteria for the product development process that was produced from the National Research Council study [NRC, 1991, p.2,18]. The key evaluation of the "accuracy" of PD Guide is considered to be the industry practitioner review described in Chapter 8; still, it is interesting to note how

Table 9.1: Comparison of Product Development Process to process criteria developed from a National Research Council study.

NRC Criteria/Items	How Reflected in PD Guide
Definition of customer needs and product performance requirements (firm definition of needs, competitive benchmarks, verify technology available).	Customer Future Needs Projection phase contains section on benchmarking, asks questions to help define needs; purpose of Technology Selection and Development phase is to investigate/assure technologies.
Plan for product evolution beyond the current design.	Final Product Definition phase calls for "base-derivative" product plan.
Planning design and manufacturing concurrently (Cross-functional, project manufacturing systems, begin training).	Product Design and Eval. phase and Mfg. System Design phase concurrent; multiple references in each phase to items in other; "Interact with Product Design" section in Mfg. System Design.
Product design (by cross-functional teams, for minimal performance variation in varying environment, simplification, standardization, with attention to product interfaces and manufacturing)	Essential element for development by an interdisciplinary team; Product Design and Evaluation phase contents on building design margin, simplifying and standardizing design, modularization (addressing interfaces), and Design for Assembly and Manufacturing.
Design product and its manufacturing processes with full consideration of the entire life cycle, including distribution, support, maintenance, recycling, and disposal; design factory for minimum inventory and high flexibility)	Product Design Specification module calls for definition of product life needs; Market and Dist. Preparation phase relates preparation of support activities; Mfg. System Design includes sections on reducing inventory and process flexibility.
Manufacturing process design (establish fabrication, assembly, test needs; analyze tolerances, estimate costs, identify production methods, factory layout, study mfg. capability, define process control needs, production plan / logistics)	Items covered in sections throughout Manufacturing System Design phase.
Production of product and monitoring of product/processes (statistical process control, feedback to design and manufacturing processes and follow-on product planning)	Manufacturing, Delivery and Use phase: sections on process control, design support activities, and marketing management.
Customer services (repair, upgrade of product, etc.)	"Product Delivery and Support" section in Manufacturing, Delivery, and Use phase.

process in PD Guide is consistent with this other research. Perhaps this consistency should not be surprising, since the study was used as an information source during the process model development (it should be noted that the base model for PD Guide had already been created and presented [Wilson and Kennedy, 1989a] - this study's contribution to the process was to identify topics that should be included in the model.)

Comparison/contribution was also performed for product development process information received from studied firms. For example, the "Xerox Delivery Process" [Xerox, 1989, p.6] emphasized the use of several "Phase Gate Reviews" to evaluate the progress of their projects. The content and timing of these reviews affected the positioning and content of the "project reviews" and "design reviews" used throughout PD Guide. In this case, the Xerox review material was then supplemented with the contents of three key reviews that were identified and described by Clausing [1990, p.9].

These types of additions and comparisons occurred repeatedly throughout the evolution of the Product Development Guide and process.

PD Guide Problems

Given the purpose of PD Guide as a communicator of good industrial practice, the two basic problems that can occur related to its contents ("are practices in PD Guide "good" practices?) and with its communication (do students/users "understand" the purpose and contents of PD Guide, and can they use it effectively?) Fortunately, PD Guide scored reasonably well on both fronts. As would be expected for a large undertaking, however, some problems were encountered with respect to these issues, as well as in several auxiliary areas.

Problems with Content

As detailed in Chapter 8, the industrial reviewers found PD Guide to be generally reflective of good product development practice. Reviewers generally indicated that their comments relating to problems were not indicators of fundamental flaws in PD Guide, but rather were proposed in the spirit of improving PD Guide. The most significant areas that were defined as weaknesses include:

- the need to include information/advice on creating and managing the development team that is so often emphasized as the key "essential element" to the development of the product [reviewers Beck, Abbott, Randall]

- the need to provide a more specific approach for converting identified needs into specifications, such as the use of Quality Function Deployment or other mechanism [reviewers Mason, Wesner, Ward];

- the need to emphasize the use of functional layouts and the definition of machine datums to control the function and configuration of the machine [reviewers Burdick and Foster];

- need to increase the use of "calls" to standard references and tools - for a technique, suggest book or other guide for information on how to do; for tools, use / discuss use of "standard" tools such as project management software. [Beck, Roof, Abbott, Randall]

The author views these concepts as useful and important future enhancements to PD Guide. In many cases, much of the information needed to develop these concepts is already available as a result of the present research and from the expert reviewers themselves.

Problems in Use/Useability

Ability to Locate Contents. Several students and expert reviewers noted that they sometimes had difficulty figuring out "where they were" within PD Guide when they "descended" to detailed levels. Student reports of trouble finding material or identifying location has gradually increased over time, corresponding with the increasing number of available PD Guide information displays.

Limited Access. Some users (both expert and student evaluators) have commented that the "cross-referencing" access capability is not as good as it could be. This problem occurs when an information display in one development phases refers to correlating concepts in another phase. Because of the restrictions imposed by the operating software (discussed later), a user cannot gain access to that information directly; instead, one must return to the "home" menu, then descend through the other phase to the desired location.

"Bottom-dwelling". One problem that the author repeatedly noted as he watched users attempt to use PD Guide is that users inevitably descended to the "bottom" of each path during their review, as opposed to answering some questions at a "higher" level. This "bottom-dwelling" led many users to complain later that they felt "lost" within PD Guide and evoked comments that PD Guide took too much time to use.

Display Layouts

Display contents. Some information displays are too "crowded", according to some students and expert reviewers. One undesirable results of this is that the displays become more difficult to read. A more-serious result, pointed out by an expert reviewer, is that it becomes more difficult to determine which questions/information is the most important. The unfortunate side effect of reducing the display "density" is that more display require additional key presses, which may increase the tendency for users to feel "lost".

Colors. Student users and expert reviewers of early-developed areas of PD Guide complained about the "use of unpleasant colors" in those sections. The author has typically used colors within PD Guide to separate the various information elements on the screen, but became "more conservative" in how this was done as the display development continued.

Selection of PDG Tools

Several reviewers made suggestions regarding the use of scheduling/project management software in place of the simple Lotus 1-2-3 schedules that are provided. The author concurs completely that commercial software would be absolutely superior to the spreadsheet for an industrial project; however, the major advantage of the Lotus sheet for students in the senior design course is that Lotus software is already available and is simple for students (partially because they already have spreadsheet experience).

As opposed to the business environment, software needs like project management software can be an expensive, difficult undertaking. The Engineering Design Center at UT, for example, has 32 computers (and already has Lotus and Quattro spreadsheets installed). Purchase of a several hundred dollar project software package for even one-quarter of the machines (which would provide about one copy per team area) is a difficult accomplishment. The other issue is one of student time; students typically do not have much time for learning new software.

As one reviewer noted, if these tools are to be useful at other universities it would likely be necessary to convert/adapt these files for use with other spreadsheets (Microsoft Excel, for example). The other suggestions for improving the schedules/worksheets have significant merit and are worthy of future implementation (reference Chapter 8 and reviewer comments).

Problems with Software "Engine"

Some of the largest and most-irritating problems with PD Guide are results of the software "engine" used to generate and control the displays. The AutoMentor™ software system used to run PD Guide is an "old" program (7 years old, ancient in software terms) with very limited capability. Among its biggest drawbacks are its lack of graphics support, problems in storing and accessing information displays, and compatibility with some systems.

Graphical Capabilities. Graphical screens, other than horizontal/vertical lines and boxes, cannot be displayed. When compared to computer graphical display capabilities that are increasingly available, some students have commented about the "poor" appearance of some displays. More importantly, however, is that this lack of capability forced the use of verbal explanations where graphical or other visual approaches would be more appropriate. For example, explanation and questions about product modularity are greatly enhanced with a visual illustration of a module within a product. Instead, concepts have to be explained verbally, which causes two other problems. The increased text needed: (1) requires more reading, which some students indicated is not as easy to do from a computer screen than it is from other mediums; and (2) the need for more text made some sections longer (the number of displays) and "deeper" (the number of selections that have to be made to reach that display).

Information Access and Storage. AutoMentor's limited selection and file handling abilities means that each display has to be contained in its own file (see Appendix S for technical data). Since PD Guide has about 1400 information displays, then 1400 files must be loaded, stored, and accessed. While each file is relatively small, PD Guide gives the appearance during installation of consuming a large amount of disk space. A compression utility had to be used to condense these files so that they would fit on one diskette; thus, PD Guide runs only from a hard disk.

The sheer number of files created problems for the operating system (DOS). AutoMentor does not support having display files in different subdirectories; thus, all display files are supposed to be located in one directory. The excessive length of this directory, however, meant that it would take over two hours to copy all files to a disk drive (DOS checks all filenames in a directory for a duplicate before writing a new one).

Directory length also slowed operation of PD Guide once it was installed; if the display was at the end of the directory, DOS read all the other directory entries first. Fortunately, a "work around" was developed that enables the information displays for each development phase to be located in its own subdirectory. The consequence of this, however, is that direct access to material in other phases cannot be provided - users must return to the home menu, then select the other phase of interest and locate the desired material. This requirement contributes to the feeling of PD Guide being a bit "rigid", as was noted by one of the reviewers.

System Compatibility Problems. AutoMentor often has been found to conflict with other software and systems. For example, it is incompatible with the Fixed Disk Organizer menu system used in the SEDP's Engineering Design Center. To "work around" this problem, users have to type a DOS command after selecting the PD Guide from the Organizer's menu. It also apparently will not run on "DOS emulator" systems, such as the DOS emulator in the new PowerPC machines (this problems were discovered during the expert reviewer evaluation). Given the increasing popularity of these systems, this incompatibility could be an increasingly irritating problem.

Typical/Recommended Uses of PD Guide

"Lessons learned" from the class sessions in which PD Guide has been used suggest that successful use of PD Guide is in great deal dependent on the instructor's initiative in making PD Guide and Tools an integral part of the design course or project. PD Guide, which is a comprehensive resource (about 1400 information displays), has been described by one professor as much like an encyclopedia. Like an encyclopedia, PD Guide can appear large and intimidating, and some practice in its use can be helpful for appreciating the amount and usefulness of its contents.

Use in Senior Introduction to Design Course

Use of PD Guide can begin during the "introduction" part of the course for preparing students for the design project. In fact, some students said they would have preferred more exposure to PD Guide, and especially the PDG Tools, during the Introduction course. These students said that this introduction would help them save time in their project, since they would already know how to use the items. In any case, specific techniques related to product development projects can be introduced - including techniques that may be excluded (for time or workload reasons) from the actual capstone project effort. Some of the ways in which PD Guide and PDG Tools can be used in introducing design and product development are shown in Table 9.2.

Even though students will not experience every product development phase in the capstone effort, students can be introduced to the overall development process, using the Introduction to PD Guide exercise (a provided PDG Tool). Seeing the overall process helps students later to gain perspective as to how the activities that they will perform fit within the overall development process. The introduction also enables students to become familiar with the contents and operation of PD Guide itself, which makes their future use of PD Guide easier. The usefulness of this exercise was demonstrated in two introduction to design courses.

Table 9.2: Some typical/potential uses of PD Guide in the senior-level introduction to design course (ME 455).

COURSE TOPIC	PD GUIDE / PDG TOOL CONTRIBUTION
Introduce students to product development process	PD Guide Tutorial presents phases and important viewpoints; Intro to PD Guide exercise acquaints students with PD Guide and development process.
Process Capability and its relation to Tolerances	Illustrate applications, explain computation of process capability.
Financial considerations in design	PD Guide explains income, expenses, profit measures used in development effort; Business Plan offers tool for business assessment.
"Controlled iteration" process for selecting best design option	Flowchart illustrates structured selection process; charts explained.

In addition to Table 9.2, instructors may wish to consider introductory (or sample) exercises for the tasks described for the senior design course (below), to give students some practice with these tools before their project begins.

Use in Senior Design Course

Use of PD Guide in the senior design course should be targeted toward helping student teams complete their projects using good practice and on schedule. Some of the activities with which PD Guide can assist the student team are shown in Table 9.3.

Table 9.3: Some typical/potential uses of PD Guide in the senior-level capstone design project course (ME 469).

DESIGN STUDENT ACTIVITY	PRODUCT DEVELOPMENT GUIDE CONTRIBUTION
Define project schedule	Design project schedule spreadsheet; corresponding section in PD Guide explains scheduling issues.
Develop design specification for specified project	Ask questions about proposed use, environment to assure a complete Product Design Specification (PDS). PDG Tool outline template available.
Develop product configuration	Ask questions pertaining to physical, control, and informational aspects of the product. Help students understand "modular" design concept.
Make parts drawings	Drawing template; corresponding section in PD Guide explains template entries and asks questions about dimensioning.
Assign tolerances to parts	Ask questions about critical product characteristics; provide tutorial on types and effects of tolerances.
Write design report	Report template and guidelines.

The project schedule generally is the first task for students when beginning the project. The schedule worksheet entries match the process defined in PD Guide, but also add additional details to remind students of specific tasks, such as ordering/acquiring parts for their prototype. A section in PD Guide offers advice for effective project scheduling.

The Product Design Specification (PDS) module and outline template help students define the comprehensive requirements for their project. In the UT program, students create a PDS for a sample product in the Introduction course, so that this step is more-straightforward once the project is presented.

Other tools then can be used throughout the project for parts drawings, bill of material, etc. PD Guide can be used repeatedly as an advisor and as a completeness review for various design steps throughout the project.

Use in Product and Process Development Course

PD Guide has also been utilized in the "broader" environment of the graduate product and process development course, as shown in Table 9.4. The application of PD Guide by necessity is more "general" than in the design project courses discussed above. PD Guide can be used to support the three primary activities of that course. PD Guide, in effect, serves as a supplemental text.

Survey comments from students in this course indicate that students need some direction in how to use PD Guide as an effective resource in this course, however. Student comments suggest that the assignment to "compare the lecture to PD Guide" was too broad for them to complete effectively (and this comment was made about a version

Table 9.4: Some typical/potential uses of PD Guide in the graduate product and process development course (ME 553).

ME 553 COURSE TASK	PRODUCT DEVELOPMENT GUIDE CONTRIBUTION
Present model for product development process	Show and explain details of the product development process
Present case studies of product development projects	Provide process information to enable compare/contrast of case study to the product development framework
Investigate, Analyze a Product Case Study	Help student to define significant issues and interview questions for study; provides "baseline" for comparing case study to model in PD Guide

of PD Guide that was much smaller than it is now). The essential complaint appears to be based on not knowing "where to look" and "what to look for" when given an assignment of this type.

Several actions could be taken to alleviate these problems in this course. The PD Guide tutorial could be assigned as "reading" at the first class meeting. Students could then be asked to complete the "Introduction to PD Guide" exercise used in the senior introduction course (an "advanced" version of this exercise could be constructed if the instructor decided that the current exercise was not at a sufficient level). These exercises would not only help students become acquainted with PD Guide, but also would directly supplement the early lectures in this course.

Later in the course, students could be directed to evaluate specific sections of PD Guide versus specific lecture or guest speaker topics. For example, a presentation by a plant manager on the importance of capable processes could trigger an assignment to review the process capability section in the Manufacturing System Design phase. Presentation of Design for Assembly features of a diskette drive [Janssen, 1987] could trigger a comparison of the techniques used in the drive versus questions presented on Design for Assembly in PD Guide. The drawback to this approach is that the instructor of this type of course has to be more familiar with PD Guide's contents than might otherwise be necessary, but student comments suggest that "more focus" in the assignment is important for PD Guide to be used effectively.

Other Potential Uses

Use Across University Programs

Since PD Guide will run on almost any IBM-compatible personal computer, it is easily transportable. Theoretically, then, PD Guide can be used by other universities with equivalent facilities, and by the many students who now have computers at home.

The word "theoretically" is used to emphasize that this transfer (or extension) of use is far from automatic. Indeed, there has been an increasing focus among educational foundations (the institutions that make many grants to improve education) on the "transferability" of new educational approaches/techniques. Some grant agencies have indicated some concern that their funding is not as effective as it could be because sponsored innovations do not cross institutional lines very well. One should not expect the transfer of PD Guide (assuming that there is any) to be significantly different.

This problem has been attacked in this project in several different ways: (1) use of simple PC-based software makes the program easily portable, since PC's are readily accessible at most institutions; (2) the materials are largely "self-contained", so they can be used without changing significantly the conduct of the course; (3) the "course plan" ideas (earlier in this chapter) provide easy ways to use PD Guide in the design curriculum.

As one reviewer noted, the ability to operate on Apple-based systems that have IBM-compatible emulation ability (which PD Guide does not currently have) is important step in helping its transferability to some institutions.

Industry Benchmarking Tool

As discussed in Chapter 4, competitive firms have found "benchmarking", a comprehensive comparison of a firm (its products and processes) versus its competitors, to be an important activity for achieving competitiveness improvements. Since this work is essentially a benchmarking activity - assessing firms to determine the "state-of-the-art" in product development - it can be used by firms to benchmark their product development processes. As discussed in Chapter 8, expert reviewer Rod Heard noted that PD Guide in some respects is oriented to larger firms, which likely have their own process. PD Guide's role in this type of firm, then, would be in a benchmarking or supplemental information capacity.

Small Firm Aid to Development

As PD Guide currently assists student product development team, it would be a natural extension to use PD Guide (or more likely, an "enhanced" PD Guide, grown to "industrial-strength") to assist small design team in smaller firms. These future versions of PD Guide may be capable of providing the needed structure and strategy for smaller firms that normally would not have access to the expertise and research results of world-class firms. Indeed, PD Guide was used successfully with one small firm to help them define their own product development process.

Cautions

Instructor Leadership in Educational Use

Two reviewers noted an important factor that is also consistent with observations made by the author and class instructors regarding use of PD Guide in a class. The "scope" of PD Guide's use must be bounded in the course assignments. The proposed use in class (above section) emphasizes a focus on a specific section/activity in the assignments, while still providing some overall perspective on the role and timing of that activity. Additional materials (such as case studies and class discussion) may be needed to support the section, or perhaps some "hands-on" simulation or real industry-based student project work needed to complete the total effort.

Balance and Flexibility Needed

Good design / product development models need to reflect a balance between realism and complexity. During the development of PD Guide, the author faced this balance question. If PD Guide was to be a successful vehicle for teaching/assisting new product development, the author recognized quickly that PD Guide must adequately address two critical challenges:

- to simplify the development process (and its presentation) to increase understanding, while still addressing the many critical issues that make "real" product development processes very complex;
- to maintain a comprehensive, "balanced" viewpoint (because a product must meet concurrently a wide variety of customer needs), while still making needed information easy to find and use, and not overwhelming or intimidating users.

Evidence from reviewers suggests that the current PD Guide fell a little short of this mark. One reviewer, generally very complementary of PD Guide, described it as a "little rigid. ... Teams need to follow the underlying principles of the guide, while being flexible where appropriate to save time." [Abbott, expert review] When students have complained about PD Guide contents, they generally claim that PD Guide is "too advanced" or "complex". This view again reinforces the author's finding that use of PD Guide should be "bounded" during its use in a course, much like covering specific sections or chapters in a textbook.

SEED leaders Pugh and Hamilton describe this need for flexibility in terms of making a "model" of the design process, as opposed to simply a "flowchart". The role of this flexibility cannot be overemphasized; the team needs to retain the option of changing the process when its circumstances indicate that it should do so. To do otherwise turns the "process" into a "procedure", which is perceived (and rightly so in many cases) as bureaucratic and unproductive.

Limitations in Usefulness

PD Guide provides a foundation, but only a foundation, towards understanding and executing a superior product development process. Thus, PD Guide is presented as a "useful, but not sufficient" tool for attaining superior product development. The concepts in PD Guide always must be implemented appropriately throughout the product development process for PD Guide to be effective.

Variations in processes and results. Like other processes, product development efforts are subject to variation. There is a wide range of potential projects that can be undertaken, each involving their own particular risks and uncertainties. Additionally, there are large variations in the effectiveness of product development activities among firms, within firms, and even within specific groups of a firm.

Firms with poor (or non-existent) product development processes sometimes manage to develop successful new products. Conversely, teams using "state-of-the-art" techniques and processes can sometimes fail. That, of course, is why product development is considered to be a risk-taking activity. Variations/changes in customer expectations, technical capabilities, the economy, etc. can sometimes mortally wound the design, marketing, and/or manufacture of even the new product that is developed using the best process.

This is why the use of any development tool, including this one, cannot *guarantee* a new product's success (assuming that anyone would be foolish enough to claim such ability). The case studies show that a wide variety of approaches can be taken, successfully, to develop a new product. Thus, there is not *one, best way* to execute product development. What the use of superior processes and techniques does do, however, is to improve the *probability* that a given product development effort will be successful; over time, teams who use the best methods will be more successful than those who do not.

The "people factor." As is noted throughout, the people (with their skills, experience, effort, *and* their weaknesses) on the team are the biggest factor affecting the development of a new product. As one expert reviewer said, "The answers to the questions and criteria (in PD Guide) are a function of who answers them."

The most important "element" to achieving desired results from the "essential elements" is that the development team work continuously to implement them throughout the product development process. While discussion is obviously necessary, it is the action of the team (and management) that determines whether any product development process is effective.

In PD Guide, the role of people is emphasized in that, although PD Guide can function as an "on-line" assistant, *the student always remains responsible* for concluding that the product meets all relevant requirements (in the case of the senior design course) or that a particular development strategy is appropriate (as might be decided in the graduate product development course). Of course, instructors also review students' decisions so that poor responses can be improved.

Difficulties in creating a model. Two design researchers have noted some common hazards that are involved in the development and communication of process models. Eder [1993, p.1743] notes that casual readers of any formal design process model will almost always overlook the iterative aspects of that model. Then, ironically, a good measure of the effectiveness of the structured model is to transfer it so well that users "say with conviction that they do not consciously) use such systematic procedures." Finally, Pugh points out perhaps the inevitable hazard incurred when creating a design model: "as soon as one produces such a model, someone, somewhere, will dispute it." [Pugh, 1986, p.168]

"Continuous Improvement" Recommendations

The expert reviewer evaluation demonstrates that the PD Guide provides a solid foundation from which to pursue product development. As with any "product", however, there exist numerous opportunities to improve it. Users (students, instructors, and expert reviewers) have contributed many suggestions for improvement, some of which have been implemented in more-recent versions of PD Guide.

"Modular" Sub-Products

The observed need to narrow the focus of PD Guide's use in the capstone design class led to an idea to create "modules" of the PD Guide, which could be used either as part of the overall PD Guide lesson, or by itself as a self-contained lesson in a technique. An experiment in "modularizing" PD Guide was performed by taking the displays for the Product Design Specification (PDS) and "splitting them out" of PD Guide itself and putting them into a separate program (the PDG-PDS program).

This approach, while somewhat detracting from the objective of showing a balanced, multi-disciplinary product development process, might have some marketing advantages. Specific modules, created along the lines of the proposed student assignments discussed earlier, could be sold individually at a lower individual price, but for a greater total price. Instructors could "pick and choose" just the ones that they wanted to use.

The lower prices would help to overcome the potential price resistance that would likely develop if attempting to sell the full package. For example, instructors likely would be much more willing to have students purchase a PDS module for $20 than they would be to require the purchase of a, say, $99 full Product Development Guide. The lower price for specific modules also would let users "try" a piece of PD Guide without risking a larger expenditure for the more-expensive, entire package.

PD Guide Contents Improvements/Additions

Reviewer Topic Recommendations. The reviewer content comments reflect significant product development expertise, and, as such, merit eventual addition to PD Guide. The enhancements to the customer future needs projection (to provide a more-straightforward method for converting customer needs to technical requirements) and addition of team-building advice deserve special consideration.

Need for and Value of Examples. Many students have noted the "examples" residing in PD Guide, and suggested that these had been important to their learning. Some have recommended that more examples in PD Guide would improve students' ability to complete assignments successfully. Several expert reviewers "wrote in" examples on some information display printouts, implying that they see examples playing an important role.

PDG Tools. Again, expert reviewer recommendations for a "complete" product cost worksheet and a simple illustration for assessing potential defect rates merit consideration. All tools eventually will need to be "genericized" so that the current Lotus spreadsheets can be run by Excel users, for example.

Technology Selection and Development. The format of the current Technology Selection and Development phase does not utilize an approach that was "invented" later and used in other phases, that of a "supplemental information" repository. As PD Guide was being developed, it became clear that so much information was being presented that it was difficult to assure that the "core" activities were being addressed. The solution, developed midway in development (after the Technology phase was finished) was to define an "Supplemental" key access path. This "S" gives users access to background information about the topic, for example, without leading users through it automatically. When used on the Product Ideas phase, the "S" approach greatly simplified the presentation of that phase. Thus, an "S" key-based content revision could be performed on the Technology phase, which would simplify the presentation of this phase.

An early, informal reviewer suggested that using essentially the same process (and information displays in PD Guide) for both the product and process Technology efforts shortchanged the process effort somewhat, since the questions are generally very product-oriented. An additional review/study of these phases, with the objective of identifying these differences, could lead to more "individualized" questions for each phase.

PD Guide Display Access Enhancement

PD Guide Navigation Features. Both students and reviewers, particularly those in the later evaluations, reported increasing difficulty in maintaining a sense of "where they were" within PD Guide. Several suggestions have been made (or developed from problem descriptions) for improving this aspect of PD Guide.

Most often suggested have been methods to show the menu "tree" or hierarchy as users move through the process. Alternatives include adding some type of screen identifier that would show the user's location in the menu, or providing a "map" or tree location somewhere on the display. Users could ask for their location tree on request. A few others suggested that the overall "tree" structure would not have to be incorporated into PD Guide, but could be provided on a printed map. One expert reviewer overcame this handicap by displaying multiple copies of PD Guide (using MS Windows) so that he could see multiple displays at once.

Some other suggestions for navigation included making displays more visually consistent, using "obvious differences" in different sections, and providing some indicator of the previous menu or selection so that users could more readily recognize from where they had arrived.

It is the author's view that some type of visual position indication is essential in an advanced version of PD Guide. An "F-key" could be defined for displaying hierarchy position on top of the current display. Another method might be to highlight the item selected from the previous screen, so that when the user returns to that screen it is clear which option had been previously selected. It is important to note that neither idea is easily incorporated using the current software "engine". When reviewing new engines, the ability to accomplish these tasks easily should be used as a key criterion.

Reference Features. Several requests have been made for methods to find specific information within PD Guide. An often-suggested feature is an "index" or "keyword search capability", to help the user find specific information or topics. Other idea is a "dictionary" for defining terms used in PD Guide.

Displays. Many students suggested that a better selection of colors, and less frequent use of differing colors, would be helpful. Based on this feedback, fewer colors and combinations were used in creating the "newer" displays that were added to PD Guide. In the interest of completing the rest of PD Guide, many of the earlier sections have not yet been improved. Successful marketing of the PDS module, for example, will require a PD Guide revision to "fix" some of the color combinations used.

Some other students have recommended using "bold" text and different font sizes instead of colors to achieve differentiation. Use of these features (not supported on current engine) would improve the ability to indicate which items on a given display are more important, which would alleviate a problem noted one of the expert reviewers. Others have noted the scarcity of graphics-based screens, the presence of which they believe would improve the presentation.

It became clear from students' written comments and verbal questions that students were confused about, and did not understand the meaning of, the "three-color" track that is used to show the product development process. Based on this conclusion, specific discussion explaining how the three colors represent the "product, market, and manufacture" aspects of product development was added to the PD Guide tutorial.

Operational improvements. Users have repeatedly suggested relatively basic use enhancements such as being able to use a "mouse" to select items. Others have suggested better key selections, such as using the "escape" key for the "return" function, rather than "F2" key (this seemingly simple change requires overhaul of all displays, if the current engine is maintained - otherwise, this change would be made now).

Impact of New "Engine"

Converting PD Guide from the current, very-limited "engine" to a more-advanced software platform may be capable of solving many of the issues defined above. A careful assessment of new alternatives may be needed if PD Guide were to become commercially successful.

Proposed new engines should be evaluated against the needs as defined above. For example, the support of mouse activation would address the operational request noted above. The newer engines likely will use a single (or small number) file structure, which would eliminate many of the loading and access problems experienced with the current engine. New authoring tools should be evaluated for these capabilities/problems. Since much of design is expressed visually, graphics capability is a must for achieving much more effective design sections.

For commercial development, the new engine needs to be more flexible about its environment; if DOS based, it needs to be capable of operating with the DOS emulator on the MacIntosh Power PC systems. To not do so eliminates some entire schools as potential customers.

Extensions to Research and PD Guide

Suggestions for significant upgrades to PD Guide range from extensions of the concept to include more presentation capability to dramatic conceptual alternatives. A few are discussed below.

Multimedia Capabilities. Students throughout the surveys have provided ideas for as to how PD Guide could extended to an advanced computer environment, including "multimedia" or "interactive" capabilities. Within this area, students have suggested Apple's "Hypercard" and Microsoft's Windows functions or features.

Small Business Version - "PDG Lite". Expert reviewer Rod Heard suggested that "a possible future activity might be to develop a 'PDG Lite' focused on development in a startup company. Some significant variations (from the current version) would include the interactions with fundraising activities needed in order to keep a company going so it can proceed with the development process."

Integration with other software. Users have occasionally expressed the desire to be able to write their answers or perform their work directly within PD Guide. This might require, for example, that the PDS module operate in conjunction with a word processor, so that teams could write their answers to the questions directly as the questions are asked.

Database Capabilities. In an extension to the previous item, others have suggested that an need for an enhanced PD Guide could be to provide some database capability to recall earlier decisions related to a current question. For example, a question on temperature testing in the Evaluation section might trigger a recall of the relevant portion of the Product Design Specification.

Addition of "Project Intelligence". A very serious extension of the Product Development Guide concept (and one which would require substantial research to achieve) is to provide PD Guide with some "intelligence", so that only relevant questions are asked. Comments about this subject have arisen from academic reviewers who teach design courses and from two industrial expert reviewers, as well as from at least one student.

The "sorting" process would assess available information and then ask the questions that appear to be most relevant to that specific project. Now, of course, PD Guide presents all questions, and depends on the team to eliminate them when they do not appear relevant. One student described this capability as a "system setup which would allow you only to call up the specific information your project required."

Achieving this capability perhaps require users to answer a set of questions. Based on the answers received, PD Guide "Plus" would then assess "what needs to be done" and present the relevant questions or tasks. If provided with sufficient capability, each user would, in effect, have a customized version of the program.

The research challenge in creating such a program is significant; determining what questions should be asked, and determining how to sort the following questions based on answers to previous ones, could be a significant and high value research area.

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APPENDICES

APPENDIX A

Product Development Guide "Quick-Reference" Instructions

"QUICK REFERENCE" INSTALL/USER INSTRUCTIONS
Revision 4 - 6/06/94

THE PRODUCT DEVELOPMENT GUIDE

Requirements: IBM or IBM-compatible personal computer running DOS 3.30 or higher. Fixed Disk Drive with approximately 4.75 MB of free space. (Once installed, PD Guide uses 3.25 MB of disk space). PD Guide must be installed onto a fixed disk; *it will not run from diskette.*

Installation: Insert diskette into drive and change DOS default to that drive. Run INSTALL to install PD Guide to the designated fixed disk. Format of command is:

INSTALL *x:* <ENTER>

where *x:* is the fixed disk drive onto which PD Guide is to be installed. Follow displayed instructions to install.

Running PD Guide: Switch DOS default drive to fixed disk drive containing installed version of PD Guide. Make sure you are in the "root" directory. Then, run PDGUIDE; format of command is:

PDGUIDE <ENTER>

PD Guide will then start. Follow instructions shown on screens. If you are a first-time user of PD Guide, we recommend that you go through the tutorial first.

Running PDG-PDS: Switch DOS to fixed disk drive containing installed version of PD Guide. Make sure you are in the "root" directory. Then, run PDG-PDS; format of command is:

PDG-PDS <ENTER>

The PD Guide's module on writing a Product Design Specification will then start. Follow instructions shown on screens. If you are a first-time user of PDG-PDS, we recommend that you review the tutorial first.

Using PDG Tools: Tools are available for use with the commercially-available programs WordPerfect, Lotus 1-2-3, and IBMCAD. Load those files into these programs just as you would for any document, worksheet, or CAD file. See the PD Guide tutorial or the PD Guide user's manual for a listing of available tools.

"QUICK REFERENCE" INSTALL/USER INSTRUCTIONS
Revision 1 - 06/08/94

"PDG TOOLS"

part of the PRODUCT DEVELOPMENT GUIDE

General Description: PDG Tools are part of the Product Development Guide ("PD Guide"). The PD Guide has been created to provide a comprehensive view of the product development process. PD Guide and the PDG Tools are "generic", to support the development of a wide range of products. The PDGTools are designed for use with the commercially-available programs WordPerfect, Lotus 1-2-3, and IBMCAD.

Requirements (for PDG Tools only): IBM or IBM-compatible personal computer running DOS 3.30 or higher. To use Lotus 1-2-3 tools, must have Lotus 1-2-3 version 2.2 or higher or another spreadsheet program capable of reading these files. For WordPerfect tools, must have WordPerfect 5.1 or other word processing program capable of reading these files. For IBM CAD files, must have IBM CAD version 2.2.1 or higher.

Descriptors: This disk contains files for WordPerfect 5.1, Lotus 1-2-3, and IBMCAD. Which files are which can be determined from the suffix of the filename, as shown below:

Filename Suffix	Type of File
*.wp	WordPerfect 5.1 document
*.wk1	Lotus 1-2-3 spreadsheet
*.cad	IBMCAD drawing file

Use of PDG Tools: Start WordPerfect, Lotus, or IBM CAD as you normally do. Load PDG Tools files into these programs just as you would for any document, worksheet, or CAD file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; the user assumes all risk associated with the use these tools in their product development activities.

PDG Tools List: See the PD Guide tutorial or the PD Guide user's manual for a more-comprehensive description of available PDG Tools. Below is a brief listing:

Filename on Disk	Task / Description
PDG-NTRO.wp	Introduction to the PD Guide Exercise
PDSFORM .wp	Form for Product Design Specification (PDS) (Use with PDG module, "PDG-PDS")
PRCE2MFR.wp	Convert Price to Target Cost (Table)
RPORTFOR.wp	Guidelines for Technical Reports
RPTSTRTR.wp	Report "Starter" Document
WRKRPT-I.wp	Design Project Progress Report, Individual
WRKRPT-T.wp	Design Project Progress Report, Team
BUSPLAN.wk1	Product Profitability Analysis
MILESTON.wk1	Project Milestones Chart / Utility
DESSCHED.wk1	Design and Evaluation Phase Schedule
CLASSCHD.wk1	Design Course Project Schedule
PARTCOST.wk1	Parts Cost Calculation Worksheet
PARTLIST.wk1	Bill of Material Format
AFRAME .cad	CAD Drawing Frame ("A" size)
CTEMPLAT.cad	CAD Drawing Frame ("C" size)
COVERLAY.cad	(merge overlay onto template before plotting)
DTEMPLAT.cad	CAD Drawing Frame ("D" size)
DOVERLAY.cad	(merge overlay onto template before plotting)

APPENDIX B

Product Development Guide User Instructions

USER INSTRUCTIONS
Revision 4 - 06/06/94

THE PRODUCT DEVELOPMENT GUIDE

GENERAL DESCRIPTION

The Product Development Guide ("PD Guide") and its associated modules/tools have been created to provide a comprehensive view of the product development process. PD Guide covers the entire product development spectrum, beginning with product ideas and continuing through to product manufacture and customer use. Its broad scope integrates engineering, manufacturing, marketing, and business practices into one coherent package. The Guide is "generic", to support the development of a wide range of products.

The Guide's easy-to-use menu selection based structure lets new users begin learning with minimal or no instruction, so it can be used easily by almost anyone.

BASIC REQUIREMENTS

The PD Guide, its associated modules, and PDG Tools are designed to operate on IBM and IBM-compatible DOS-type computers. Minimum requirements for installing and running the PD Guide and its Modules include:

- MS-DOS or IBM-DOS version 3.30 or higher
- Fixed Disk Drive, approximately 3.25 MB of disk space (net). An additional 1.50 MB is required during installation.

A color monitor is recommended. PD Guide does not require, nor does it currently support, use of a mouse.

PD Guide **must first be installed** to a fixed disk before it will run, because the PD Guide installation diskette contains "compressed" data files that must be expanded first. Thus, the PD Guide will NOT operate directly from the diskette.

INSTALLING THE GUIDE ONTO YOUR COMPUTER'S FIXED DISK

An easy-to-use program utility, appropriately named "INSTALL.BAT", **must** be used to install the Product Development Guide to a fixed disk. INSTALL will automatically expand and load all PD Guide files onto a fixed disk specified by the user.

DO NOT attempt to install PD Guide without using this utility; PD Guide program files must be located in specific locations for PD Guide to operate properly.

Procedure:

(1) Select the fixed disk drive onto which PD Guide is to be installed. Check this drive to make sure that at least 3.75 MB of free space is available. Free space available can be determined from using DOS commands "DIR" or "CHKDSK", or from many other disk management programs.

Example: You have decided to install PD Guide onto fixed disk "C:". You can check the amount of free space on disk "C:" ...

type: **DIR C:** <ENTER>

At the end of the directory listing, the number of "bytes free" on that drive will be shown. Make sure that the free space is greater than 3.75 MB (which is equal to 3 840 000 bytes).

(2) Insert the PD Guide installation diskette into your diskette drive. Change the computer's default drive/directory to the diskette drive into which you just inserted your disk.

Example: If you just inserted the PD Guide installation disk into drive "A:", change the default directory to drive "A":

type: A: <ENTER>

(3) To begin installation,

type: INSTALL *x:* <ENTER>

where "*x:*" is the fixed disk onto which you want PD Guide installed. If you make a mistake, or select an invalid drive, the installation program will inform you of your mistake. You will be shown some examples of correct entries, and be returned to the DOS prompt, where you can try again.

Example: If you want to install PD Guide onto your fixed disk drive "C:", then:

type: INSTALL C: <ENTER>

NOTE: PD Guide must be installed on the "root" directory. However, the only files stored in the root directory of the drive that you designate will be files needed to start the program; there are fewer than 6 of these, and their filenames all begin with the letters PDG.

The installation program will create a subdirectory called "PDGFILES" if it does not already exist from a previous PD Guide installation. The PDGFILES subdirectory and the others that will be created "below" PDGFILES contain all of the PD Guide's files, except for the very few used in the root directory.

(4) If you enter a valid drive designation, an installation notice will be displayed. Make sure that the drive shown is the drive TO which you want to install PD Guide. If the drive listed is correct and you want to continue, press the Y key to indicate "yes" (no ENTER key is necessary). If something is wrong and you wish to exit, press the N key for "no" to abort the installation.

(5) The install utility will look for previous PD Guide versions on the drive that you selected. It then asks you to confirm its conclusion as to whether PD Guide has been installed there before. If yours is a first-time installation and the utility agrees, answer Y to continue installation. Owners with previous PD Guide versions on disk will be asked some additional questions - consult the note at the end of this section.

(6) The installation program will load PD Guide files for several minutes. While there are many files (about 1500), each file is very small, so you do not have to worry that PD Guide is stealing your entire disk. Also, as noted above, they are all placed in the PDGFILES directory or in additional directories below PDGFILES.

PLEASE be patient during this part of the installation. Installation speed will vary based on your processor and fixed disk speeds. For example, installation on a 386-16 computer required about 20 minutes; loading on a 486-33 machine required less than 9 minutes.

(7) When installation is finished, the installation program will ask if any unexplained error messages appeared during installation.

If they did, note the error and press Y. Consult the "Common Installation Errors" section in the Appendix.

If no errors occurred, congratulations! Press N. You are ready to run PD Guide.

Note for users who have a previously installed version of PD GUIDE:

If you have a previous version already installed on the target disk, the installation utility should detect it (refer to Step 5, above).

Procedure (addendum to Step 5):

(a) If the utility finds a previous version, it will ask if one has been previously installed - if this is true, respond with Y to continue. If not, respond with N to abort installation.

(b) You will be asked for permission to erase "old" PD Guide files before installing the new version. Installation time can be decreased significantly by either giving permission for the installation utility to erase these files or by erasing these files yourself.

NOTE: The installation utility will only erase *.PLY files in the PDGFILES directory and in those directories under PDGFILES. It will erase these files, however, only if you give your permission for it to do so.

You do NOT have to perform this procedure if you do not want to. However, installation may take significantly longer to complete, perhaps exceeding 30 minutes. Also, some of the files in the "older" version may now be obsolete, but will NOT be erased with the update. Thus, more disk space will be required than would be needed otherwise.

Either give (Y) or refuse (N) permission for the installation utility to erase the old files from your fixed disk. If you prefer to erase these files yourself manually, answer "N".

(c) If you provided permission to erase files, the installation utility will indicate that it is erasing files. Depending on which version of PD Guide was previously installed, this process may take a few minutes.

If you did *not* provide permission, the utility will advise you of the potential for longer installation time and more disk space discussed above.

If these drawbacks are acceptable, press Y to continue. The installation utility then installs the new PD Guide (step 6 of installation procedure).

If you wish to erase the old files manually or have decided to abort the installation, respond N. To erase files manually, refer to the "Deleting the Product Development Guide" section.

STARTING THE GUIDE FROM YOUR COMPUTER'S FIXED DISK

This simple procedure is used to start the Product Development Guide (PDGuide) or the PDG Product Design Specification Module (PDG-PDS).

This procedure assumes that you have already used the INSTALL utility to load Product Development Guide to a fixed disk. See "INSTALLING THE GUIDE ONTO YOUR COMPUTER'S FIXED DISK", located elsewhere in the User's Manual.

Procedure:

(1) Recall (or find) the drive onto which you installed the Product Development Guide. Change the default directory to that drive.

Example: If you installed the Guide onto fixed disk drive "C", change the current disk to drive "C":

type: C: <ENTER>

(2) Change to (or make sure that you are already in) the "root" directory of this drive:

Example: One way to be sure that you are in the root directory is:

type: cd\ <ENTER>

(3a) To start the Product Development Guide,

type: **PDGUIDE** <ENTER>

(3b) or, to start the Product Design Specification module,

type: **PDG-PDS** <ENTER>

(4) Follow the instructions shown at the bottom of each display screen to operate the Guide. See "USING THE PRODUCT DEVELOPMENT GUIDE", elsewhere in the User's Manual, for additional information.

USING THE PRODUCT DEVELOPMENT GUIDE

The Product Development Guide and its associated modules are designed to be used without the aid of written instructions. However, some general information can be helpful to new PD Guide users. The basic layout, organization, and control of PD Guide are described in this section.

ORGANIZATION: PD Guide and its modules are structured as a tree-branch style programs. After some brief introductory information, PD Guide shows the "product development process for an innovative product". Referred to as the "home" screen, this development process display serves as the "trunk" of the tree. One can "branch out" from the trunk through the tree by selecting the various options presented on the displays, as described below.

PD Guide modules, such as PDG-PDS (a Guide to writing the Product Design Specification), are structured similarly, although their "home" screens may be different.

OPERATION: The bottom line of each information display describes what selection options are available from that display. Selection is typically done in one of three ways:

(a) pressing a highlighted number or letter key that is connected to a certain word or concept presented on that display - this operation provides more specific information about that word or concept. In this way users can "branch out from the trunk" to more specific levels of information;

(b) pressing a "function key" (such as the "F3" key) - this operation returns the user back toward the trunk of the tree", to the more general level of information;

(c) moving a colored bar to the desired selection using the arrow keys, then pressing the ENTER key - this operation selects topics related to the product development phases.

KEYBOARD ENTRIES: In general, the following keys are used to control the PD Guide:

KEY(S)	DESCRIPTION
0-9	Select numbered options presented on information display
E	Show examples of concepts on information display
S	Select supplemental information about a concept
F2	Return "back" one level towards "home" or "trunk"
F3	Go back to the "home" menu
F5	Toggle between tutorial and "home" screens
F10	Quit the program, and return to operating system
PgUp	Go to previous page of a multi-screen display
PgDn	Go to next page of a multi-screen display

Users do not have to remember these keys; available options are always explained at the bottom of each information display.

REMOVING THE PRODUCT DEVELOPMENT GUIDE

If you desire to remove PD Guide from your fixed disk, or wish to erase an "old" version manually before updating PD Guide, you can do so by completing the following:

Procedure:

(1) Erase all of the files from the PDGFILES subdirectory and from all of the subdirectories under the PDGFILES directory. The DOS command "DELTREE" can be used for this task (available on DOS 5.0 and higher).

Example: **DELTREE *x*:\PDGFILES**

where *x:* is the drive on which PD Guide is installed. This command will also erase all of the subdirectories associated with PD Guide.

WARNING: DELTREE erases ALL files and deletes the subdirectories PDGFILES and the ones "under" PDGFILES. If you have other files (word processing documents, etc.) in these directories, these files will also be lost!

NOTE: The PD Guide installation utility does not use DELTREE to remove an old version; it only erases the *.PLY files from the directory PDGFILES and those directories under PDGFILES.

(2) Erase the below-listed files from the root directory. Not all files will be present - which exist on your disk depends on which version of PD Guide is installed.

PDGUIDE.BAT	PDGKEY.COM
PDG-PDS.BAT	PDGCHD.COM
PDG2DISK.BAT	

NOTE: All "root directory" files associated with the Product Development Guide always begin with the letters "PDG".

INFORMATION / COMMENTS

The PD Guide and its modules are developing prototypes: we solicit your comments on how to improve their contents, operation, and use. Please forward your suggestions to:

Dr. Clement C. Wilson
Professor, Mechanical & Aerospace Engineering
(615) 974-6144

or

Michael E. Kennedy
Ph.D. Candidate
(615) 974-5246

The University of Tennessee
414 Dougherty Engineering Building
Knoxville, TN 37996-2210

FAX (615) 974-5274

APPENDIX

POSSIBLE PD Guide INSTALLATION ERRORS:

Error Description	Comments / Corrective Action
"Bad Command or File Name" "File not Found"	If you cannot get the installation utility started or you get a series of error messages, you may not have set the current directory properly. If you inserted the PD Guide installation disk in drive "A", the DOS prompt should show "A:>".
"Disk Full"	(1) You do not have enough room on your disk. You need about 3.75 MB of space to install PD Guide. (2) You may have attempted to install the PD Guide onto its installation disk. For example, if the PD Guide disk is in drive "A", you cannot install the program onto drive "A", using "INSTALL A:", because you are asking the installation program to put the PD Guide onto a nearly full diskette.

POSSIBLE PD Guide OPERATION ERRORS:

Error Description	Comments / Corrective Action
"Bad Command or File Name" "File not Found"	Make sure that the current directory is set to the "root" directory of the drive on which PD Guide is installed. If PD Guide was installed on fixed disk "C:", make sure that DOS is set to the "C:\" directory.
"Automentor Error"	PD Guide operational error. Note where you where in PD Guide when the error occurred and call for assistance. Since a memory-resident program may remain in memory, you may need to reboot the computer after this error if you wish to run another program.

USE LIMITATIONS / RESTRICTIONS

Thus, please do NOT make unauthorized copies of the PD Guide, its modules (such as PDG-PDS), or of any of the PDG Tools.

Unlimited copies of PDG Tools files may be made for use in the licensee's product development activities, so long as all references to "PD Guide", Product Development Guide", and licensing information remain in those files and on all documents produced from the files. Other persons that wish to use any PDG Tool must obtain permission from the copyright owners or become a licensee of the PD Guide.

APPENDIX C

PDG Tools - Introduction to PD Guide Exercise (and answers)

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"PD Guide Introductory Exercise"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Product Development Guide Introductory Exercise" is intended to be used to introduce students to PD Guide. It provides questions about the product development process, answers to which can be found in the PD Guide. Students can answer the questions either individually or in teams.

Filename for Tool: PDG-NTRO.wp Introduction to PD Guide

Computer/Software Requirements: To use this tool, user must be able to use WordPerfect 5.1 or another word processing program that is capable of reading/using files written in the WordPerfect format. Computer must be able to read disks formatted in the IBM drive format. If one is not available, a printout of the questions can still be distributed for use as the introductory exercise.

Use of this PDG Tool: Start WordPerfect or other word processing program (one capable of reading WordPerfect files) as you would normally do. Retrieve specified Tool file just as you would for any other document. Individuals or teams can type their answers to the questions beneath each question.

Other Notes: In team-based labs, students can run the PD Guide on one computer, while entering their answers into the template using an adjoining computer. Answers to this exercise are available (for instructors only) from the file, "PDG-NTRO.ANS". Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

Product Development Process Introductory Exercise
Team Problems

Team: (Team Name)

Members: (Names of team members)

INSTRUCTIONS: Use the "PDGUIDE" software to answer the following questions. Answer these problems and submit results as a team. Enter your answers onto a copy of the supplied template file; create a printout of your file to submit your answers.

Before beginning the exercise, the team should generate and select an idea for a new product. Use your team's product idea when asked to answer product-specific questions.

1. Name the nine major phases for the development of an innovative product.

2. Describe the three "overall" essential elements for the product development process, and explain the significant factors associated with fulfilling each of the three elements.

3. What are three topics to be considered when evaluating new product ideas?

4. What is the most-prominent activity of those that should occur during the Customer Future Needs Projection phase? What is the objective of this particular activity?

5. What is the key output resulting from the completion of the Technology Selection and Development phase?

6. What project targets should be established along with the Final Product Definition?

7. What are two of the ways that items listed in the Product Definition should be ranked or categorized?

8. What is the first step of the Product Design and Evaluation phase?

9. Within what two major steps within the Product Design and Evaluation phase is the concept of "controlled iteration" illustrated?

10. What are two major items that should be reviewed to evaluate whether the product design is complete and ready for production, before executing the product's "release for manufacture"?

11. What are the "4 P's" of marketing?

12. What is the major goal for the Manufacturing System Design phase?

13. What phase of product development most often requires the most engineering work/effort?

14. In what phase is the Product Concept Description created?

15. On a separate page (in a separate disk file), use the critical questions in PDGUIDE to create a Product Concept Description for your team's product idea.

M.E. 455.93 CCW/MEK
Product Development Process Exercise
Team Problems
Due: Thursday, September 23, 1993

Team: Faculty

Members: Answer Key

INSTRUCTIONS: Use the "PDGUIDE" software to answer the following questions. Answer these problems and submit results as a team. Use the supplied WordPerfect template to submit your answers.

Earlier this term, you defined an idea for a new product. Select one of these ideas as your team's product. Use your team's product idea when asked to answer product-specific questions.

1. Name the nine major phases for the development of an innovative product.

Product Ideas
Customer Future Needs Projection
Technology Selection and Developmment (Product)
Technology Selection and Developmment (Process)
Final Product Definition and Project Targets
Product Marketing and Distribution Preparation
Product Design and Evaluation
Manufacturing System Design
Product Manufacturing and Delivery

2. Describe the three "overall" essential elements for the product development process, and explain the significant factors associated with fulfilling each element.

(1) Control by a Single Team

Team controls all aspects of product development, from Technology Selection through Product Manufacture and Delivery;

Integration of broad skills: the team has the proper skill "mix" and experience to design, test, manufacture and market the new product.

(2) Projection of Customers' Future Needs

Team participates in the needs determination;

Customer input is provided directly to the development team.

(3) Information Convergence at the Product Definition Phase

Early, simultaneous consideration of all design, manufacturing, and marketing aspects of a new product;

Development of common goals and plans to be used by ALL members of the development team.

3. What are three topics to be considered when evaluating new product ideas?

Choose 3 of the following:
General strength of concept
Financial Returns/Risk
Product Strategy Match
Technology Assessment (initial)
Product Mix Goals
Market Analysis/Assumptions
Internal Capabilities Match
"Barriers to Entry"

4. What is a prominent activity of the Customer Future Needs Projection phase? What is the objective of this activity?

Competitive benchmarking - the objective of benchmarking is to assess competitors' standing with respect to their products, existing best features, and their business processes.

5. In selecting a product technology, what are two important factors that should be considered?

Select two of the following:
* Performance Comparisons versus other alternatives
* How well does technology meet customer needs and other customer considerations?
* What barriers might prevent success?
* Is it a NEW technology?
* Is Firm competence enough to use this technology?

6. What is the key output resulting from the completion of the Technology Selection and Development phase?

The Technology Feasibility Statement

7. What project targets should be established along with the Final Product Definition?

Marketing Targets
Business Targets
Target Milestones
Target Resources

8. What are two of the ways that items listed in the Product Definition should be ranked or categorized?

Select two of the following:
- Increasing or decreasing importance?
- Expected or excitement feature?
- Expressed of unexpressed need?
- Fundamental or peripheral to success?

9. What is the first step of the Product Design and Evaluation phase?

Prepare the Product Design Specification

10. What are two major items to be reviewed before releasing the product design for manufacture?

Select two of the following:
* Product meets or exceeds all requirements in the Product Design Specification
* Comprehensive Test Plan tasks complete and successful
* All problems in Product Problem/Failure log have been addressed satisfactorally
* Documentation complete: design calculations done, bill of material & assembly drawings verified, tolerance analyses done

11. What are the "4 P's" of marketing?

Product, Price, Place and Promotion

12. What is the major goal for the Manufacturing System Design phase?

The milestone goal for the Manufacturing System Design phase is to select and construct cost-effective, capable manufacturing processes for parts manufacture and assembly. Critical process technologies are identified as such and are usually controlled by the firm, for maximum process quality control.

13. What phase of product development most often requires the most engineering work/effort?

Product Design and Evaluation phase

14. In what phase is the Product Concept Description created?

The Product Ideas phase

15. On a separate page (in a separate disk file), use the critical questions in PDGUIDE to create a Product Concept Description for your product.

APPENDIX D

PDG Tool - Product Design Specification (PDS) Document Template

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Product Design Specification Template"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Product Design Specification Template" is intended to be used in conjunction with the Product Design Specification (PDS) step of the PD Guide's product development process. This tool is a "starter" document for the PDS, which is the first step of the Product Design and Evaluation phase. For convenience, the PDS portion of the PD Guide can be run from its own module, named "PDG-PDS", a guide to creating a PDS. It is recommended that students complete the PDS while working in teams.

Filename for Tool: PDSFORM.wp

Computer/Software Requirements: To use this tool, user must be able to use WordPerfect 5.1 or another word processing program that is capable of reading/using files written in the WordPerfect format. Computer must be able to read disks formatted in the IBM drive format. If one is not available, a printout of the questions can still used to provide the necessary header information.

Use of this PDG Tool: Start WordPerfect or other word processing program (one capable of reading WordPerfect files) as you would normally do. Retrieve specified Tool file just as you would for any other document. Teams enter the required specifications beneath each header and sub-header item. The questions and examples in the PDG-PDS module should be used in conjunction with this template to make sure that the entered specifications are sufficiently comprehensive.

Other Notes: In team-based labs, students can run the PDG-PDS module of the PD Guide on one computer, while entering their specification data into the template using an adjoining computer. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

Product Design Specification

Team: (Team name)

Members: (Names)

Version Number / Date: x.x / xx MONTH 19xx

Product Name or Description: (Product Name here)

Summary Description (as required)

(Provide brief summary of product, from Final Product Definition)

Section 1: Product Characteristics

1.1 **Features:**

1.2 **Performance:**

1.3 **Product Cost Target:**

1.4 **Quality / Reliability Targets:**

1.5 **Aesthetics:**

1.6 **Ergonomics:**

1.7 **Size:**

1.8 **Weight:**

Section 2: Product Life Specification

2.0 **Product Life Targets:**

Section 3: Customer Use Considerations

3.1 Installation:

3.2 Documentation:

3.3 Maintenance:

3.4 Disposal:

Section 4: Development Considerations

4.1 Development Time:

4.2 Use Environment:

4.3 Materials Used:

4.4 Standards / Safety:

4.5 Testing:

4.6 Company Constraints:

4.7 Patents / Legal:

Section 5: Manufacturing Factors

5.1 Process Selections:

5.2 Product Volumes:

5.3 Product Packaging:

5.4. Product Shipment:

Section 6: Market Factors

6.1 Key Customer Characteristics:

6.2 Competitive Conclusions:

6.3 Anticipated Market Window / Life:

APPENDIX E

PDG Tools - Progress Report Templates

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Design Project Progress Reports - Team and Individual"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Design Project Progress Reports - Team and Individual" are intended to help students report on their projects in the capstone design course. In some design classes, professors require submission of written, interim reports; these templates provide common formats to aid professors' review of these reports. Progress report formats are provided for both individual design team members and the design team itself.

Filename for Tool:	WRKRPT-I.wp	Design Project Progress Report, Individual
	WRKRPT-T.wp	Design Project Progress Report, Team

Computer/Software Requirements: To use this tool, user must be able to use WordPerfect 5.1 or another word processing program that is capable of reading/using files written in the WordPerfect format. Computer must be able to read disks formatted in the IBM drive format. If one is not available, a printout of the format can be distributed and used to provide the necessary structure information.

Use of this PDG Tool: Start WordPerfect or other word processing program (one capable of reading WordPerfect files) as you would normally do. Retrieve specified Tool file just as you would for any other document. Users can enter text directly into the template.

Other Notes: The "indent" key should be used when adding new task items to the reports. The table used for each individual member in the team report can be copied as many times as necessary to provide for all team members. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

ENGINEERING DESIGN PROJECT PROGRESS REPORT - TEAM

TEAM : (team name)
PROJECT : (name of project)

DATE : xx JAN 199x

REPORT # : x
COVERING EFFORTS from: xx JAN 199x to: xx JAN 19xx

WORK COMPLETED THIS REPORTING PERIOD (as a team):

(1) (Description of effort/achievement - #1)

(2) (etc.)

(3)

(4)

WORK PLANNED FOR THE NEXT REPORTING PERIOD (as a team):

(1) (Description of planned effort - #1)

(2) (etc.)

(3)

(4)

EFFORT LOG - INDIVIDUAL TEAM MEMBERS:
[Copy table repeatedly as needed for each team member; each team member shall sign his/her initials in assigned area.]

Team Member Name:	(Member Name)	Initials:
Total Hours Worked, THIS reporting period:		xx.x hrs
Tasks Completed during THIS Period by this member:	(Description of tasks performed and completed by this team member during this reporting period.)	
Tasks to be performed during the NEXT Period by this member:	(Description of tasks that are scheduled to be completed by this team member during the next reporting period.)	

Team Member Name:	(Member Name)	Initials:
Total Hours Worked, THIS reporting period:		xx.x hrs
Tasks Completed during THIS Period by this member:	(Description of tasks performed and completed by this team member during this reporting period.)	
Tasks to be performed during the NEXT Period by this member:	(Description of tasks that are scheduled to be completed by this team member during the next reporting period.)	

Team Member Name:	(Member Name)	Initials:
Total Hours Worked, THIS reporting period:		xx.x hrs
Tasks Completed during THIS Period by this member:	(Description of tasks performed and completed by this team member during this reporting period.)	
Tasks to be performed during the NEXT Period by this member:	(Description of tasks that are scheduled to be completed by this team member during the next reporting period.)	

ENGINEERING DESIGN PROJECT PROGRESS REPORT - INDIVIDUAL

NAME : (team member name)

TEAM : (team name)
PROJECT : (name of project)

DATE : xx JAN 199x

REPORT # : x
COVERING EFFORTS from: xx JAN 199x to: xx JAN 19xx

SIGNATURE : ______________________________

INDIVIDUAL WORK COMPLETED DURING THIS REPORTING PERIOD:
[classified by task; hours worked reported by task]

Effort (HRS)	Task Description
x.x	(Description of task performed - #1)
x.x	(task #2, etc.)
x.x	(etc.)

APPENDIX F

PDG Tool - Design Report Format

DATE: January 31, 1994

TO: Engineering Design Students

Copies to: R.P. Smith
J.J. Jones

FROM: Product Development Guide (PD Guide)

(signature here)
P. D. Guide

ADDRESS: 414 Dougherty Engineering Building
Mechanical & Aerospace Engineering Dept.
The University of Tennessee
Knoxville, TN 37996-2210

SUBJECT: GUIDELINES FOR TECHNICAL REPORTS

TABLE OF CONTENTS

BACKGROUND

Nearly all technical reports can be grouped into two categories: (1) to convey information; or (2) to convey information and recommend action. This report is intended to serve as a guide to make both types of reports more effective. A primary objective for effective report writing is to help readers to be able to find needed information quickly. To assist engineering design students, this report also discusses the use of this format and typical contents for a design project report.

CONCLUSIONS

PD Guide recommends that technical reports be written using the three sections described below, in the prescribed order:

1. BACKGROUND. State very briefly why the investigation was carried out and what critical questions were to be answered.

2. CONCLUSIONS. State very briefly the important results of the investigation and what action should be taken.

3. DISCUSSION. State how the results were obtained. Include appropriate and frequent subheadings.

A fourth section, APPENDICES, should be added when needed to convey other pertinent detailed information. Detail drawings, parts lists, and other documentation related to a design project may be added to a report by putting them into separate appendices for convenient reference.

Some managers/professors prefer that the Background and Conclusions sections be grouped together under one heading, the "Executive Summary". Authors should use whichever format is preferred by the persons to whom they report.

Regardless of the header titles that are used, Background and Conclusions contents should be at the beginning of the report, and generally should not exceed one page total, single-spaced.

DISCUSSION

Report Sequence And Section Headings

Sequence Rationale. Reports are prepared for readers. The most logical sequence for the report from a reader's standpoint may not be the same as that from the author's. Authors have seen their technical report develop chronologically by: (1) learning why the investigation was necessary (Introduction); (2) determining what questions need to be answered (Objectives); (3) carrying out steps

needed to learn the answers (Procedure); (4) learning the answers (Results); and finally, (5) recommending actions to be taken (Recommendations). However, readers want to know why work was done and what questions were to be answered; then they need answers and recommended actions. Readers eventually will want to know how the answers were determined, but readers' initial focus (and thus, the report's) will be towards results and what to do about them.

Major Section Headings. The Introduction and Objectives are closely related and can be difficult to separate without being repetitive; consequently, they can be grouped under one major heading, the BACKGROUND. Similarly, Results and Recommendations are closely tied, the latter being a logical extension of the former, so they can be combined under a CONCLUSIONS heading. The DISCUSSION heading captures additional, detailed information that needs to be communicated. Descriptive subheadings are critical for leading readers through the Discussion section.

Contents of Each Section

BACKGROUND Contents. In this section, the author informs the reader why the work was done and what goals were established; i.e., what questions needed answering. Typically, this section is read by engineers directly involved in the project and their managers. When these persons have been kept informed throughout the effort described in the report, they will already be aware of the background. However, these readers may need to be reminded when reviewing the report at a later date. Other readers need a concise introduction to the investigation covered in the report.

CONCLUSIONS Contents. The Conclusions section is most critical, for here the author answers the questions posed within the Background section and specifically recommends what action(s) is/are needed. When examining reports, many managers will read only the Conclusions section, and may then review it repeatedly throughout the development process.

This section needs to be written briefly and clearly, for readers want to understand quickly an author's results and recommendations. The Background and Conclusions sections combined should normally be no longer than one, single-spaced page.

Some firms/instructors prefer an alternative format which combines the Background and Conclusions sections into a single section called the "Executive Summary"; in this case, the Executive Summary should generally be no longer than one page. Authors should ask their managers/instructors which format is preferred.

To create a Conclusions section that is as short and as clear as possible, authors who write outstanding reports:

- do not present extensive numerical results (such as computer printouts, calculations, etc.) in the Conclusions section. Instead, these materials reside in either the Discussion or Appendix sections. However, a concise table or graph is used within the Conclusions section when it effectively and concisely illustrates critical results and conclusions.

- use numbered items or "bullets" when multiple results and conclusions need to be presented.

- always mention important limitations of the results presented, and note any reservations to pursuing the recommended actions.

- include the basis for recommendations when they can be added without making the Conclusions section too long. For example, "The Task Force recommends that the proposed drive system be adopted. Based on measurements in three machines, the proposed system reduces the impact force by a factor of three over the existing configuration."

DISCUSSION Contents. The objective of the Discussion is to provide enough detail to explain and/or justify the statements made in the Background and Conclusions sections. Often, this section must be custom-designed by the author to fit the particular investigation.

Readers of this section most likely will be other engineers. They may want to evaluate how the author conducted the investigation to gain confidence in the author's Conclusions, or may want to learn a technique described in the report. Others simply may want to know more about a project in which they were also involved. Managers typically will only skim through the Discussion to find details on specific items of interest.

The methods and procedures used are most frequent topics within a typical Discussion section; however, many other subjects can be discussed as well. When appropriate, a Discussion section may:

- explain more-fully why work was done. (e.g., an author might present failure data to show why an effort was initiated.)

- describe the approach used to determine the solution, what other approaches were discarded, and why.

- note any conditions that were imposed on the investigation and, in particular, on any tests performed.

- explain theoretical assumptions and analyses used. (Usually, only a description of how key equations were "set up" and solved, and the "final" form of the equation itself, would be shown. Any step-by-step derivation of the equation would be placed in an Appendix.)

- show graphs and tables of calculated and/or measured results (when provided a choice, graphs are generally more effective than tables).

- discuss the reasoning or rationale behind conclusions, if not otherwise obvious.

Only when the above topics are needed in a report are they actually presented; if an issue is not important to the report, it is left out. Removing all potential discussion topics that are not needed helps to assure that the report is as short as possible.

Because of the wide variety of topics that may be presented, good authors use subheadings liberally within a Discussion section to provide easy reference to information.

Contents of APPENDICES. Appendices may contain drawings, bill of materials, evaluation data, equation derivations, computer programs, photographs, and other relevant data generated during the investigation. Primarily, an Appendix contains pertinent reference information that should be retained, but whose contents are more-detailed than what should be presented within the report itself.

For example, an investigation might lead to the derivation of an important equation. Although its derivation may have been a key step, generally only the "final" equation is shown within the report itself. Readers can be referred within the discussion to the Appendix that contains the actual equation derivation.

Handwritten copy is acceptable within an Appendix, but all Appendix materials should be legible, logical, and useful.

Variations From The Prescribed Format

Special Needs. Some reporting needs will not fit the prescribed format; in such cases, authors will need to devise their own. However, all technical reports should include the Background and Conclusions sections (or, alternatively, the Executive Summary), and these should always appear at the beginning of the report.

Long Reports. Lengthy reports should generally be avoided, for they are much more difficult to organize/write effectively and are more difficult to read than shorter reports. Development projects are often better served by a series of shorter, timely progress reports than one delayed, comprehensive report.

Report Format Details

Figures and Tables. Effective authors utilize tables and figures (such as illustrations, graphs, and photographs) whenever possible to summarize and illustrate key results. Tables are often very effective for summarizing data, as shown in the example, Table I.

A well-constructed figure can often eliminate a need for lengthy explanation; for example, the figure shown (Figure 1) greatly reduces the amount of explanation needed to communicate the investigator's problems with a motor drive system.

Table I: Prototype processing costs for the UT Robot. ($/robot)

CATEGORY	COST ($/robot)
Cast Parts	$1,964.
"From Stock" Parts	$848.
"Modified" Vendor Parts	$36.
TOTAL	$2,848.

Figures and tables can be placed as a group after the section in which they are referenced, or may be positioned within the text (as done in this report). Either approach can be effective; the key is to be consistent. If a report is produced manually (handwritten or typewriter), it is often easier to place figures at the end of a section. Many computer-based word processing programs greatly simplify the effort needed to insert figures within the report.

Some programs also enable authors to insert the figure's contents directly, which eliminates the task of "cutting-and-pasting" the figure into the finished document. Unless the report must be transmitted electronically (eg. "E-Mail"), authors should not hesitate to use "cut-and-paste" methods when they are more effective or simpler to use for a given occasion.

<u>Headings and Spacing</u>. Recommended heading formats and spacings have been demonstrated throughout this report. Appendix A contains some general specifications concerning report format.

<u>Optional Sections</u>. Reports longer than just a few pages should include a TABLE OF CONTENTS. The Table of Contents often can be integrated within the cover page, as is done for this report. Longer reports may dictate putting the Table of Contents on a separate page behind the cover page.

A BIBLIOGRAPHY or REFERENCES section is needed when the investigation and/or report makes significant use of other written materials.

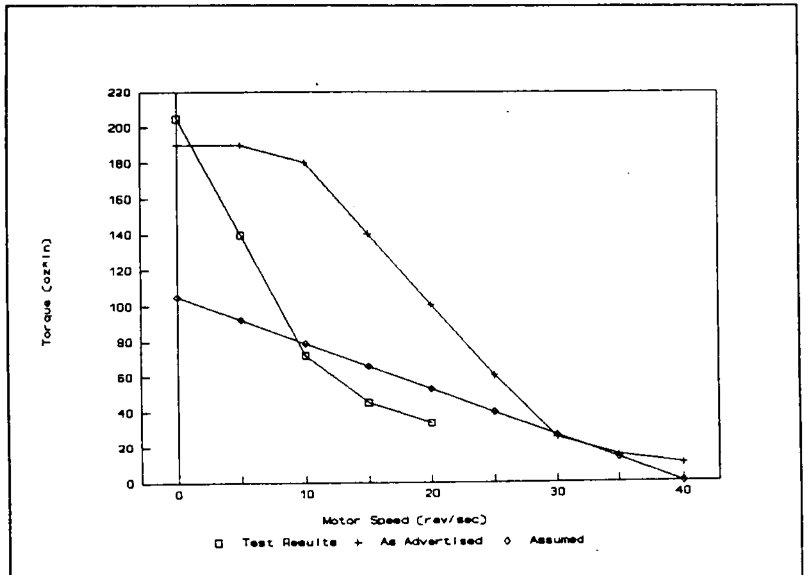


Figure 1: Stepper motor torque comparison. "As advertised" values are from vendor literature; "assumed" values are used to compute theoretical performance. Test results are from testing at the University of Tennessee.

<u>Special Features/Issues Related to Design Course Reports</u>

Most students in a design project course will be required to write a technical report covering their design. The guidelines below apply specifically to the format and preparation of that report.

<u>Team Approach</u>. Most instructors require that all members of the team contribute to writing the report. For many students, this occasion will be the first that they are asked to write a report as a group, rather than as individuals. Effective team authorship requires some special report management considerations:

- Although it will be drafted by several individuals, the report should appear to be written by a single entity; its style and format should be consistent throughout, regardless of the author. One way to improve consistency is to assign a report "editor", who modifies each contribution for style and format.

- The team should create, and agree to, a detailed, written outline before beginning any writing on the report. Some members may claim that they can write without an outline; even if they can, this claim will be true only for their individual reports, not for a team report. All authors need to know how their work contributes to the report to write their sections effectively. Team members then can be assigned to write specific sections from the outline.

- Members may want to write sections of the report (as defined from the agreed-to outline) of which they are most familiar; for example, the member who designed a particular subassembly is likely to write the section describing it. In these cases, the author (and the editor) must remember to make the report understandable to those who are not as familiar with the project. Unfamiliar words, concepts, etc. need to be defined carefully within the text to assure that readers will understand the message.

- When possible, each member should review the entire draft for technical accuracy.

<u>Contents Considerations</u>. The items below appear frequently in design reports, and are provided to assist teams in defining the contents for their reports. Each team must evaluate how (if at all) each topic applies to their project:

- BACKGROUND: the basic design problem that was to be solved during the project.

- CONCLUSIONS: the essential elements of the solution generated by the team; how well the solution meets design objectives (performance, price, etc.); recommended future action (eg. should project continue, major improvements to pursue, etc.).

- DISCUSSION: coverage of specific project items, including...

  + Problem statement and assessment - the Product Concept Description, project criteria and restrictions, key conclusions from assessment of customer needs analysis.

  + Product Design Specification (PDS) summary - discussion of key portions of the PDS, which defines the product's technical requirements.

  + Alternative solutions - description of other solution candidates; process/criteria used for selecting the configuration, reasons for rejecting ones not selected.

  + Final design solution - description of the configuration selected as a solution, unique or important features, reasons for selecting this configuration over others.

  + Detailed design data:
    - product's theory of operation (eg. how it works)
    - description/function of key product components
    - the design's "critical variables" and functions
    - significant design calculations
    - materials selection
    - working drawings, graphs, diagrams, and schematics
    - methods for manufacture

  + Product evaluation activities:
    - tests performed and test results
    - comparison of actual performance versus the Product Design Specification (PDS)
    - assessment of environmental effects on the life, performance, or durability of the product
    - description of potential product impact/hazards on its environment (contamination, noise, etc.)
    - compatibility to the physical and biological limitations of man (safety), where applicable

  + Product cost analysis - Product cost estimate and other pertinent data/costs, in adequate detail to either justify or discourage further product development.

  + Design improvements - recommendations for improving the proposed solution, based on team's analysis and testing.

- Bibliography

- Appendices: (typical contents to include)
  + Problem Statement / Information
  + Product Concept Description
  + Needs Analysis Results
  + Product Design Specification
  + Configuration Selection Process: Sketches/Tables/Charts
  + Assembly Drawings
  + Parts Drawings
  + Bill of Materials
  + Parts and Assembly Cost Estimates
  + Critical component specifications or data sheets
  + Significant Equation Derivations
  + Significant Analyses (simulations, stress analysis, etc.)
  + Results of Failure Mode and Effects Analysis (FMEA)
  + Project Progress reports
  + Assembly Instructions
  + Operating Instructions
  + Operating or analysis software code

Format considerations. The design report often places a few special demands on the format of the report, including:

- Many instructors require that the report be bound or otherwise placed within a folder or report cover. The left margin of the report may have to be adjusted so that the report can be read easily after it is bound.

- The "From:" section of the report's cover page should list the team leader and all team members, with their signatures. The team leader's name should clearly designated; for example, "John Smith, Team Leader".

REFERENCES

Sources for report format and contents:

Becker, Stanley E., "ME 469 Mechanical Design Project", Instructor handouts to students for the University of Tennessee ME 469 course, Spring 1993.

Wilson, Clement C., "Guidelines for Technical Reports", Memo to engineering design students at The University of Tennessee, dated April 10, 1991.

Various authors and titles, from submitted student design reports from course Mechanical Engineering 469, The University of Tennessee, 1992-93.

Sample figure and table are from:

Kennedy, Michael Earl, "Low-Volume Production Design and Manufacture of a Low-Cost Industrial Robot", M.S. thesis in mechanical engineering, The University of Tennessee, Knoxville, May 1991.

APPENDIX A

Format Information for The Report

Forms/Paper to use. If the firm has one, an "internal memo" form or letterhead paper should be used for the first page. Bond or "copier" paper is acceptable for the remainder of the report.

Margins. In general, one-inch (1") margins should be set around the entire page. These margins are adequate for many reports, but an inch-and-one-half (1.5") margin may be necessary on the "binding edge" if the report is to be assembled using a binding process.

The "Cover" Page. The "cover" page for this report is a model for creating a cover page. Primary report recipients are listed in the section marked, "TO:". Other persons who should see the report, but who are not primary recipients, are listed beside "Copies to:". In the "FROM:" section, space is provided for the author(s) to sign the report. The "SUBJECT:" presents the title of the report.

The TABLE OF CONTENTS begins several lines below the "Subject". If the report is so short that a Table of Contents is not used, then BACKGROUND begins in this space. Exceptions are made when the "copies to" and Table of Contents (or Background, in the case of short reports) sections are of the length that their contents do not "fit" well on one page. For example, if the "copies to" list is so long that only two entries of the Table of Contents is shown on the title page, the entire Table is moved to the next page.

Headings. This report models an acceptable format for showing headings and sub-headings. Major headings, like DISCUSSION, are fully capitalized, bolded, underlined, and centered. Major sub-headings are bolded, underlined, and placed flush left. Minor sub-headings are underlined at the start of the first paragraph for that section. Authors using word processors that use scalable fonts and/or italics may want to modify heading formats to take advantage of these features. In all cases, however, the heading format should be consistent throughout the document.

Spacing. The final report is single-spaced. Two blank lines are used after the last paragraph of a section before a main heading such as CONCLUSIONS, while one blank line separates it from its text below. One blank line above and below separates major subheadings. One blank line is inserted between paragraphs.

Good report format dictates that new sections not begin near the bottom of a page unless there is adequate space to include at least two lines of text under the header. Also, well-designed reports never leave just one line of a paragraph "hanging" on a previous or subsequent page. The "widow/orphan protection" on many word processors can prevent this error.

APPENDIX G

PDG Tool - Design Report Template

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Design Project Report - Format and Template"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Design Project Report - Format and Template" are intended to help users write professional, complete design reports. The format document explains and demonstrates the guidelines and format to use when writing technical reports. The format can be useful both for technical reports during product development and for academic "final design reports". The "starter" template is a "nearly-blank" document in the format of the design report, and contains the generic title page, table of contents, and header features that are specified in the Guidelines for Technical Reports. This file can be retrieved and edited when starting a new report.

Filename for Tool:	RPORTFOR.wp	Guidelines for Technical Reports
	RPTSTRTR.wp	Report "Starter" Template

Computer/Software Requirements: To use this tool, user must be able to use WordPerfect 5.1 or another word processing program that is capable of reading/using files written in the WordPerfect format. Computer must be able to read disks formatted in the IBM drive format. If one is not available, a printout of the report guidelines can be distributed and used to provide the necessary report structure information.

Use of this PDG Tool: Start WordPerfect or other word processing program (one capable of reading WordPerfect files) as you would normally do. Retrieve specified Tool file just as you would for any other document. Users can edit, delete, etc. template headers as required, and enter text after loading the template.

Other Notes: Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

DATE: February 1, 1994

TO: Receiver's Name

Copies to: R.P. Smith
J.J. Jones

FROM: Author's Name

____
Author's Name

ADDRESS: Author's Street Address
Firm or Affiliation
City, ST xxxxx-xxxx

SUBJECT: Subject of Report

TABLE OF CONTENTS

BACKGROUND

Begin your background text here ... (See "Guidelines for Technical Reports" paper for full discussion of format requirements.)

CONCLUSIONS

Write your conclusions here ...

DISCUSSION

"First" Header Format

Sub-header format. Begin text under this sub-header here ....

(copy and edit as the headers and sub-headers as needed for your specific report. You may wish to use the below-listed, often-used headers in your Final Design Report. See the "Guidelines for Technical Reports" paper for a full listing of topics. If the below topics are not needed, simply delete or edit them ...)

Problem Statement and Assessment

Product Design Specification (PDS)

Alternative Solutions

Final Design Solution

Theory of Operation.

Key Product Components.

"Critical Variables" and Functions.

Significant Design Calculations.

Materials Selection.

Methods for Manufacture.

Product Evaluation

Product Cost Analysis

Design Improvements

- 1 -

REFERENCES

(Typical reference citation:)

Kennedy, Michael Earl, "Low-Volume Production Design and Manufacture of a Low-Cost Industrial Robot", M.S. thesis in mechanical engineering, The University of Tennessee, Knoxville, May 1991.

APPENDIX A

Typical Contents of the Appendices

(Listed below are items that are often contained in the Appendices: reorder, edit or delete these headers as necessary)

Problem Statement and Related Information

Product Concept Description

Needs Analysis Results

Product Design Specification

Configuration Selection Process: Sketches/Tables/Charts

Assembly Drawings

Parts Drawings

Bill of Materials

Parts and Assembly Cost Estimates

Critical component specifications or data sheets

Significant Equation Derivations

Significant Analyses (simulations, stress analysis, etc.)

Results of Failure Mode and Effects Analysis (FMEA)

Project Progress Reports

Assembly Instructions

Operating Instructions

Operating or Analysis Software Codes

APPENDIX H

PDG Tool - Product Development Profit Worksheet ("Business Plan")

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Product Profit Analysis Worksheet - 'Business Plan'"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Product Profitability Analysis - 'Business Plan'" is intended to help teams determine potential financial returns from a product development effort. It is used with the "Business Targets" section in the "Final Product Definition" phase.

Filename for Tool: BUSPLAN.wk1 Product Profitability Analysis

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be distributed and used to provide the necessary structure; the equations used are presented in the "Business Targets" section of PD Guide (in the Final Product Definition phase).

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input all data in the region called the DATA INPUT ZONE. The spreadsheet will compute profit measures from the data in this zone. Requested data and the computations are defined/explained in PD Guide. In some Lotus configurations, the "undo" feature may have to be turned "off" before loading the spreadsheet to avoid a "out of memory (mem)" error.

Other Notes: Print borders and ranges are set for 8.5x11 paper, compressed mode print on an IBM dot matrix printer; some "printer setup string" modifications may be necessary to use other printers or paper. All other zones other than the DATA INPUT ZONE are "protected", so that the spreadsheet cannot be inadvertently changed; advanced users who want to customize their Profit Analysis must turn the protection feature OFF. In team-based labs, students can run the PD Guide on one computer, while running the spreadsheet using an adjoining computer. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

Business Plan by PDG Today: 08/23/94

Project ....: Product "X"

			YEAR			
End of Year....	1993	1994	1995	1996	1997	1998
Base Year (Intro = 0)	-1	0	1	2	3	4

DATA INPUT ZONE:

Project Name	:	Product "X"
Year Product to be Introduced	:	1994
# of yrs to develop to intro	:	1

INCOME DATA:

Average Sales Price	$0.00	$49.00	$45.00	$39.00	$34.00	$29.00
Total Mkt Size (units/yr)	0	15000	15500	16500	17000	17600
Product Market Share (%)	0.0%	2.0%	5.0%	7.0%	10.0%	12.0%
Services - net ($)	$0	$0	$0	$0	$0	$0
Spares/Parts - net ($)	$0	$0	$0	$0	$0	$0
Options - net ($)	$0	$0	$0	$0	$0	$0
Misc. Income - net ($)	$0	$0	$0	$0	$0	$0

EXPENSES:

Avg. Unit Manuf. Cost ($)		$10.00	$9.50	$9.00	$8.50	$8.00
Engineering - Fixed ($)	$10,000	$20,000	$1,000	$0	$0	$0
Marketing - Fixed ($)	$0	$1,000	$1,000	$1,000	$1,000	$1,000
Marketing - % of sales	0.0%	11.0%	11.0%	11.0%	11.0%	11.0%
G&A - fixed ($)	$0	$2,000	$2,000	$2,500	$2,500	$2,000
G&A - % of sales	0.0%	1.0%	1.0%	1.0%	1.0%	1.0%

Business Plan by PDG   Today: 08/23/94

Project ....: Product "X"

	YEAR					
End of Year....	1993	1994	1995	1996	1997	1998
Base Year (Intro = 0)	-1	0	1	2	3	4
BUSINESS PLAN RESULTS:						
UNIT SALES REVENUES:						
Total Mkt Size (units/yr)	0	15000	15500	16500	17000	17600
Product Market Share (%)	0.0%	2.0%	5.0%	7.0%	10.0%	12.0%
Unit Sales (units)	0	300	775	1155	1700	2112
Average Sales Price ($)	$0.00	$49.00	$45.00	$39.00	$34.00	$29.00
Product Sales - YR ($)	$0	$14,700	$34,875	$45,045	$57,800	$61,248
UNIT SALES EXPENSES:						
Avg. Unit Mfg. Cost ($)	$0.00	$10.00	$9.50	$9.00	$8.50	$8.00
Cost of Goods Sold ($)		$3,000	$7,363	$10,395	$14,450	$16,896
SUPPORT EXPENSES:						
Engineering - TOTAL ($)	$10,000	$20,000	$1,000	$0	$0	$0
Marketing - Fixed ($)	$0	$1,000	$1,000	$1,000	$1,000	$1,000
Marketing - % Sales ($)	$0	$1,617	$3,836	$4,955	$6,358	$6,737
Marketing - TOTAL	$0	$2,617	$4,836	$5,955	$7,358	$7,737
G&A - fixed ($)	$0	$2,000	$2,000	$2,500	$2,500	$2,000
G&A - % of sales ($)	$0	$147	$349	$450	$578	$612
G&A - TOTAL	$0	$2,147	$2,349	$2,950	$3,078	$2,612
Operating Expense ($)	$10,000	$27,381	$13,021	$14,860	$17,794	$18,087
TOTAL EXPENSES ($)	$10,000	$30,381	$20,384	$25,255	$32,244	$34,983
Profit - YR ($)	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265

Business Plan by PDG Today: 08/23/94

Project ....: Product "X"

	YEAR					
End of Year....	1993	1994	1995	1996	1997	1998
Base Year (Intro = 0)	-1	0	1	2	3	4
PERFORMANCE MEASURES:						
Product Profit - YR ($)	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265
Return on Sales (%) - YR		-106.7%	41.6%	43.9%	44.2%	42.9%
Gross Margin ($)	$0	$11,700	$27,513	$34,650	$43,350	$44,352
Gross Margin (%)		79.6%	78.9%	76.9%	75.0%	72.4%
Cumulative Sales ($)	$0	$14,700	$49,575	$94,620	$152,420	$213,668
Cumulative Profit ($)	($10,000)	($25,681)	($11,190)	$8,600	$34,156	$60,421
Cum Gross Margin ($)	$0	$11,700	$39,213	$73,863	$117,213	$161,565
Avg. Return on Sales (%)		-174.7%	-22.6%	9.1%	22.4%	28.3%
Avg. Gross Margin (%)		79.6%	79.1%	78.1%	76.9%	75.6%
% Volume Chg, Yr-to-Yr			158.3%	49.0%	47.2%	24.2%
% Chg $ Sales, Yr-to-Yr			137.2%	29.2%	28.3%	6.0%
% COGS chg, Yr-to-Yr			145.4%	41.2%	39.0%	16.9%
% Price Chg, Yr-to-Yr			-8.2%	-13.3%	-12.8%	-14.7%
% Unit Cost Chg Yr-to-Yr			-5.0%	-5.3%	-5.6%	-5.9%
Engr. (% of total expns)	100.0%	65.8%	4.9%	0.0%	0.0%	0.0%
Mkting (% of total expns)	0.0%	8.6%	23.7%	23.6%	22.8%	22.1%
G&A (% of total expense)	0.0%	7.1%	11.5%	11.7%	9.5%	7.5%
INCLUDING EFFECT OF OTHER REVENUES/EXPENSES:						
Profit from Product ($)	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265
Total Other Profits ($)	$0	$0	$0	$0	$0	$0
NET TOTAL Profit-YR ($)	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265
% Chg $ Profit, Yr-to-Yr				36.6%	29.1%	2.8%
% Return on Product Sales		-106.7%	41.6%	43.9%	44.2%	42.9%
Cum NET TOTAL Profit ($)	($10,000)	($25,681)	($11,190)	$8,600	$34,156	$60,421
Avg. Return on Sales (%)		-174.7%	-22.6%	9.1%	22.4%	28.3%

Business Plan by PDG   Today: 08/23/94

Project ....: Product "X"

			YEAR			
End of Year....	1993	1994	1995	1996	1997	1998
Base Year (Intro = 0)	-1	0	1	2	3	4
"SUMMARY" PAGE:						
Average Sales Price	$0.00	$49.00	$45.00	$39.00	$34.00	$29.00
Average Unit Mfg. Cost	$0.00	$10.00	$9.50	$9.00	$8.50	$8.00
Gross Margin (%)		79.6%	78.9%	76.9%	75.0%	72.4%
Unit Sales (units)	0	300	775	1155	1700	2112
TOTAL SALES ($)	$0	$14,700	$34,875	$45,045	$57,800	$61,248
Cost of Goods Sold ($)		$3,000	$7,363	$10,395	$14,450	$16,896
Engineering - TOTAL ($)	$10,000	$20,000	$1,000	$0	$0	$0
Marketing - TOTAL ($)	$0	$2,617	$4,836	$5,955	$7,358	$7,737
G&A - TOTAL ($)	$0	$2,147	$2,349	$2,950	$3,078	$2,612
Operating Expense ($)	$10,000	$27,381	$13,021	$14,860	$17,794	$18,087
TOTAL EXPENSES ($)	$10,000	$30,381	$20,384	$25,255	$32,244	$34,983
Product Profit - YR ($)	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265
Cumulative Profit ($)	($10,000)	($25,681)	($11,190)	$8,600	$34,156	$60,421
Return on Sales (%) - YR		-106.7%	41.6%	43.9%	44.2%	42.9%
Avg. Return on Sales (%)		-174.7%	-22.6%	9.1%	22.4%	28.3%
Profit incl. other income	($10,000)	($15,681)	$14,491	$19,790	$25,556	$26,265
"Fixed" Costs	$10,000	$23,000	$4,000	$3,500	$3,500	$3,000
"Fixed" Csts (% of Expns)	100.0%	75.7%	19.6%	13.9%	10.9%	8.6%

APPENDIX I

PDG Tool - Parts Cost Estimate Worksheet

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Parts Manufacturing Cost Worksheet"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Parts Manufacturing Cost Worksheet" is intended to help teams compute a simply-defined, estimated cost for machined parts. Worksheet computes "per part" costs of product components, based on setup, processing, and tooling needs, while providing options for "batch" processes and different process costs.

Filename for Tool: PARTCOST.wk1 Parts Cost Calculation Worksheet

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be distributed and used to provide the necessary structure.

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input all data in the region called the DATA INPUT ZONE. The spreadsheet will compute cost and manufacturing results from the data in this zone. In some Lotus configurations, the "undo" feature may have to be turned "off" before loading the spreadsheet to avoid a "out of memory (mem)" error.

Other Notes: Print borders and ranges are set for 8.5x11 paper, compressed mode print on an IBM dot matrix printer; some "printer setup string" modifications may be necessary to use other printers or paper. All other zones other than the DATA INPUT ZONE are "protected", so that the spreadsheet cannot be inadvertently changed; advanced users who want to customize their cost estimate must turn the protection feature OFF. In team-based labs, students can run the PD Guide on one computer, while running the spreadsheet using an adjoining computer. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

PARTS MANUFACTURING COST ASSESSMENT
Product Name

Prod. Qty Mfg. in Batch: 3

Cost Structure ($/hr) ...	Type 1	Type 2
Set-up Costs:	$25.00	$10.00
Process Costs:	$20.00	$6.00

PART NUMBER P011
PART NAME .... XY Plate

--------- PART DATA INPUT SECTION ----------

Part Number		P011
Part Name		XY Plate
Quantity Required per Product	(#/prdct)	4
MATERIAL COSTS:		
Matl. Costs, per unit (gross)	($/unit)	$0.09
-- Unit of Measure		in^2
-- # of units required per part	(unit/prt)	40
Per Order ("lot") Charges, if any	($/lot)	$20.00
Volume Purchase Discounts, if any	(%)	2.0%
OPERATIONS COSTS:		
Setup Time to begin Batch, Type 1	(hr/lot)	0.2
Setup Time per Ea. Part, Type 1	(hr/part)	1.5
Processing Time Per Part, Type 1	(hr/part)	2.0
Setup Time to begin Batch, Type 2	(hr/lot)	0.1
Setup Time per Ea. Part, Type 2	(hr/part)	0.2
Processing Time Per Part, Type 2	(hr/part)	0.3
TOOLING COSTS:		
Standard Tooling	($/tool)	$40.00
-- Life of Std. Tools, # parts	(#/tool)	50
Special Tool #1	($/tool)	$100.00
-- Life of Sp. Tool #1, # parts	(#/tool)	200
Special Tool #2	($/tool)	$45.00
-- Life of Sp. Tool #2, # parts	(#/tool)	350
Disposables	($/part)	$1.00

PARTS MANUFACTURING COST ASSESSMENT
Product Name

Prod. Qty Mfg. in Batch: 3

Cost Structure ($/hr) ...	Type 1	Type 2
Set-up Costs:	$25.00	$10.00
Process Costs:	$20.00	$6.00

PART NUMBER		P011
PART NAME		XY Plate
-------- PARTS COST RESULTS SECTION ---------		
Quantity Required per Product	(#/prdct)	4
MATERIAL COSTS:		
Material Cost, "List" per Part	($/part)	$3.60
Order Charge Allocation	($/part)	$1.67
Volume Discount, per part	($/part)	($0.07)
SUBTOTAL	($/part)	$5.19
TOTAL	($/prdct)	$20.78
OPERATIONS COSTS:		
Initial Setup Cost Allocation	($/part)	$0.50
Per Part Setup, Total	($/part)	$39.50
Processing, Total	($/part)	$41.80
SUBTOTAL	($/part)	$81.80
TOTAL	($/prdct)	$327.20
Type 1 Operations, Total	($/part)	$77.92
Type 2 Operations, Total	($/part)	$3.88
TOOLING COSTS:		
Standard Tool Allocation	($/part)	$0.80
Special Tool #1 Allocation	($/part)	$0.50
Special Tool #2 Allocation	($/part)	$0.13
Disposables	($/part)	$1.00
SUBTOTAL	($/part)	$2.43
TOTAL	($/prdct)	$9.71
PART COST, TOTAL (per part)	($/part)	$89.42
PART COST, TOTAL (per product)	($/prdct)	$357.69

PARTS MANUFACTURING COST ASSESSMENT
Product Name

Prod. Qty Mfg. in Batch: 3

Cost Structure ($/hr) ...	Type 1	Type 2
Set-up Costs:	$25.00	$10.00
Process Costs:	$20.00	$6.00

PART NUMBER		P011
PART NAME		XY Plate

----- MFG. PREPARATION RESULTS SECTION ------

MATERIAL REQUIREMENTS, per BATCH (or "lot"):		
Total Matl Req'd per Batch ...	in^2	480
Material Cost, "List"	($/lot)	$43.20
Per Order ("lot") Charges	($/lot)	$20.00
Volume Discounts	($/lot)	($0.86)
TOTAL	($/lot)	$62.34
OPERATIONS NEEDS, per BATCH (or "lot"):		
Total # of Parts to Make, batch	(#/lot)	12
Process Type 1 - Time Req'd:		
Initial Setup Time	(hrs/lot)	0.2
Per Part Setups Time, Total	(hrs/lot)	18.0
Processing Time, Total	(hrs/lot)	24.0
SUBTOTAL	(hrs/lot)	42.2
Process Type 2 - Time Req'd:		
Initial Setup Time	(hrs/lot)	0.1
Per Part Setups Time, Total	(hrs/lot)	2.4
Processing Time, Total	(hrs/lot)	3.6
SUBTOTAL	(hrs/lot)	6.1
Operations Costs:		
Operations, Type 1, Total	($/lot)	$935.00
Operations, Type 2, Total	($/lot)	$46.60
TOTAL	($/lot)	$981.60
TOOLING CONSUMPTION, per BATCH (or "lot"):		
Standard Tool Use, this lot	(% life)	24.0%
Special Tool #1 Use, this lot	(% life)	6.0%
Special Tool #2 Use, this lot	(% life)	3.4%
TOTAL	($/lot)	$29.14
BATCH COST, TOTAL	($/lot)	$1,073.08

APPENDIX J

PDG Tools - Milestone, Design, and Design Course Schedule Worksheets

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Target Milestones Worksheet"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Target Milestones Worksheet" is intended to help teams establish their "Project Milestones", using the ones defined throughout the "Target Milestones" section of PD Guide (in "Final Product Definition and Project Targets" phase).

Filename for Tool: MILESTON.wk1 Project Milestones Chart / Utility

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be distributed and used to provide an outline of the necessary structure; the milestone definitions are presented in the "Target Milestones" section of PD Guide.

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input all schedule dates in the indicated region. The spreadsheet will generate the bar or "Gantt" chart automatically. Milestone definitions are explained in PD Guide. In some Lotus configurations, the "undo" feature may have to be turned "off" before loading the spreadsheet to avoid a "out of memory (mem)" error.

Other Notes: Print borders/ranges are set for 8.5x11 paper, compressed mode print on IBM dot matrix printers; some "printer setup" modification may be necessary to use other printers/paper. Zones other than the input dates area are "protected", so that the spreadsheet cannot be inadvertently changed; advanced users who want to customize schedules must turn the protection feature OFF. In team-based labs, students can run the PD Guide on one computer, while running the spreadsheet on another. Users should save their work under a new filename to avoid altering the existing file. The start/end dates provided are examples - do not use them verbatim.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

TARGET MILESTONES by PDG TODAY: 23-Aug-94

Project: Your Project Name

For month ending ...
Base Month (Intro = 0).......

MILESTONE DESCRIPTION	START DATE	COMPLETE DATE	<	Sep-93 -10	Oct-93 -9	Nov-93 -8	Dec-93 -7	Jan-94 -6	Feb-94 -5
PRIMARY MILESTONES:									
First Customer Delivery	01-Jul-94								
Product Announcement	01-Jun-94								
Start of Production	01-Jun-94								
Manufacturing Pilot Run	01-May-94	15-May-94							
Product Design & Evaluation:	01-Jan-94	25-Apr-94						|------	-------
+ Design release	20-Apr-94	25-Apr-94							
+ Product Verification Tests	01-Mar-94	15-Apr-94							
+ Configuration Design	01-Jan-94	25-Jan-94						|----|	
Manufacturing System Design:	01-Dec-93	01-May-94					|------	------	-------
+ Approve Long-lead Items	15-Jan-94	25-Jan-94						|----|	
Marketing & Dist. Preparation:	01-Mar-94	01-May-94							
+ Pre-Market Tests	01-Mar-94	15-Mar-94							
+ "Beta" Tests	01-Mar-94	15-Apr-94							
Final Prod. Def'n + Targets	01-Dec-93	15-Dec-93					|----|		
OTHER MILESTONES:									
Transfer Operations to Mfg Org	01-Sep-94	01-Dec-94							
Project Review #1	15-Dec-93	18-Dec-93					|----|		
Project Review #2	25-Jan-94	28-Jan-94						|----|	
Project Review #3	01-Mar-94	03-Mar-94							
Project Review #4									
Product Options Development	01-Jun-94	01-Sep-94							
Derivative #1 Development	01-Sep-94	31-Dec-94							

USER INSTRUCTIONS and USER HINTS

Revision 1.0 - 08/25/94

"Design Schedule Worksheet"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Design Schedule" is intended to help teams establish an appropriate Design Phase Schedule. The schedule items correspond to PD Guide's "Product Design and Evaluation" phase model.

Filename for Tool: DESSCHED.wk1 Design and Evaluation Phase Schedule

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be used to provide an outline of the structure; the definitions are presented in the "Design Planning and Scheduling" section of PD Guide (in Product Design and Evaluation phase).

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input all schedule dates in the indicated region; if an item does not apply, use "space" (or /Range Erase) to erase the dates. The spreadsheet generates the bar or "Gantt" chart automatically. Milestone definitions are explained in PD Guide. In some Lotus configurations, the "undo" feature may have to be turned "off" before loading the spreadsheet to avoid a "out of memory (mem)" error.

Other Notes: Print borders/ranges are set for 8.5x11 paper, compressed mode print on IBM dot matrix printers; some "printer setup" modification may be necessary to use other printers/paper. Zones other than the input dates area are "protected", so that the spreadsheet cannot be inadvertently changed; advanced users who want to customize schedules must turn the protection feature OFF. In team-based labs, students can run the PD Guide on one computer, while running the spreadsheet on another. Users should save their work under a new filename to avoid altering the existing file. The start/end dates provided are examples - do not use them verbatim.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

DESIGN/EVALUATION SCHEDULE TODAY: 23-Aug-94

For Period Beginning ...

Project: Your Project Name

Base Month (Intro = 0).......

MILESTONE DESCRIPTION	START DATE	COMPLETE DATE	<	01-Sep 1993	15-Sep 1993	01-Oct 1993	15-Oct 1993	01-Nov 1993	15-Nov 1993
First Customer Delivery	01-Jul-94								
PRIMARY DESIGN/EVAL ITEMS:									
Design Release - REVIEW	01-May-94	15-May-94							
Product Validation Testing	01-Apr-94	25-Apr-94							
Design-Build-Test Cycle #3:	01-Mar-94	31-Mar-94							
+ Corrective Action	20-Mar-94	31-Mar-94							
+ Comprehensive Testing	01-Mar-94	25-Mar-94							
Design-Build-Test Cycle #2:	01-Feb-94	28-Feb-94							
+ Corrective Action	20-Feb-94	28-Feb-94							
+ Comprehensive Testing	01-Feb-94	25-Feb-94							
Initial Build and Test:	01-Dec-93	31-Jan-94							
+ Corrective Action	20-Jan-94	31-Jan-94							
+ Comprehensive Testing	01-Jan-94	20-Jan-94							
+ Proto. Build & Debug	01-Dec-93	31-Dec-93							
Initial Creation / Design:	01-Oct-93	30-Nov-93				|-------------------------|			
+ INTERNAL Design Review	25-Nov-93	30-Nov-93							|----|
+ Parts Design	01-Nov-93	20-Nov-93						|-----------|	
+ Subsystems Design	15-Oct-93	10-Nov-93					|-----------|		
+ Configuration REVIEW	20-Oct-93	24-Nov-93					|------------------|		
+ Configuration Model/Proto.	15-Oct-93	20-Oct-93					|----|		
+ Configuration DESIGN	01-Oct-93	20-Oct-93				|-----------|			
Prod. Design Spec. (PDS)	01-Dec-93	15-Dec-93							
OTHER RELATED ITEMS:									
Market/Field Test Support #1	01-Sep-94	01-Dec-94							
Market/Field Test Support #2	01-Apr-94	25-Apr-94							
Official Tests (UL, etc.)	01-Apr-94	15-Apr-94							
Design Review - Special #1	01-Mar-94	03-Mar-94							
Design Review - Special #2									
"Long-Lead" Items Deadline #1	01-Nov-93	15-Nov-93						|-----------|	
"Long-Lead" Items Deadline #2									

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Student Project Schedule Worksheet"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Student Design Project Schedule" is intended to help student teams establish an appropriate schedule for a capstone design class assignment. It includes items for design, construction and evaluation of a prototype product. The provided items are those that PD Guide finds to be often needed in a student design project.

Filename for Tool: CLASSCHD.wk1 Design Course Project Schedule

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be used to provide an outline of the structure; the definitions are presented in the "Design Planning and Scheduling" section of PD Guide (in Product Design and Evaluation phase).

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input all schedule dates in the indicated region; if an item does not apply, use "space" (or /Range Erase) to erase the dates. The spreadsheet generates the bar or "Gantt" chart automatically. In some Lotus configurations, the "undo" feature may have to be turned "off" before loading the spreadsheet to avoid a "out of memory (mem)" error.

Other Notes: Print borders/ranges are set for 8.5x11 paper, compressed mode print on IBM dot matrix printers; some "printer setup" modification may be necessary to use other printers/paper. Zones other than the input dates area are "protected", so that the spreadsheet cannot be inadvertently changed; advanced users who want to customize schedules must turn the protection feature OFF. In team-based labs, students can run the PD Guide on one computer, while running the spreadsheet on another. Users should save their work under a new filename to avoid altering the existing file. The start/end dates provided are examples - do not use them verbatim.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

```
CAPSTONE DESIGN CLASS SCHEDULE    TODAY: 23-Aug-94

                                                               For WEEK Beginning ...
                     Project:  Your Project Name
                        Team:  Your Team Name

                                 START   COMPLETE |    09-Jan 16-Jan 23-Jan 30-Jan 06-Feb 13-Feb
    MILESTONE DESCRIPTION        DATE      DATE   |  <   1994   1994   1994   1994   1994   1994
-----------------------------  --------- --------- | -- ------ ------ ------ ------ ------ ------
                                                   |
PRIMARY DESIGN/EVAL ITEMS:                         |
------------------------------                     |
Corrective Action:             01-May-94 07-May-94 |
 + Test Changes                02-May-94 07-May-94 |
 + Identify needed changes     01-May-94 03-May-94 |
                                                   |
Initial Test:                  22-Apr-94 30-Apr-94 |
 + Perform Tests               24-Apr-94 30-Apr-94 |
 + Get equip., set-up tests    22-Apr-94 24-Apr-94 |
 + Define test methods         22-Apr-94 23-Apr-94 |
                                                   |
Initial Build:                 15-Mar-94 22-Apr-94 |
 + Assemble proto. system      15-Apr-94 20-Apr-94 |
 + Assemble sub-assy's         08-Apr-94 15-Apr-94 |
 + Make "custom" parts         15-Mar-94 08-Apr-94 |
 + Order/obtain raw materials  01-Mar-94 15-Mar-94 |
 + Order supplier parts        01-Mar-94 15-Apr-94 |
                                                   |
Subsystem & Parts Design:      01-Feb-94 10-Mar-94 |                         |--------------------
 + Assembly/exploded drawings  25-Mar-94 31-Mar-94 |
 + Bill of Material            20-Mar-94 25-Mar-94 |
 + Product Cost Estimate       10-Feb-94 15-Mar-94 |                                |-------------
 + Drawing Revisions           09-Mar-94 10-Mar-94 |
 + Define Supplier Parts       25-Feb-94 05-Mar-94 |
 + Parts Drawings Review       06-Mar-94 08-Mar-94 |
 + Parts Drawings              22-Feb-94 05-Mar-94 |
 + Failure Mode Anlysis (FMEA) 20-Feb-94 25-Feb-94 |
 + Layouts Review/Checks       20-Feb-94 22-Feb-94 |
 + Subsystems Layouts          10-Feb-94 20-Feb-94 |                                |-------------
 + Analyses / Simulations      01-Feb-94 20-Feb-94 |                         |--------------------
 + Allocations/Requirements    01-Feb-94 10-Feb-94 |                         |-----------|
                                                   |
Configuration Design:          20-Jan-94 10-Feb-94 |           |-------------------------|
 + Select/Rev'w Configuration  05-Feb-94 10-Feb-94 |                         |-----------|
 + Configuration model/proto.  05-Feb-94 10-Feb-94 |                         |-----------|
 + "Zero" Drawing              28-Jan-94 08-Feb-94 |                  |------------------|
 + Define Modules              28-Jan-94 08-Feb-94 |                  |------------------|
 + Create/evaluate Candidates  20-Jan-94 05-Feb-94 |           |------------------|
```

CAPSTONE DESIGN CLASS SCHEDULE   TODAY: 23-Aug-94

```
                                                               For WEEK Beginning ...
                     Project:  Your Project Name
                        Team:  Your Team Name

                                 START    COMPLETE |   09-Jan 16-Jan 23-Jan 30-Jan 06-Feb 13-Feb
    MILESTONE DESCRIPTION         DATE      DATE   | <  1994   1994   1994   1994   1994   1994
 -----------------------------  --------- --------- | -- ------ ------ ------ ------ ------ ------
 PREPARE FOR DESIGN:                                |
 -----------------------------                      |
 Prod. Design Spec. (PDS)       15-Jan-94 20-Jan-94 |   |-----------|
 Business Targets               15-Jan-94 20-Jan-94 |   |-----------|
 Final Product Definition       13-Jan-94 15-Jan-94 |   |----|
 Technology Investigations      13-Jan-94 20-Jan-94 |   |-----------|
 Competitive Benchmarking       13-Jan-94 20-Jan-94 |   |-----------|
 Create Development Schedule    13-Jan-94 13-Jan-94 |   |----|
                                                    |
 REPORTING & CONTROL:                               |
 -----------------------------                      |
 Final Design Report            04-May-94 09-May-94 |
 Final Presentation             04-May-94 09-May-94 |
 Mid-Term Presentation          12-Mar-94 15-Mar-94 |
                                                    |
 Progress Report / Mtg. - #6    15-Apr-94 15-Apr-94 |
 Progress Report / Mtg. - #5    01-Apr-94 01-Apr-94 |
 Progress Report / Mtg. - #4    15-Mar-94 15-Mar-94 |
 Progress Report / Mtg. - #3    01-Mar-94 01-Mar-94 |
 Progress Report / Mtg. - #2    15-Feb-94 15-Feb-94 |                                      |----|
 Progress Report / Mtg. - #1    01-Feb-94 01-Feb-94 |                        |----|
                                                    |
```

APPENDIX K

PDG Tool - Bill of Materials Template

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Parts List Worksheet - Bill of Material"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Parts List Worksheet - Bill of Material" is intended to help student teams establish an appropriate listing of the machine parts used for their capstone design class assignment. The provided column listings are those that PD Guide finds to be often used in industrial-level Bills of Material.

Filename for Tool: PARTLIST.wk1 Bill of Material Format

Computer/Software Requirements: To use this tool, user must be able to use Lotus 1-2-3 or other spreadsheet program capable of reading/using files written in *.WK1 format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout can be used to provide an outline of the structure.

Use of this PDG Tool: Start Lotus 1-2-3 or other spreadsheet program (capable of reading *.WK1 files) as you would normally do. Retrieve specified Tool file just as you would for any spreadsheet. Input part names and related data as shown in the example listing provided in the worksheet.

Other Notes: Print borders/ranges are set for 8.5x11 paper, compressed mode print on IBM dot matrix printers; some "printer setup" modification may be necessary to use other printers/paper. As opposed to many other of the Lotus Tools, no zone on this spreadsheet is "protected", so that entries can be made anywhere on the spreadsheet. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

BILL OF MATERIAL STRUCTURE by PDG

PROJECT: Project "X"

DATE : 23-Aug-94

P/N	PART NAME, DESCRIPTION	QTY REQ'D	REL TO AS'SY P/N	AS'SY LEVEL	SUPPLIER	SUPPLIER P/N
P/N A516: ASSEMBLY, PRODUCT						
P001	Support, Corner	4	A516	1	Internal Ass'y	---
A521	Assembly, Slider	4	A516	1	Internal Ass'y	---
A541	Assembly, Cartridge, X-Y	1	A516	1	Internal Ass'y	---
S406	Shaft, X Guide	2	A516	1	Thomson	
S407	Shaft, X Control	1	A516	1	Thomson	
S408	Shaft, Y Guide	2	A516	1	Thomson	
S409	Shaft, Y Control	1	A516	1	Thomson	
S451	SHCS, 0.312 UNF, 0.75 lng	8	A516	1	McMaster-Carr	91252A581
S491	Nut, Hex, 0.312-24 UNF	8	A516	1	Knox Bolt	(none)
P/N A521: ASSEMBLY, SLIDER						
P021	Housing, Slider	1	A521	2	Internal Mfg.	---
S401	Brg, Linear, 1" Tube Dia.	1	A521	2	Thomson	A162100
S402	Seal, Lin Brg, 1" Dia.	2	A521	2	Thomson	S-1000
P/N A541: ASSEMBLY, X-Y CARTRIDGE						
P051	Cartridge, right-angle	1	A541	2	Internal Mfg.	---
S401	Brg, Lin, 1" Tube Dia.	4	A541	2	Thomson	A162100
S402	Seal, Lin Brg, 1" Dia.	4	A541	2	Thomson	S-1000
S496	Pin, Dowel, 0.25d, 0.751	2	A541	2	McMaster-Carr	90145A540

APPENDIX L

PDG Tool - Price Conversion Template

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"Price Conversion Table"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The "Price Conversion Table" is intended to be used in conjunction with the Business Targets portion of the PD Guide (in the Final Product Definition and Project targets phase). This tool is a simple table to illustrate the conversion of a product's "retail" price to the manufacturing firm's actual cash received. The objective of this exercise is to show students that the price paid for many products is *not* the same as the price that is received by the manufacturer.

Filename for Tool: PRCE2MFR.wp Price Conversion Worksheet

Computer/Software Requirements: To use this tool, user must be able to use WordPerfect 5.1 or another word processing program that is capable of reading/using files written in the WordPerfect format. Computer must be able to read disks formatted in the IBM drive format. If not available, a printout of the table can be used.

Use of this PDG Tool: Start WordPerfect or other word processing program (one capable of reading WordPerfect files) as you would normally do. Retrieve specified Tool file just as you would for any other document. Teams can enter the required values directly into the table.

Other Notes: In team-based labs, students can run the PD Guide on one computer, while entering their pricing data into the template using an adjoining computer. Users should save their work under a new filename to avoid altering the existing file.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

"Quick Estimate" Worksheet: Derive Manufacturer's Price from Customer Price (Customer "Price-Based" Approach)		
Product Price or Cost Category	How Price/Cost is estimated or computed	Price or Cost ($)
Retail price	Based on evaluation of customers' value perceptions	
Retailer "markup" amount, including retailer costs and profit	Retailer "markup" for this product class in the selected market channels; if not known, estimate as 25-100% markup from wholesale price (20-50% of retail price)	
Target Wholesale Price	Subtract retailer markup from retail price	
Wholesaler "markup" amount, including wholesaler costs and profit	Wholesaler "markup" for this product class in the selected market channels; if not known, estimate as 10-25% markup from manufacturer's price (9%-20% of wholesale price)	
Target Manufacturer's Price	Subtract wholesaler markup from Wholesale price	

APPENDIX M

PDG Tools - Parts Drawing Template and "Critical" Symbols

USER INSTRUCTIONS and USER HINTS
Revision 1.0 - 08/25/94

"CAD Drawing Frames"

part of PDG Tools in the Product Development Guide

General Description of all PDG Tools: PDG Tools are part of the Product Development Guide ("PD Guide"). PDG Tools are "generic" and designed for use with the commercial programs WordPerfect, Lotus 1-2-3, and IBMCAD (or other programs which can read these files).

Description/Purpose of this specific Tool: The drawing frames assist students with good drawing practice and control. The drawing templates may be used by themselves or in conjunction with the "Parts Design" portion of the PD Guide (in the Product Design and Evaluation phase).

Filename for Tool:	AFRAME .cad	CAD Drawing Frame ("A" size)
	CTEMPLAT.cad	CAD Drawing Frame - template ("C" size)
	COVERLAY.cad	CAD Drawing Frame - overlay ("C" size)
	DTEMPLAT.cad	CAD Drawing Frame - template ("D" size)
	DOVERLAY.cad	CAD Drawing Frame - overlay ("D" size)

Computer/Software Requirements: To use this tool, user must be able to use IBMCAD™, or another drawing program capable of converting/using drawing files of a *.DXF format. Computer must be able to read disks formatted in IBM drive format. If IBMCAD is used, select the filenames ending in ".CAD"; for DXF versions, use the "*.DXF" version.

Use of this PDG Tool: Start IBMCAD or other CAD program (one capable of reading DXF files) as you would normally do. Retrieve the "template" file for the size drawing you want to use, just as you would for any other drawing file. Use text edit feature to input requested text data. Immediately before plotting a "final" copy of a "C" and "D" size drawing, merge the "overlay" file over the "template" file to create the full drawing frame. The "C" and "D" frames are split into two portions (overlay and template) so that "draft" plots of drawings do not "waste time" plotting the entire frame.

Other Notes: Users should save their work under a new filename to avoid altering the existing file. Depending on the particular CAD system, you may or may not have to use a "conversion utility" in your CAD program to convert the DXF file into the format used by that program.

Disclaimer: PD Guide does NOT warrant the fitness of any tool for any particular use nor the accuracy of the tool itself; users assume all risk associated with the use these tools in their product development activities.

REL FOR ASM	QTY	TECHNICAL APPROVALS			INT	DATE	EC #	P/N P/N HERE
		MECHANICAL						"A" SIZE TEMPLATE 0 .25" REAL SIZE

TEAM NAME

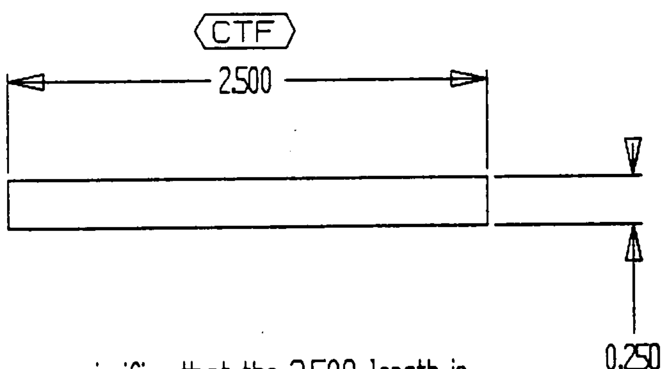
SCALE 1:1	DIMENSIONS IN INCHES		PART # P/N HERE		UT
MATERIAL MATL	TOLERANCES UNLESS NOTED				
	LINEAR +/-	LINTOL	TITLE DRAWING TITLE		
	ANGLES +/-	ANGTOL			
OTHER NOTES	RADII UNLESS NOTED	RADTOL	DESIGNER	DES	00 XXX 91
	EDGE/ CORNER BREAKS OUTSIDE MAX	OUTBRK	CHECKED	CHK	00 XXX 91
IBMCAD FILE FILENAME.001	INSIDE MAX	INBRKL	APPROVED	APP	00 XXX 91

"Critical To" Table from CRITICAL.SYM file:

DIMENSIONAL 'KEY' CODES:

SYM	SYMBOL DESCRIPTION
⟨CTA⟩	"CRITICAL TO ASSEMBLY" DIMENSION
⟨CTF⟩	"CRITICAL TO FUNCTION" DIMENSION
⟨CTM⟩	"CRITICAL TO MANUFACTURE" DIMENSION

Example Use of "Critical To" Symbol on Part:



... signifies that the 2.500 length is critical to the function of the part in its intended assembly.

APPENDIX N

Student Survey Report, ME 455 Course, Fall 1992

PRODUCT DEVELOPMENT GUIDE

Results of ME 455 Student Survey - September 1992

Michael E. Kennedy
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The University of Tennessee

SUMMARY

Twenty-seven (27) University of Tennessee mechanical engineering students in the senior-level "Introduction to Design" course (course number ME 455) completed a survey pertaining to their perceptions of the UT-SEDP Product Development Guide (the "Guide"), a computer-based aid for teaching product development. The survey was conducted primarily to identify additional software features and improvement needs, and specifically was not constructed to prove formally the educational efficacy of the Guide as a teaching aid. Nonetheless, student views were also solicited concerning the relative effectiveness of the Guide as a supplement or replacement to regular instruction and textbooks.

Students completed two assignments using the Guide, then were asked for their opinions using 14 "agree-disagree" questions and five short-answer questions. The "agree-disagree" questions provided a statement, then asked the student to agree or disagree with the statement on a seven point scale. Comments were solicited to obtain student views on the Guide's operation, format, layout, and ease of use. Students were also asked to suggest items or concepts that should be covered in the tutorial for the Guide, which at the time of the survey, had not yet been developed. The responses were tabulated and analyzed statistically to determine student views on the Guide. Comments were compiled and grouped by subject.

CONCLUSIONS

The surveyed group developed several very positive opinions about the Guide's potential value in design education; students very strongly indicated that:

- they prefer to use the Guide than to obtain the same material from a textbook (question #10)
- they believe that they learned something important about the product development process (question #11)
- they think the Guide will help them complete their design project that they will be assigned in the subsequent design course, ME 469 (question #13)

Students also adapted very well to the format and structure of the Guide; they clearly reported that:

- the Guide was easy to use, even without a tutorial or previous training (question #1)
- the Guide's instructions (even as incomplete as they were at the time of the survey) were adequate to enable them to utilize the Guide effectively (question #2)
- they had no trouble navigating through the menus in the Guide (question #3)
- completing a problem assignment helped them to understand better the contents of the Guide (question #12)

Students expressed less strong (but still statistically significant) positive opinions regarding several other aspects of the Guide. Students said that:

- they prefer to use the Guide than to have a traditional lecture on the same material (question #9)
- they perceive that they understand the development process much better than they did before they used the Guide (question #8)
- they did not have much trouble finding the information that they needed from the Guide to complete their assignments (question #5)
- that they were able to use the Guide without an introductory lecture on how to use the Guide (question #7)

Students were split in their opinions regarding:

- the need to complete a tutorial (which was not available when these students completed this survey) before using the Guide effectively (question #6)
- whether bar menus used for general descriptions of each development phase should be replaced with "press a number" menus (question #4)

DISCUSSION of METHODOLOGY

Background and Goals

A survey was distributed to senior-level design students to capture their perceptions of the UT-SEDP Product Development Guide (the "Guide"), a computer-based aid for teaching product development. The survey was conducted primarily to identify additional software features and improvement needs, and specifically was *not* constructed to prove formally the educational efficacy of the Guide as a teaching aid. Nonetheless, student views were also solicited concerning the relative effectiveness of the Guide as a supplement or replacement to regular instruction and textbooks.

Student Group Composition and Assignment

Twenty-seven (27) University of Tennessee mechanical engineering students in the senior-level "Introduction to Design" course (course number ME 455) completed and returned the structured survey. All students in the class were mechanical engineering seniors. The ME 455 course generally serves to prepare students for completing a comprehensive design project, also known as a "capstone" design, during the following semester.

Before responding to the survey, students completed two assignments using the Guide. Students first were asked to identify some key elements for the successful development of an innovative product, which are shown within the Guide. Next, students working in teams were asked to create a Product Design Specification for a proposed product.

Survey and Analysis

Students were asked to answer 14 "agree-disagree" questions and five "open-ended" questions. The "agree-disagree" questions provided a statement, then asked the student to agree or disagree with the statement on a seven point scale (-3 to +3). The "open-ended" section was designed to stimulate student comments regarding the Guide's presentation and layout, contents, and how the Guide might be used in the course. Students were also asked to suggest items or concepts for the Guide's tutorial, which at the time of the survey, had not yet been developed. The agree-disagree portion of the survey is shown in Figure 1. The questions asked in the comments section are presented in Figure 2.

Responses to the "agree-disagree" questions were both tabulated and analyzed statistically to discover student perceptions. Lotus 1-2-3 and Quattro Pro spreadsheets were used extensively to tabulate the data, generate relevant statistics, and plot results.

The frequency distribution of student responses to the survey questions is shown in Table 1. The numbers define how many students in the survey responded to the statement with the scale value defined for that slot. Thus, the left-most number for each question defines how many students responded to that statement with a "-3" (strongly disagree), while the right-most value is the number of students who strongly agreed with that statement. Plots of these distributions were also prepared as part of the analysis.

Appropriate statistical tests were utilized to decide when student opinion was sufficiently strong to make a conclusion. In general, a 95% confidence interval (using a t-distribution) was constructed for each statement. Opinions were deemed significant when the confidence interval did not include "0", or the neutral opinion. This procedure would be equivalent to a one-sided t-test, using an alpha of 0.025. These results are shown in Table 2.

Differences in response between different subgroups were evaluated by computing a confidence interval for the difference between two means, using an alpha of 0.05. Response differences for a particular question were deemed significant when the confidence interval did not include "0", or "no difference". This procedure is equivalent to a one-sided t-test, using an alpha of 0.025.

Small alphas were used in the evaluation to be conservative in making conclusions about the Guide. Confidence intervals were used in place of standard t-tests because they were more easily computed using the spreadsheet format.

Product Development Guide - ME 455 Survey
Dr. Wilson's Section - after initial use - 9/22/92

Please indicate how much you agree or disagree with the following statements; read questions carefully.

		STRONGLY DISAGREE			NEUTRAL			STRONGLY AGREE
1.	The Guide was easy to use, even without a tutorial or previous training.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
2.	The Guide's instructions were not sufficient for me to use the Guide effectively.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
3.	I had trouble moving through the menus.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
4.	The "bar" menus (used to get to the essential elements, videos, etc.) should be "press a number" menus instead.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
5.	I had trouble finding what I needed.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
6.	I would have done much better if I had completed a tutorial before I used the Guide.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
7.	I needed a lecture on the subject first.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
8.	I understand the development process much better than I did before.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
9.	I would rather have had a traditional lecture for presenting this information.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
10.	Using the Guide was better than reading the material from a book.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
11.	I don't think that I learned anything important about product development.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
12.	Doing a problem assignment helped me to understand the material better.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
13.	I see how the Guide will help me in completing my design project later.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
14.	I have significant product design experience (through work, co-op, etc.).	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)

Figure 1: ME 455 survey for Product Development Guide, Fall 1992, agree-disagree portion.

Product Development Guide - ME 455 Survey
Dr. Wilson's Section - after initial use - 9/22/92

Comments section:

Presentation and layout of the Guide: Were materials presented in a usable format? Easy to read? Good colors? Flowcharts clear? Operation and selections obvious?

Contents: Easy to understand? Unfamiliar terms that need defining? Logical flow? Did you understand what you were doing?

How do you think the Guide can/should help you in this class?

What materials/instructions need to be in the tutorial?

Other suggestions or comments:

(original survey included more space between questions)

Figure 2: ME 455 survey for Product Development Guide, Fall 1992, comments portion.

Comments in the free-form section of the survey were compiled and grouped by subject.

DISCUSSION of RESULTS

Use of the Guide

Overall ease of use. Students reported that the Guide was very easy to use (question #1), that instructions within the Guide were adequate (question #2), and that they did not have trouble navigating through the program (question #3). Responses to all three "ease of use" questions were statistically significant from neutral opinion. The significant strength of student opinion regarding how easy the Guide is to use is shown in Figure 3.

Some typical student comments regarding ease of use include:

- "Presentation overall was impressive - clear and user-friendly." (student "A02")
- "All material was easy to follow and clear..." (student A07)
- "The material in flowcharts was easily accessed and self-explanatory" (student A19)

Table 1: Frequency distribution of responses to ME 455 survey (Fall 1992).

QUESTION	NUMBER OF RESPONSES (n=27) Strongly Disagree						Strongly Agree
	-3	-2	-1	0	+1	+2	+3
1. The Guide was easy to use, even without a tutorial or previous training.	0	0	1	0	4	19	3
2. The Guide's instructions were not sufficient for me to use the Guide effectively.	1	15	9	1	1	0	0
3. I had trouble moving through the menus.	8	15	3	1	0	0	0
4. The "bar" menus (used to get to the essential elements, videos, etc.) should be "press a number" menus instead.	2	4	2	13	2	2	2
5. I had trouble finding what I needed.	1	7	10	2	7	0	0
6. I would have done much better if I had completed a tutorial before I used the Guide.	2	5	5	8	5	2	0
7. I needed a lecture on the subject first.	6	7	4	4	5	1	0
8. I understand the development process much better than I did before.	0	1	2	3	15	4	2
9. I would rather have had a traditional lecture for presenting this information.	4	4	7	5	5	2	0
10. Using the Guide was better than reading the material from a book.	0	0	2	2	11	6	6
11. I don't think that I learned anything important about product development.	4	9	12	1	1	0	0
12. Doing a problem assignment helped me to understand the material better.	0	0	2	2	12	8	3
13. I see how the Guide will help me in completing my design project later.	0	1	0	3	9	12	2
14. I have significant product design experience (through work, co-op, etc.).	7	3	4	3	6	3	1

Operation. Students expressed no preference for bar menus versus "press a number" menus (question #4).

Table 2: Response statistics for ME 455 survey (Fall 1992).

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Statistical Summary of Responses (n=27), (α=0.05)		
	LOWER Confidence Interval	MEAN Value	UPPER Confidence Interval
1. The Guide was easy to use, even without a tutorial or previous training.	1.55	1.85	2.15
2. The Guide's instructions were not sufficient for me to use the Guide effectively.	-1.83	-1.52	-1.21
3. I had trouble moving through the menus.	-2.40	-2.11	-1.82
4. The "bar" menus (used to get to the essential elements, videos, etc.) should be "press a number" menus instead.	-0.75	-0.15	0.46
5. I had trouble finding what I needed.	-1.22	-0.74	-0.26
6. I would have done much better if I had completed a tutorial before I used the Guide.	-0.99	-0.44	0.10
7. I needed a lecture on the subject first.	-1.68	-1.07	-0.47
8. I understand the development process much better than I did before.	0.50	0.93	1.36
9. I would rather have had a traditional lecture for presenting this information.	-1.26	-0.67	-0.08
10. Using the Guide was better than reading the material from a book.	1.00	1.44	1.89
11. I don't think that I learned anything important about product development.	-1.88	-1.52	-1.16
12. Doing a problem assignment helped me to understand the material better.	0.90	1.30	1.70
13. I see how the Guide will help me in completing my design project later.	0.97	1.37	1.78
14. I have significant product design experience (through work, co-op, etc.).	-1.34	-0.59	0.16

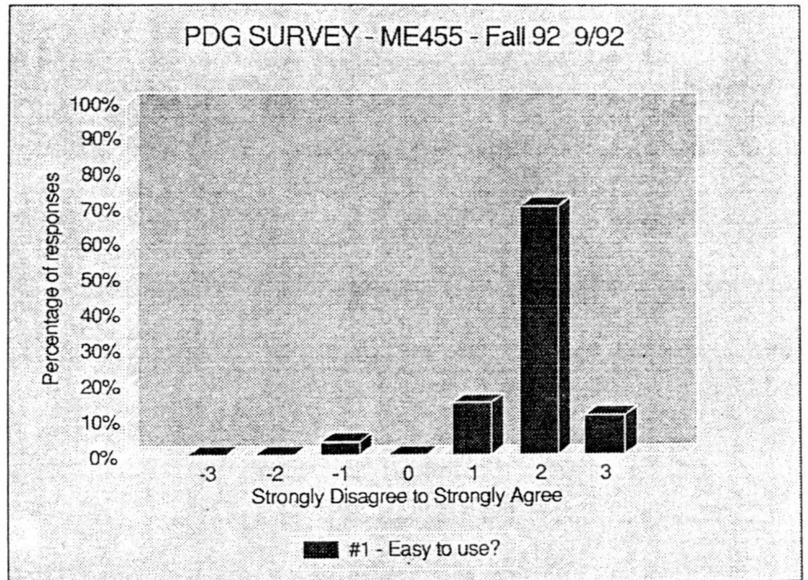

Figure 3: ME 455 class (Fall 1992) response to statement, "The Guide was easy to use, even without a tutorial or previous training."

Role of Problem Assignments. A significant student majority indicated that completing a problem assignment as part of the Guide's introduction assisted their learning (question #12). About 85% of the students concluded that completing a specific problem assignment as part of the Guide's introduction was somewhat helpful to understanding the material contained in the Guide. Almost one-half of those students characterized the assignment as very helpful. These results suggest that specific assignments are important elements in learning with the Guide.

Finding Needed Information. About one-fourth of students reported that they had at least some small difficulty in finding what they needed to complete their assignment (question #5). This difficulty may decline as students continue to use the Guide and learn about the development process. As one student summarized: "Realize that the guide has only been explored once and with more time using it the easier the guide will become to understand and implement." (student A05)

Learning Experience

Value. Over 90% of students believed that they learned something of some importance (question #11), and that they believe that they understand product development somewhat better than they did previously (77%, question #8).

Student Application. Fully 85% of students said that they now had some vision as to how the Guide may help them with their design project later in the course (question #14). Some responses to the survey question, "How do you think the Guide can/should help you in this class?", are shown below:

- "It breaks the design down into steps that can (be) easily followed." (student A01)
- "... gives a logical plan for developmental work." (student A10)
- " ... mostly it will "guide" me through developing a product, so that I won't skip any essential steps." (student A27)
- "... help me understand the steps required for product development much better." (student A09)

Comparison to Lecture and Text Resources

Guide versus text. Large majorities convincingly preferred using the Guide to finding similar information from a textbook (question #10). Eighty-five percent (85%) of students indicated, to varying extents, that they preferred the Guide. About one-fifth of the total respondents indicated strongly that they would rather use the Guide than have to locate similar information in a text.

Guide versus lecture. Two-thirds of those expressing a preference said that they would prefer to use the Guide than to have a traditional lecture on the subject (question #9). Almost one-fifth indicated *strongly* that they preferred the Guide. About one-quarter indicated that they would rather have had a lecture.

Given the wording of the survey question, it is possible that students preferring a lecture may have thought that the lecture option would require less effort; in retrospect, the question statement may have unintentionally led these students to think that, by choosing a lecture option, they could have avoided having to complete the associated exercise. Subsequent surveys could test to determine if students who prefer a lecture prefer it because they believe that a lecture would be more effective, or if they simply think that the lecture approach requires less student effort and participation.

Differences in Response. There were significant statistical differences in response between those who preferred the Guide to a lecture versus those who preferred a lecture to the Guide with regard to two questions; students who preferred the Guide to a lecture generally:

- felt more strongly about the Guide being better than a book (question #10 and Figure 4)
- felt less of a need for an introductory lecture (question #7 and Figure 5)

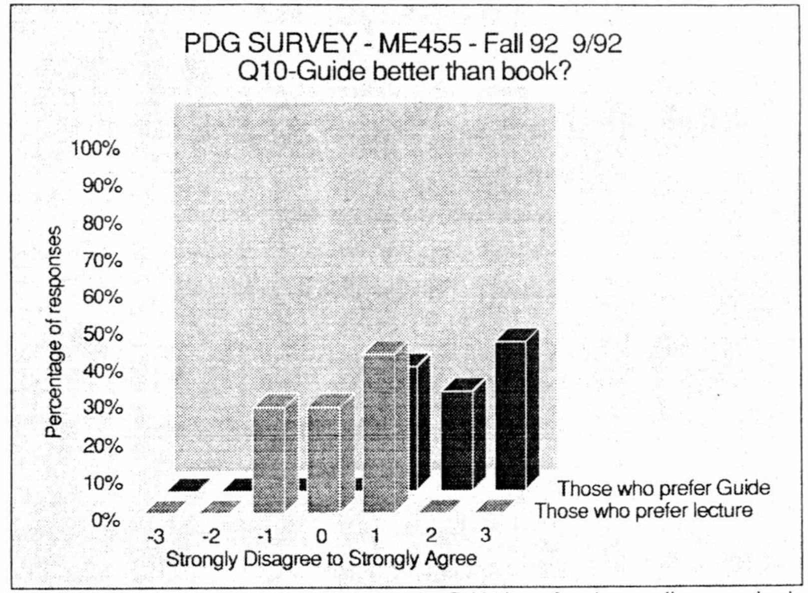

Figure 4: Student response regarding whether the Guide is preferred to reading a textbook, showing the difference between the students who preferred the Guide over a lecture and those who did not (ME 455, Fall 1992).

Also, students who preferred the Guide to a lecture tended to believe that they learned more than the group that preferred a lecture (question #11 and Figure 6), but this observed difference was less statistically significant (one-sided, 0.05 alpha level) than the other two (one-sided, 0.025 alpha level).

Correlations. As noted above, significant differences were observed between students who preferred the Guide and those who preferred a lecture. A "bubble graph", Figure 7, was created to evaluate the association between how highly a given student rated the Guide versus a lecture and how (s)he rated the Guide better a textbook. (On this figure, the size of the "bubble" reflects how many students answered with a given response combination). It is clear that:

- students overall feel more strongly about the Guide being better than a book than they do about the Guide being better than a lecture
- a student who feels more strongly about the Guide being better than a lecture than another student is also likely to feel more strongly that the Guide is better than a book

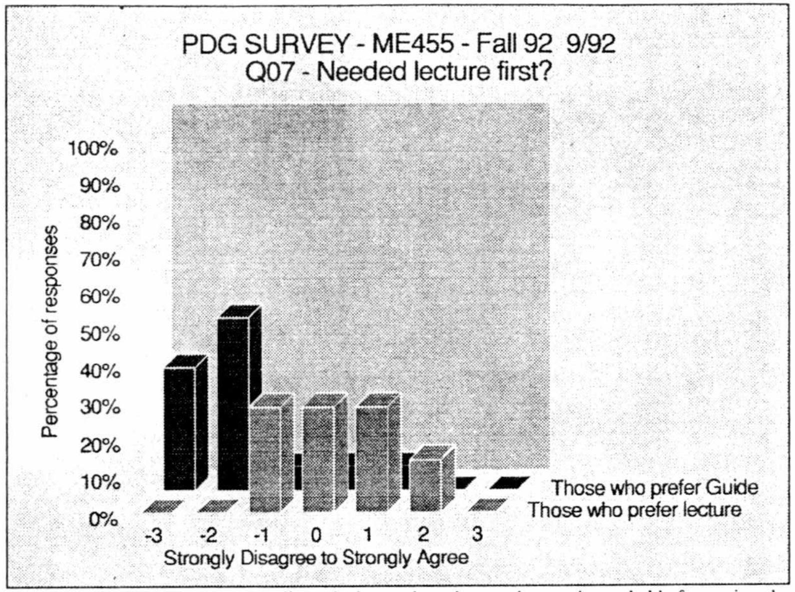

Figure 5: Student response regarding whether an introductory lecture is needed before using the Guide, showing the difference between the students who preferred the Guide over a lecture and those who did not (ME 455, Fall 1992).

A linear regression line through these response combinations fits the data well, accounting for over 50% of the variation observed in the response.

Tutorial and Introductory Training

Need. Students were split in their opinions about the need for a tutorial to accompany the Guide, although slightly more students tended to believe that a tutorial was not needed than those that did (question #6). While about one-quarter of students indicated that a tutorial would have helped them some, a roughly equal percentage indicate fairly strongly that a tutorial was not necessary for them to use the Guide.

When asked what a tutorial should contain, several students suggested that one was not needed:

- "I think the program is quite self-explanatory." (student A22)

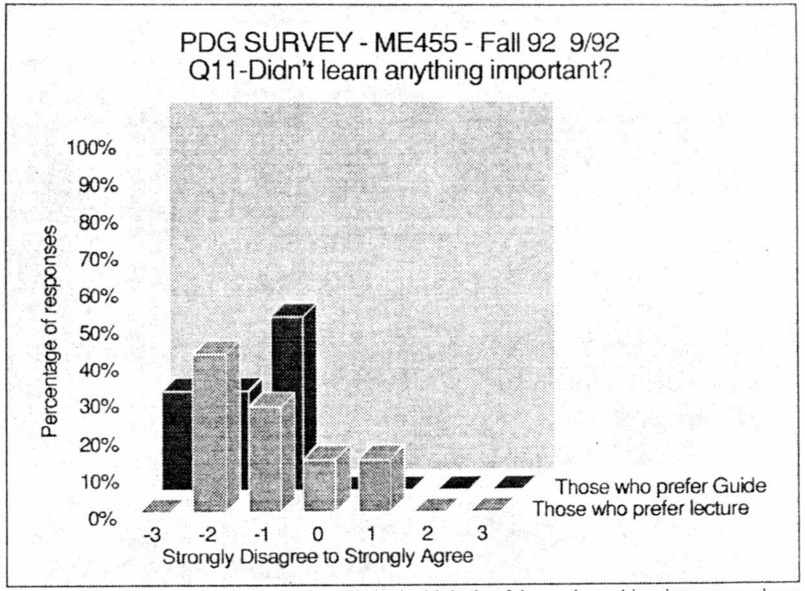

Figure 6: Student response to question, "I don't think that I learned anything important about product development," showing the difference between the students who preferred the Guide over a lecture and those who did not (ME 455, Fall 1992).

- Instructions for use are not necessary because they are already on the screen and rather straightforward. (student A08)
- I had no problem operating the software without instructions other than those at the bottom of the screen. (student A23)

Tutorial Contents. Consistent with the above responses, those who did suggest items for the tutorial recommended fairly simple items, such as providing "a general overview" on contents (student A13), and describing "the concept and intent of (the) software." (student A02)

Several students suggested that some procedural information should also be included in the tutorial. Specifically, students suggested that the tutorial should explain how the program begins and, "for people that are less computer-oriented, maybe a general guide on how to scroll through the menus." (student A27)

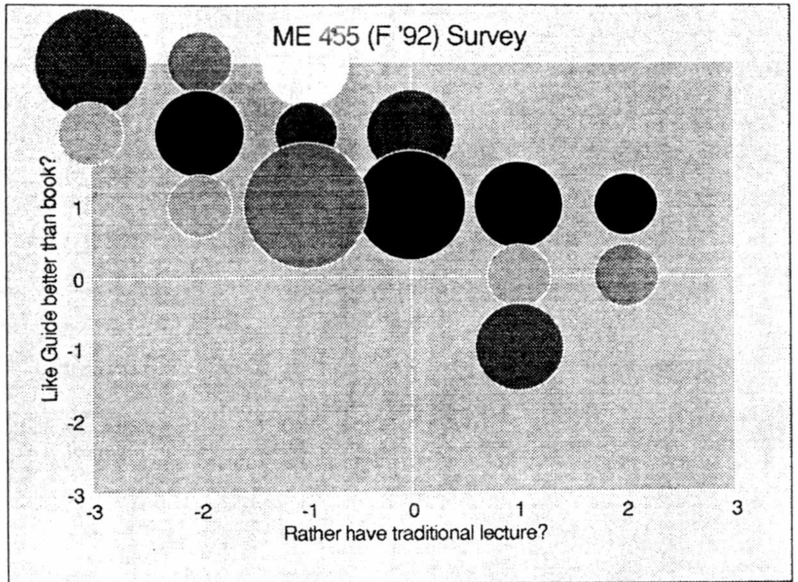

Figure 7: Bubble graph showing student responses regarding the Guide versus a textbook and the Guide versus a lecture.

Additionally, comments in other survey sections indicate that the "three color" scheme, used to delineate the product engineering, manufacturing, and customer-marketing flows, need to be explained. The strategic presentation of the menu access numbers (in relation to what the number accesses) should be shown, and the "zero" option (which appears on the title bar) which exists on some menus should be pointed out specifically so that the student knows (s)he can access general information about a topic. One student suggested that the operation of the "bar" menu should also be explained.

Introductory Lecture. Most students indicated that they did not need a lecture before using the Guide (question #7). About 48% of students believed rather strongly that a lecture was not needed; only about 20% expressed any need for a lecture on the subject first. Even these needs may be minimal: one student who requested an introductory lecture suggested that "a fifteen minute lecture on the purpose of the Guide and a familiarization with the menus" would be adequate to use the Guide effectively. (student A05)

Suggestions for Improvement and Comments on Them

Several students suggested mouse support as a desirable menu selection method. While desirable, this feature is not supported by the current software engine. Other software vehicles, which could be used in a later, more-commercial version, probably should support a mouse option.

Some innovative ideas suggested by students included providing "a short! demo of the program" (student A26), creating a "glossary of definitions of some of the (technical) terms (used in the Guide)," (student A15), and using "an example product carried through the process (student A24). The "example problem" was recommended previously by faculty reviewers at the University of Kentucky, but as part of a supplemental text rather than as part of computer tutorial. A glossary would be quite feasible for a Guide using an alternative software platform that supports "hypertext"-type operations. It is not clear how convenient glossary access can be obtained using the present platform.

Other Comments

The Guide, as tested by this class, was an incomplete prototype version of the software, dated August 1992. As such, several "avenues" of information were not available. Some students apparently were puzzled with the incompleteness, as shown by these comments:

- "Logical flow, but I was confused for a while because the initial information I requested only read 'to be developed'". (student A06)
- "Why did some pull-down menus have 'not yet defined' or something like that?" (student A25)

These comments do not appear to be serious as regards the Guide's development, but does point out the need to inform the class during these experiments that the Guide is an incomplete prototype and not a finished product.

The responses from this survey are being used to improve the Guide and its presentation. Additional surveys and evaluations are planned.

Student response distributions, relevant statistics, and compiled student comments are available from the research files. Bar graph plots of the response distributions are also available.

SURV455.RES
Original draft 9/92
Updated - edit, add tables and graphs, reformat 10/93
Updated - edit 9/94

APPENDIX O

Student Survey Report, ME 553 Course, Spring 1993

PRODUCT DEVELOPMENT GUIDE

Results of ME 553 Student Survey - February 1993

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SUMMARY

Nineteen (19) University of Tennessee students in the graduate-level "Development of Superior Products and Processes" course (course number ME 553) completed a survey pertaining to their perceptions of the UT-SEDP Product Development Guide (the "Guide"), a computer-based aid for teaching product development. The survey was conducted primarily to identify how well students were able to use the Guide and what they perceived to be the Guide's educational uses. While the survey was specifically *not* constructed to prove formally the educational efficacy of the Guide, views were solicited concerning the relative effectiveness of the Guide as a supplement or replacement to regular instruction and textbooks.

Students used the Guide to complete a homework assignment, then were asked for their opinions using 13 "agree-disagree" questions and four open-ended questions. The "agree-disagree" questions provided a statement, then asked the student to agree or disagree with the statement on a seven point scale. The responses were tabulated and analyzed to determine student perceptions. Comments to the open-ended questions were compiled and grouped by topic.

CONCLUSIONS

Students registered four very positive opinions about the Guide; they concluded strongly that:
- the Guide was easy to use, even without a tutorial or previous training (question #1)
- the Guide's instructions (even as incomplete as they were at the time of the survey) were adequate to enable users to utilize the Guide effectively (question #9)
- the Guide would prove useful in helping students complete their individual case study (which is performed as part of the ME 553 course) (question #12)
- the Guide would be useful to them outside of the course (question #10)

Students expressed less strong (but still statistically significant) positive opinions regarding several other aspects of the Guide. Students said that:
- the approach used by the Guide is a good method for communicating the material contained within the Guide (question #4)
- the Guide is an important resource for the ME 553 course (question #8)
- they would prefer to obtain the material from the Guide than attempting to access the same material from a textbook (question #11)

The Guide did not fare as well when compared to the lecture format used in the ME 553 course. Students indicated that they would:
- find it slightly easier to learn the material through lectures instead (question #3)
- learn more in a lecture format than they would by using the Guide (question #13)

Contrary to results of an earlier survey of undergraduate students (in ME 455, Fall 1992), ME 553 students said that the Guide should be introduced with a lecture first (question #7). As in the earlier survey, respondents were essentially neutral regarding whether they needed to complete a tutorial before using the Guide (question #6).

Students who received "A's" in the course responded significantly differently to three survey questions when compared to those who did not. In general, students who received an "A" in the course found the Guide to be:
- much less intimidating, in terms of the amount of data presented (question #2)
- a better method for communicating the material (question #4)
- more effective for learning versus a lecture format (question #3)

DISCUSSION of METHODOLOGY

Background and Goals

A survey was administered to students to assess their response to the UT-SEDP Product Development Guide (the "Guide"), a computer-based aid to teaching product development. The survey was conducted primarily to identify how well students adapted to using the Guide and what they perceived to be the Guide's educational uses. The survey was specifically *not* constructed to prove formally the educational efficacy of the Guide as a teaching aid. Nonetheless, views were solicited concerning the relative effectiveness of the Guide as a supplement or replacement to regular instruction and textbooks.

Student Group Composition and Assignment

Nineteen (19) University of Tennessee engineering students in the graduate-level "Development of Superior Products and Processes" course completed structured evaluations of the Guide; one additional student (a graduate student in mechanical engineering) provided "free-form" comments. The breakdown of the students responding to the survey is shown in Table 1. Senior students taking the course needed the instructor's approval to take the course, so these students in general were expected to be above-average undergraduates.

Before completing the survey, students used the Guide to complete a homework assignment. Students were asked to compare the Guide's contents to key lecture points from two or three previous class sessions dealing with Technology Selection and Development.

Table 1: Breakdown of ME 553 course students by degree program.

Type of Student	Number of Students	Subtotals
Graduate students (M.S.):		15
Industrial Engineering	7	
Mechanical Engineering	1	
Electrical Engineering	1	
Statistics	1	
Computer Science	1	
Engineering (unknown)	4	
Undergraduate - seniors:		4
Mechanical Engineering	4	
TOTAL		19

Survey and Analysis

The survey was comprised of 13 "agree-disagree" questions and four "open-ended" requests for comments. The "agree-disagree" questions provided a statement, then asked the student to agree or disagree with the statement on a seven point scale (-3 to +3). In the "open-ended" section, students were solicited for their views on the Guide's presentation and layout, contents, and value. Students were also asked to suggest any other items, features, or concepts that occurred to them while they used the Guide. A copy of the agree-disagree portion of the survey is shown in Figure 1. The questions asked in the comments section are presented in Figure 2.

Responses to the "agree-disagree" questions were both tabulated and analyzed statistically to discover student perceptions. Lotus 1-2-3 and Quattro Pro spreadsheets were used extensively to tabulate the data, generate relevant statistics, and plot results.

The frequency distribution of student responses to each survey question is shown in Table 2. The numbers define how many students in the survey responded to the statement with the scale value defined for that slot. Thus, the left-most number for each question defines how many students responded to that statement with a "-3" (strongly disagree), while the right-most value is the number of students who strongly agreed with that statement. Plots of these distributions were also prepared as part of the analysis.

Product Development Guide - ME 553 Survey - Spring '93

Please indicate how much you agree or disagree with the following statements; read questions carefully.

		STRONGLY DISAGREE			NEUTRAL			STRONGLY AGREE
1.	I found the Guide easy to use, even without a tutorial or previous training.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
2.	I found the large amount of data contained in the Guide to be intimidating.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
3.	I would find it easier (as a student) to learn the material in the Guide through class lectures instead.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
4.	The approach used by the Guide is a poor method for communicating this material.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
5.	I got "lost" repeatedly as I moved through the menu items.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
6.	It would have been easier if I had completed a tutorial before I tried to use the Guide.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
7.	The Guide needs to be introduced with a lecture on the subject first.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
8.	The Guide is an important resource that is/will help me learn the most possible from taking the course.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
9.	The Guide's instructions were not adequate for me to use the Guide effectively.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
10.	I don't think that the Guide would ever be useful to me outside of this course.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
11.	I prefer to use the Guide than to obtain the same information from a textbook.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
12.	The Guide will be useful later in helping me complete my case study project.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
13.	I will learn more using the Guide than I will hearing the same material in a lecture.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)

Figure 1: ME 553 survey for Product Development Guide, Spring 1993, agree-disagree portion.

Product Development Guide - ME 553 Survey - Spring '93

Comments section:

Presentation and layout of the Guide: Comment on your perceptions of, and reactions to, HOW information is presented in the Guide. What areas or layouts were confusing? How could the presentation be improved?

Contents: Comment on the contents of the Guide, as you perceive them. How do the Guide's contents compare to the information that has been presented in class? What are the most important "lessons" that you hope to learn from the Guide?

Value: How do you think the Guide can/should help you in this class? How might it be useful elsewhere?

Other: What about a tutorial? Other suggestions or comments.

(original survey included more space between questions)

Figure 2: ME 553 survey for Product Development Guide, Spring 1993, comments portion.

Appropriate statistical tests were utilized to decide when student opinion was sufficiently strong to make a conclusion. In general, a 95% confidence interval (using a t-distribution) was constructed for each statement. Opinions were deemed significant when the confidence interval did not include "0", or the neutral opinion. This procedure would be equivalent to a one-sided t-test, using an alpha of 0.025. These results are shown in Table 3.

Differences in response between different groups of students were evaluated by computing a confidence interval for the difference between two means, using an alpha of 0.05. Differences in groups for a particular question were deemed significant when the confidence interval did not include "0", or "no difference". This procedure is equivalent to utilizing a one-sided t-test, using an alpha of 0.025.

A small alpha (0.025) was used in the evaluation to be conservative in making conclusions about the Guide. Confidence intervals were used in place of standard t-tests because they were more easily computed using the spreadsheet format.

Comments provided as answers to questions in the free-form section of the survey were compiled and grouped by topic.

Table 2: Frequency distribution of responses to ME 553 survey.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree)	Frequency Summary of Responses (n=19)						
QUESTION	-3	-2	-1	0	+1	+2	+3
1. I found the Guide easy to use, even without a tutorial or previous training.	1	0	0	1	3	11	3
2. I found the large amount of data contained in the Guide to be intimidating.	0	3	1	4	5	6	0
3. I would find it easier (as a student) to learn the material in the Guide through class lectures instead.	0	2	1	4	5	6	1
4. The approach used by the Guide is a poor method for communicating this material.	0	5	9	2	2	1	0
5. I got "lost" repeatedly as I moved through the menu items.	2	2	5	3	7	0	0
6. It would have been easier if I had completed a tutorial before I tried to use the Guide.	2	1	4	3	4	5	0
7. The Guide needs to be introduced with a lecture on the subject first.	2	0	1	3	4	6	3
8. The Guide is an important resource that is/will help me learn the most possible from taking the course.	0	0	2	4	8	3	2
9. The Guide's instructions were not adequate for me to use the Guide effectively.	6	5	4	3	1	0	0
10. I don't think that the Guide would ever be useful to me outside of this course.	4	7	6	1	0	1	0
11. I prefer to use the Guide than to obtain the same information from a textbook.	0	1	2	7	2	4	3
12. The Guide will be useful later in helping me complete my case study project.	0	0	0	1	8	6	4
13. I will learn more using the Guide than I will hearing the same material in a lecture.	1	5	5	4	2	2	0

Table 3: Response statistics for ME 553 survey.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Statistical Summary of Responses (n=19), (α=0.05) LOWER Confidence Interval	MEAN Value	UPPER Confidence Interval
1. I found the Guide easy to use, even without a tutorial or previous training.	1.00	1.63	2.26
2. I found the large amount of data contained in the Guide to be intimidating.	-0.14	0.53	1.20
3. I would find it easier (as a student) to learn the material in the Guide through class lectures instead.	0.13	0.79	1.45
4. The approach used by the Guide is a poor method for communicating this material.	-1.32	-0.79	-0.26
5. I got "lost" repeatedly as I moved through the menu items.	-1.07	-0.42	0.23
6. It would have been easier if I had completed a tutorial before I tried to use the Guide.	-0.68	0.11	0.89
7. The Guide needs to be introduced with a lecture on the subject first.	0.11	0.95	1.78
8. The Guide is an important resource that is/will help me learn the most possible from taking the course.	0.42	0.95	1.48
9. The Guide's instructions were not adequate for me to use the Guide effectively.	-2.22	-1.63	-1.04
10. I don't think that the Guide would ever be useful to me outside of this course.	-2.15	-1.58	-1.01
11. I prefer to use the Guide than to obtain the same information from a textbook.	0.10	0.79	1.48
12. The Guide will be useful later in helping me complete my case study project.	1.27	1.68	2.10
13. I will learn more using the Guide than I will hearing the same material in a lecture.	-1.30	-0.63	0.04

DISCUSSION of RESULTS

Learning Experience

Usefulness. Students strongly indicated that they believed the Guide would be useful during their individual product development case studies, which they are required to complete as part of the ME 553 course (question #12). Additionally, however, students perceive that the Guide also can be useful beyond the confines of the course (question #10).

Students believe less strongly (but still significantly on a statistical basis) that the approach used by the Guide is a good method for communicating the material contained within the Guide (question #4). Two-thirds of the respondents agreed (to a varying extent) with the statement, "The Guide is an important resource that will help me learn the most possible from the course" (question #8).

Students wrote (in the comments section) that they think the Guide is a "remarkable reference for someone familiar" with the product development process (student "G05") and serves as "an excellent refresher" of product development issues (student G02).

Comprehensiveness. Over one-third of the students in the survey wrote within the comments section that they perceive the Guide as very comprehensive, covering much more material than that presented in ME 553 class lectures and/or the textbook (multiple student comments). One student (G03) found the Guide's contents to be "thought provoking and thorough", while another saw the Guide as a collection of valuable source information located in one place (students G14, G17). However, roughly one-half of the responding students did find the comprehensive nature of the Guide to be somewhat intimidating (question #2).

Comparison to Lecture and Text Resources

Guide versus text. Students in this class generally said that they would prefer the Guide's method of access to the material in the Guide to having to refer to a textbook (question #11), although one student (G20) specifically commented that he thought that a "book with tabs is better and faster than using a computer and reading from the screen."

Guide versus lecture. A Fall 1992 survey of senior mechanical engineering students (in ME 455) generated some questions as to how students really perceive the effectiveness of the Guide versus a lecture. In that survey, students were asked if they would rather have had a traditional lecture instead of using the Guide. Unfortunately, it was not clear whether students that said they would prefer a lecture indicated this because they thought that a lecture was more effective or because they thought that a lecture would require less personal effort. Thus, students in this survey were asked two questions: one pertaining to the learning effectiveness of the Guide versus a lecture (question #13), and one pertaining to which method was "easier" (question #3).

Analysis of ME 553 student responses to these questions indicated that students would:

- find it slightly easier to learn the material through lectures instead (question #3)
- learn more from a lecture format than by using the Guide (question #13)

The "combination" response to these questions are shown on the bubble graph in Figure 3. On this graph, the size of the "bubble" reflects how many students answered with a given response combination. The graph shows that many students felt a distinction between "easier to learn" and "learning more". Somewhat disappointingly, a significant student minority in this class felt that lectures were not only easier, but more effective for maximum learning.

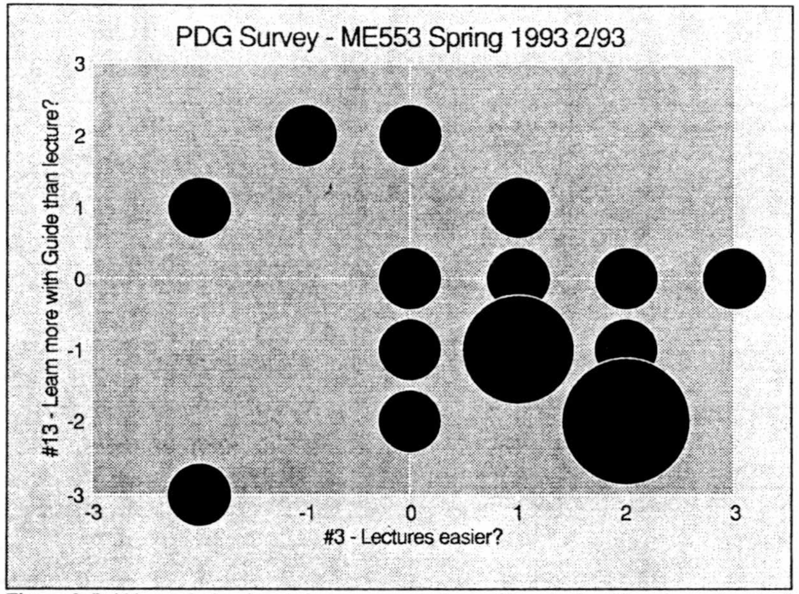

Figure 3: Bubble graph showing student responses to "ease of learning" and "maximum learning" questions.

The somewhat unfavorable comparison of the Guide versus lecture may be due more to the effectiveness of ME 553 course lectures than from any specific Guide inadequacy. In contrast to a traditional course, many "lectures" in this course are case study presentations by the actual engineers/managers who worked on the project. These highly interactive discussions have proven every effective in communicating key lessons in product development. The comparison may also

have been affected by the "open-ended" nature of the homework assignment: since the topic was quite broad, students would have to comprehend broad areas of the Guide over a short time. Several, more-focused assignments over a longer time might yield different results.

Content amount comparison. Several students perceived that course contents were covered more comprehensively in the Guide than they were (or could be) in class lectures (Students G04, G10, G06). One student (G19) noted that all material in the Guide could not be covered in class; "in this way, it is a helpful supplement to the class."

Students particularly noted the presence of "questions to ask" and that topics were "broken down more", so that essential elements from class were "flesh(ed) out" and expanded in the Guide (students G06, G13). Others stated that they saw the Guide as having more information than their text materials (students G14, G20).

Consistency. Students noted a broad consistency between the material presented in class and that presented in the Guide. Two students (G16, G08) described the match as nearly "identical" while others used terms such as "similar" and "parallel".

Use of the Guide

Student Application. Students identified several useful applications for the Guide within the course and beyond. While two students (G02, G05) specifically said that they did not think that the Guide should be used to "teach" the process, many students envisioned areas for use in the ME 553 course. Students suggested that the Guide would be useful for reinforcing class discussions (student G15), clarifying aspects of the development process (G19), and matching class lessons/discussion against sections of the Guide (G15). Students also saw use for the Guide in preparing and analyzing the case study assignment: preparing questions to ask (student G07), identifying key focus items (G03), helping to "recognize a 'healthy', potentially successful process" when one is encountered (students G16, G03).

Beyond the course, many students projected how they might use the Guide in product development projects (students G18, G07, G06, and others). Some observed that the systematic, orderly flow of the Guide would be important to emulate in a project (students G07, G16, G13). One student (correctly) pointed out that the ordering of events in the Guide is important, and could be used to define when the team should focus on particular project elements (student G13). Others (students G18, G02, G03) saw a role for the Guide as check-list, to "make sure you have addressed all parameters" (student G18). These extended applications of the Guide did not come without some questions, however; one student inquired, "Does the Guide maintain application across the board even when some questions won't pertain to some processes?" (student G06)

Preparation for Using the Guide. Students had about evenly distributed strength of opinion about the need to complete a tutorial before using the Guide, although slightly more students tended to believe that a tutorial was needed than did not (question #6). Suggestions for what should be in that tutorial are discussed below in another section. Most students in the ME 553 class did express a desire to have the Guide introduced with a lecture first (question #7) before using it. As discussed below in another section, this conclusion stands in contrast with that expressed by an earlier survey of a different class. The proposed contents of an introductory lecture were similar to those advised for the tutorial, suggesting that either by itself might be sufficient for the final version of the Guide.

Ease of Use

Overall assessment. General student response to the Product Development Guide was very favorable. Students overwhelmingly reported that they found the Guide easy to use, even without a tutorial or previous training (question #1). As part of this opinion, they also found the Guide's instructions (even as incomplete as they were at the time of the survey) adequate to enable users to utilize the Guide effectively (question #9).

Two students commented that the examples presented in the Guide were especially helpful in understanding the material (students G13, G18).

Information density. Students commented on the amount of information and how it was presented in the Guide. One student called information content "overwhelming" (student G19), while another described it as "fairly detailed and intimidating" (student G10). One student (student G18) thought it "difficult to absorb concentrated doses of information" contained in the Guide. One student said that the extensive detail had a "tendency to cloud the overall process" and confuse users (student G06).

Several students claimed that screen displays are too busy and carry too much information; two students (G09, G01) suggested that these displays should be "broken down" further, both to reduce the number of colors needed (to separate displayed information visually) and to reduce their "busyness". Unfortunately, this solution might aggravate the problems of another respondent who was bothered and felt "lost" by the large number of sub-menus that were available (student G14). About one-third of respondents indicated a slight tendency to feel "lost" as they descended through the menus of the Guide (question #5), although two students (G05, G18) praised the Guide's "conciseness" and its concise "points".

These observed difficulties likely reflect the software author's continuing battle between simplifying the development process (and its presentation) to increase understanding, while still addressing the many relevant issues that make the "real" product development process very complex. While the Guide's comprehensive nature was noted and applauded (as discussed above), this comprehensiveness apparently has created a feel of "busyness" and "intimidation" for some users.

Presentation and Colors. Students overall found the presentation of the Guide to be relatively "user friendly" (students G17, G12) and easy to navigate (student G06 and question 1). Many students clearly understood the layout of the various screens in the Guide. Students generally found the blocks, numbers, and arrows "very helpful in presenting the flow" of the development

process (student G03). One student (G07) suggested that he had some difficulty in determining where to begin on charts where multiple process flow paths/arrows were shown.

Many students commented, usually negatively, about the use of colors throughout the Guide, although one student (G19) described the variety of layouts as "eye-catching". Students generally described some color schemes as "distracting" or "ugly" (students G05, G16, G14, others), and said that some screens had too many different colors. As with an earlier survey, some students apparently were confused by the "three-color" track for the product development process (one color each for product, manufacturing, and customer based phases); one commented that screens under this menu did not seem to relate to three primary colors in any obvious fashion (student G13).

Several students did note that they sometimes had difficulty recalling "where they were" within the Guide when they "descended" to the very-detailed levels (comments and question #5). In spite of the number of suggestions presented to alleviate this problem (discussed in another section below), the neutral response to survey question #5 suggests that the problem was not serious.

Operation. One student (G19) reported that he had experienced problems with text-screen contrast while running the Guide with a monochrome monitor. This same student also reported a problem with loading the software into a subdirectory instead of the "root" directory.

Tutorial and Introductory Training

Comments varied widely on the need for a tutorial, ranging from "every program needs a tutorial" (student "G16") to would be "useful" (student G17) to "not needed" (student G11) and "not necessary" (student (G01). This dichotomy of opinion also appeared in student responses to question #6, which averaged to a nearly neutral opinion on whether a tutorial was needed to use the Guide effectively.

Student suggestions for tutorial or introductory comments included:

- explanation of the menu system (student G19)
- a brief discussion on Guide's purpose and what it contains (student G06)
- comments on meanings of different colors in the Guide (student G13)
- a development project example (students G18, G12)

Some in-class introduction to the Guide was provided by the class instructor, but most of this consisted on guidance for how to get the software running. Some students suggested that an introduction should also describe the Guide's objectives and elements (Student G03), and that some guidance on "what to look for" would have been helpful (Student G09).

Others found the Guide "largely self-explanatory once general knowledge is provided" (student G03), although one student (G02) noted that having seen the development process first presented in class made using the Guide much easier.

Response Differences Based on Respondent's Grade in Course

After the end of the course, student responses were sorted based on the course grade earned by each individual respondent. Significant differences were observed between the group that received an "A" in the course versus the group that did not for three survey questions (questions #2, #3, #4).

In general, the eleven (11) students who received an "A" in the course found the Guide to be:

- much less intimidating, in terms of the amount of data presented (question #2)
- more effective for learning versus a lecture format (question #3)
- a better method for communicating the material (question #4)

While "non-A" students apparently were somewhat intimidated by the large amount of data in the Guide, "A" students were largely neutral; these differences graphically are shown in Figure 4. Non-A students said that they would find it easier to learn the material through a lecture; again, "A" students were neutral, as shown in Figure 5. The "A" student group indicated strongly that they had found the Guide to be a good method for communicating the materials contained within; non-A students were almost exactly neutral in their opinion (Figure 6).

Comparison to Results from ME 455 Survey

Five of the questions in this survey matched inquiries asked in Fall 1992 of students in the senior course ME 455, Introduction to Design. Student responses in both classes were evaluated to discover any difference of opinion between the two classes.

Students in both sections were roughly equivalent in their assessment of the Guide's ease of use (question #1), and the adequacy of the Guide's instructions (question #9). ME 553 students generally expressed a stronger need to complete a tutorial first (question #6), although the overall response was not significant statistically.

Student responses between the two classes were significantly different in two areas:

- ME 553 students concluded that a lecture was needed before using the Guide (question #7), while ME 455 students felt equally strongly that a lecture was *not* needed (significant with a one-sided alpha of 0.025);
- ME 553 students, while also concluding that they preferred obtaining information from the Guide rather than from a textbook (question #11), felt much less strongly about this than did the undergraduate students in the ME 455 course (significant to one-sided alpha of 0.05).

Figure 7 and Figure 8 show graphically how the responses were different across the two classes. That the ME 553 students expressed a need for an introductory lecture (and, to a lesser extent, a tutorial) that the ME 455 seniors did not is particularly surprising, considering that one typically would expect graduate students to be less dependent and more assertive than undergraduates.

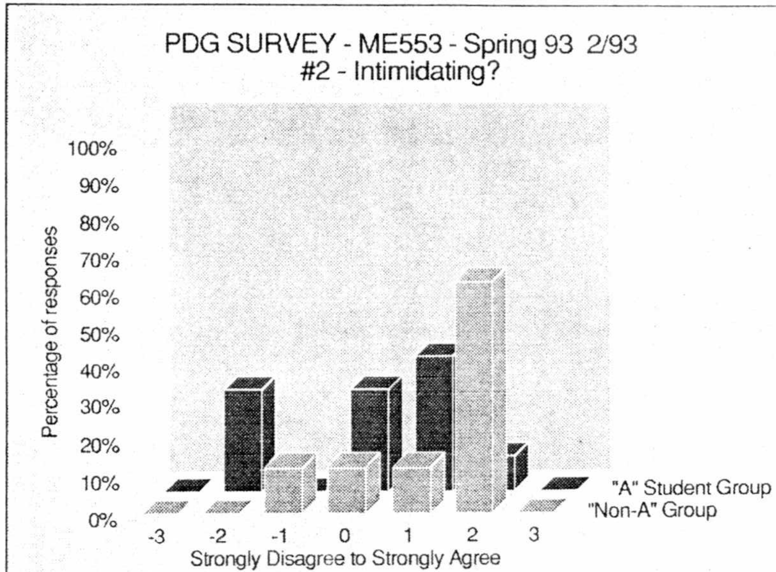

Figure 4: Differences between "A" and "non-A" students regarding an "intimidation factor" created by the Guide.

The above results naturally suggest the question, "Why were they different?" Several factors might account for these differences in response:

- the version of the Guide used by the ME 553 students was larger than the version tested by the ME 455 students
- ME 455 students completed a more-structured exercise than did the ME 553 students
- the two classes received significantly different introductions to the Guide

The ME 553 version was larger because it was a later version, containing more completed sections. The Technology Selection and Development phase, which was the focus of the ME 553 assignment, was especially complex. Students were essentially assigned with the difficult task of reviewing the entire phase, then comparing and contrasting the Guide with concepts presented in class. While the introduction to the Guide was not procedurally controlled, the same instructor was used, and the material content of these verbal introductions were not thought to be materially different.

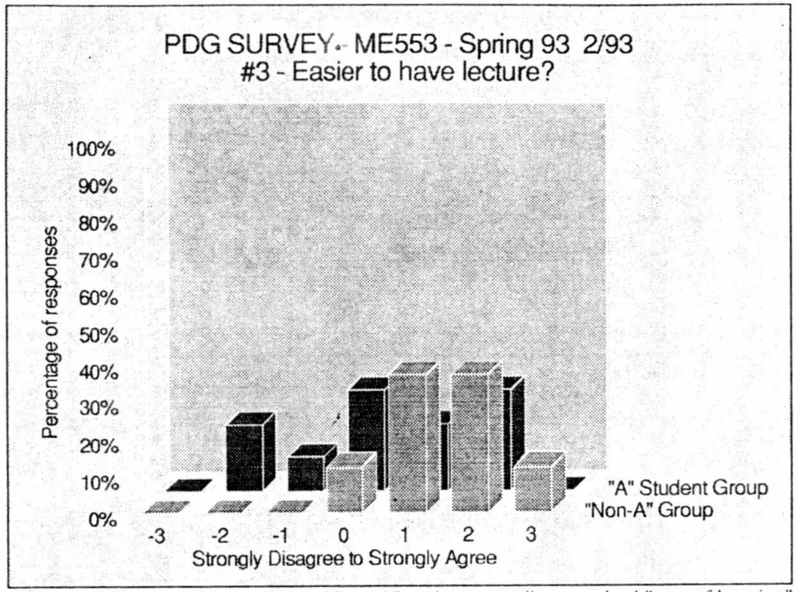

Figure 5: Differences between "A" and "non-A" students regarding perceived "ease of learning" from the Guide versus class lectures.

On the other hand, senior-class students in the ME 455 survey used a simpler, less-complete version to complete two specific assignments: (1) answer a set of well-defined questions about the product development process, specific answers to all of which were contained in the Guide; and (2) use a specific section of the Guide to help them create a Product Design Specification. Thus, it could be argued that ME 455 students may have found the Guide to be more effective because it helped them more for their particular assignment. The ME 455 then would feel less need for an introductory lecture because it was clear to them that the Guide had provided them with the desired answers (or specific help).

None of these potential causes can be tested well using the existing survey data, however.

Suggestions for Improvement and Comments on Them

Student suggestions for improving the Guide's presentation focused on the information display, a method for keeping track of one's "path" through the menus, and moving through the Guide.

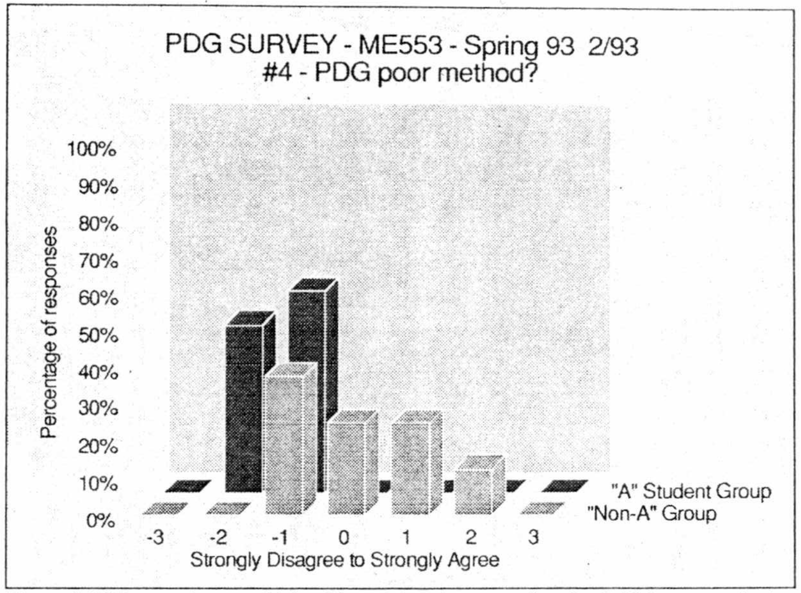

Figure 6: Differences between "A" and "non-A" students regarding the Guide's communication effectiveness.

Displays. Many students suggested that a better selection of colors, and less frequent use of differing colors, would be helpful to the presentation (students G08, G20, G03). Another student (G12) suggested that displays needed to be more "color-coordinated", which would also help users keep track of "where they are" in the program. One respondent (G20) suggested that bold text and different font sizes could be used effectively to show emphasis, instead of colors, in many circumstances. Student "G11" (correctly) detected an important lack of graphics-based screens, and suggested that text screens are more easily read on paper.

The author has typically used colors within the Guide to separate the various information elements on the screen. The "title bar" for each screen matches the "color" for that phase on the overall product development chart (the "home screen"), although it is clear from the survey that not many students have detected this relationship. As noted above, students also do not comprehend the "three-color" scheme used on the "home" menu. The tutorial or introduction should demonstrate the color characteristics of the title bars and of the "home" menu. Fewer colors should be used with "new" information added to the Guide.

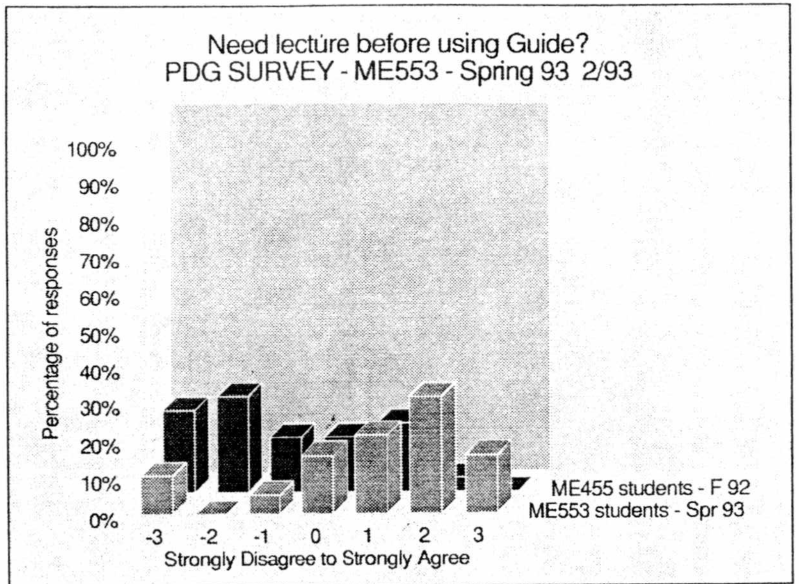

Figure 7: Difference in perceived need for a introductory lecture, between ME 553 class (Spring 1993) and ME 455 class (Fall 1992).

Bold and different fonts are not supported by the current "software engine". The current engine also does not support a graphics-mode; this deficiency has frustrated the software's author on more than one occasion, as he would very much like to incorporate more figures in the Guide. New authoring tools should be evaluated for these capabilities.

Navigation through Guide. Several students suggested methods for showing the menu tree or hierarchy so that users would not get "lost" when moving through the process. Alternatives included:

- providing a "map" or tree location somewhere on each screen (student G01)
- providing a method for users to "call up" the hierarchial tree on request (student G02)
- providing some indicator of the previous menu (G05)
- providing a printed map of how all the displays and menus are related (G09)

Another student suggested making screens more visually consistent; for example, second-level displays for each topic should look similar (student G06).

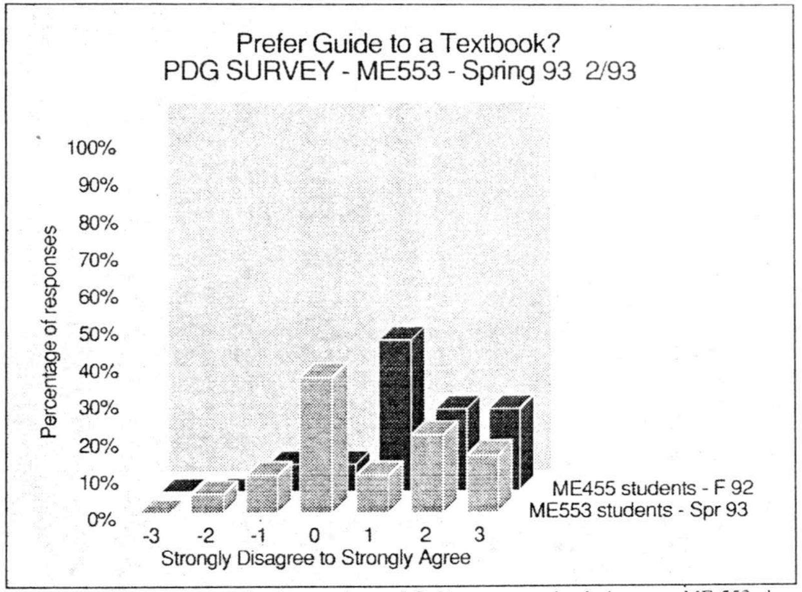

Figure 8: Difference in perceived ease of use of Guide versus textbook, between ME 553 class (Spring 1993) and ME 455 class (Fall 1992).

In terms of operation and display, a student (G06) suggested that screens should include some indication (a box, etc.) of the next step so that users could follow more of the process. This person also suggested that it would be useful to move from phase to phase without having to return to "home" screen. One student (G04) suggested that the "escape" key would be better for the "return" function, rather than "F2" key. Another thought that "mouse" selection of topics would be useful (student G20).

It is the author's view that a visual indication of the user's position within the Guide's hierarchy is essential in an advanced version of the Guide. An "F-key" could be defined for displaying hierarchy position on top of the current display. Another method might be to highlight the item selected from the previous screen, so that when the user returns to that screen it is clear which option had been previously selected. Unfortunately, neither idea is easily incorporated using the current software "engine", since both ideas would require creation of a large number of individual displays. When reviewing new engines, the ability to accomplish these tasks easily should be used as a key criterion.

A mouse cannot supported on the current engine. The key assignments (eg. ESC for F2) could be changed, but not easily, since the current engine requires that key assignments and text be changed individually on each screen. The author personally supports changing to ESC for the "return" function and providing mouse support.

Other Needs. Students provided several significant needs/suggestions for the Guide; these included:

- an "index", to help user find specific information or topics (student G12)
- definitions of some terms used in the Guide (student G02)
- example of how a product would go through the process with the Guide (student G02)
- software switch to accommodate mono-color display systems (suggested by the student with monochrome display problem - student G19)

Advanced feature suggestions. Several reviewers provided ideas as to how the Guide might be extended for use in an advanced computer environment. Some suggested that it could function in a "multimedia" or "interactive" environment, with a report/project planning program, or a "notepad" option to enable note-taking as the Guide is viewed. One student (G17) thought that the Guide would make a good "hypercard" application.

Student "G20" emphasized that the Guide needs to utilize advanced computer advantages: database functions, cross-listing, sound and animation. Another (student G02) suggested that the information could be adapted to allow a user to answer a set of questions, then have the Guide define "what needs to be done" next. Expansion of the Guide to include checklists to match a design team's process, and providing interactive tools for "tracking closure" on their process, was suggested by another (student G15).

Other Comments

The Guide, as tested by this class, was an incomplete prototype version of the software, dated January 1993. As such, information for several important phases of the product development process were not available. The responses from this survey are being used to improve the Guide and its presentation. Additional surveys and evaluations are planned.

Student response distributions, plots of the response distributions, relevant statistics, and compiled student comments are available from the research files.

SURV553.RES
Original 5/93
Updated 10/93
Edited 9/94

APPENDIX P

Student Survey Report, ME 455 Course, Fall 1993

PRODUCT DEVELOPMENT GUIDE

Results of ME 455 Student Survey - September 1993

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SUMMARY

Twenty-four (24) University of Tennessee mechanical engineering students in design course ME 455 (Fall semester 1993) completed two class assignments using the UT-SEDP Product Development Guide (the "Guide"), a computer-based aid for teaching product development. Students then answered a structured survey to register their perceptions of the Guide.

The survey consisted of 14 "agree-disagree" questions and five short-answer questions. The "agree-disagree" responses were tabulated and analyzed statistically. Student comments on the Guide's presentation, contents, and other issues were compiled and grouped by subject.

The survey was conducted primarily to assess student reaction to the Guide, and to identify needed improvements. While not specifically constructed to prove formally the educational efficacy of the Guide, the survey also solicited student opinions concerning the relative effectiveness of the Guide as a supplement or replacement to regular instruction and textbooks.

CONCLUSIONS

Overall, students' composite response to the Guide was quite positive. Students felt most strongly that:

- the approach used by the Guide is a good method for communicating this material (question #4);
- they learned something important about the product development process (question #11);
- they learned more by working in teams to complete the assignments than they would have by working individually (question #8);
- completing problem assignments helped them to understand better the contents of the Guide (question #12).

Students expressed less strong (but still statistically significant) opinions regarding several other aspects of the Guide. Students indicated that:

- the Guide was easy to use, even without a tutorial or previous training (question #1);
- the Guide is effective for teaching product development concepts (question #14);

- it was easier to use the Guide than to have a traditional lecture on the same material (question #3);
- they preferred using the Guide to obtaining the same material from a book (question #10);
- they understood how the Guide would help them complete their design project that would be assigned in the subsequent course (question #13).

Six questions in this survey were similar those asked of two previous classes. Thus, results from this survey were compared to earlier results; this comparison revealed that all three classes:

- found the Guide easy to use (question #1), although the extent declined in this survey versus the earlier two;
- said that using the Guide was superior to using a book to obtain the same material (question #10), although the extent has declined from the first class survey;
- strongly believed that they had learned something important from using the Guide (question #11);

The two undergraduate classes that were surveyed tended to prefer using the Guide to having a lecture on the same topic, while the graduate class tended to prefer a lecture format (question #9).

DISCUSSION of METHODOLOGY

Background and Goals

A survey was administered to senior-level design course students to capture their perceptions of the UT-SEDP Product Development Guide, a computer-based aid for teaching product development. The survey was conducted primarily to assess student reaction to the format and contents of the Guide within a design course and to identify needed improvements in both the Guide and in the associated class assignments. It specifically was *not* constructed to prove formally the educational efficacy of the Guide as a teaching aid. Nonetheless, student views were solicited concerning the relative effectiveness of the Guide as a supplement or replacement to alternative methods of instruction, including lectures and textbooks.

Student Group Composition and Assignment

Twenty-four (24) University of Tennessee mechanical engineering students in the Fall 1993 senior-level "Introduction to Design" course (course number ME 455) completed and returned the structured survey. All students in the class were mechanical engineering seniors. The basic purpose of the ME 455 course is to prepare students for their comprehensive design project, also known as a "capstone" design, during the following semester.

Before answering the survey, students completed two assignments using the Guide. Students were grouped into 3 person teams and asked to answer 14 questions related to the development process, answers to which could be found within the Guide. Next, the teams were asked to utilize the Guide while creating a Product Design Specification for a proposed product.

Survey and Analysis

Students responded to 14 "agree-disagree" questions and five "open-ended" comment questions. The "agree-disagree" questions (shown in Figure 1) provided a statement, then asked the student to agree or disagree with that statement on a seven point scale (-3 to +3). The "open-ended" section solicited student comments regarding the Guide's presentation/layout, contents, how they might use the Guide, and needed improvements. These questions are presented in Figure 2.

Responses to "agree-disagree" questions were tabulated and analyzed statistically. Lotus and Quattro spreadsheets were used extensively to tabulate data, generate statistics, and create graphs.

Statistical tests were used to decide when student opinion was sufficiently strong (from a neutral opinion) to make a conclusion. In general, a 95% confidence interval (using a t-distribution) was constructed for each statement. Opinions were deemed significant when the confidence interval did not include "0", or the neutral opinion. This procedure is equivalent to a one-sided t-test, using an alpha of 0.025.

Differences in response between different groups (such as between this class and previous ones) were evaluated by computing a confidence interval for the difference between the two groups' means, using an alpha of 0.05. Response differences for a particular question were deemed significant when the confidence interval did not include "0", or "no difference". This procedure is equivalent to a one-sided t-test, using an alpha of 0.025.

Small alphas were used in the evaluation to be conservative in making conclusions about the Guide. Confidence intervals were used in place of standard t-tests because they were more easily computed using the spreadsheet format.

Comments in the survey's short answer section were compiled and grouped by subject. These results were used to gain additional insight into the conclusions derived from the numerical analysis and to gather ideas for improvements. One of the professors teaching the surveyed class led a short, informal class discussion about the Guide after the written survey was collected. The instructor's notes from that discussion were used to supplement the written comments.

DISCUSSION of RESULTS

Response Tabulation and Statistics

The frequency distributions of student responses are shown in Table 1. The numbers to the right of each statement define how many students responded to that statement with the scale value defined for that slot. Thus, the left-most number for each statement defines how many students responded with a "-3" (strongly disagree), while the right-most value is the number of students who strongly agreed (+3) with that statement. The confidence intervals computed from the statistical compilation of responses are shown in Table 2.

Product Development Guide - ME 455 Survey
Dr. Wilson's and Dr. Speckhart's Section - 9/23/93

Please indicate how much you agree or disagree with the following statements; read questions carefully.

		STRONGLY DISAGREE			NEUTRAL			STRONGLY AGREE
1.	The Guide was easy to use, even without a tutorial or previous training.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
2.	I found the Guide to be intimidating.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
3.	It would have been easier to have had just a lecture on this subject instead.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
4.	The approach used by the Guide is a poor method for communicating this material.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
5.	I had trouble finding what I needed.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
6.	I would have done much better if I had completed a tutorial before I used the Guide.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
7.	I needed a lecture on the subject first.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
8.	I believe that I learned more working in teams than I would have working alone.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
9.	I would have learned more if a lecture had been used to present this material instead.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
10.	Using the Guide was better than reading the material from a book.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
11.	I don't think that I learned anything important about product development.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
12.	Doing a problem assignment helped me to understand this material better.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
13.	I do not understand how the Guide is supposed to help me complete my design project later.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)
14.	Overall, I found the Guide to be an effective method for teaching this course material.	(-3)	(-2)	(-1)	(+0)	(+1)	(+2)	(+3)

Figure 1: ME 455 survey for Product Development Guide, Fall 1993, agree-disagree portion.

Product Development Guide - ME 455 Survey
Dr. Wilson's and Dr. Speckhart's Section - 9/23/93

Comments section:

Presentation and layout of the Guide: Comment on how the material in the Guide was presented.

Contents: Comment on your perception of the material presented in the Guide.

Ease of use: With what did you have the most difficulty? What was easiest?

Help: How do you think the Guide can/should help you in this class? elsewhere?

Your turn: What would you do differently to make the Guide better? Other suggestions or comments.

(original survey included more space between questions)

Figure 2: ME 455 survey for Product Development Guide, Fall 1993, comments portion.

Overall Presentation

In general, the presentation of the Guide was well received. About one-third of all students in the survey wrote specific comments such as "orderly" [student "number" W13], "clear" [W14], "logical" [W15], and "appropriate" [W24]. Twenty (20) of 24 students (83%) said that the Guide was a good method for communicating this material (question 4). Seventy percent (70%) agreed with the statement, "Overall, I found the Guide to be an effective method for teaching this course material" (question #14). The two students (8%) who said that the Guide was a poor method for communication (question #4) claimed that the Guide was "too advanced" or "complex" [students W11, W20] for them to use effectively.

Completeness. Many students [W02, W07, W15, W23, and others] specifically noted a "completeness" and "depth" to the Guide. One student [W15] found the Guide to have "an abundance of information", while another [W18] suggested that the Guide had two seemingly contradictory qualities: "It was to the point but in depth." Yet another student [W04] remarked that he perceived the Guide to be "very helpful to design an entire product from start to finish, (covering) all parts and (helping) to make sure the design is not lacking in important areas."

Table 1: Frequency distribution of responses to ME 455 survey (Fall 1993).

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree)	Frequency Summary of Responses (n=24)						
QUESTION	-3	-2	-1	0	+1	+2	+3
1. The Guide was easy to use, even without a tutorial or previous training.	1	0	3	4	8	8	0
2. I found the Guide to be intimidating.	2	8	1	7	4	2	0
3. It would have been easier to have had just a lecture on this subject instead.	3	7	5	6	2	1	0
4. The approach used by the Guide is a poor method for communicating this material.	1	11	8	2	1	0	1
5. I had trouble finding what I needed.	1	3	3	2	7	7	1
6. I would have done much better if I had completed a tutorial before I used the Guide.	1	6	1	7	5	2	2
7. I needed a lecture on the subject first.	2	3	5	4	6	4	0
8. I believe that I learned more working in teams than I would have working alone.	0	0	3	2	5	8	6
9. I would have learned more if a lecture had been used to present this material instead.	0	6	4	9	3	2	0
10. Using the Guide was better than reading the material from a book.	1	2	1	4	5	7	4
11. I don't think that I learned anything important about product development.	7	9	4	3	1	0	0
12. Doing a problem assignment helped me to understand the material better.	0	1	1	2	7	9	4
13. I do not understand how the Guide is supposed to help me complete my design project later.	6	5	7	2	3	1	0
14. Overall, I found the Guide to be an effective method for teaching this course material.	0	2	1	4	9	8	0

Table 2: Response statistics for ME 455 survey (Fall 1993).

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Statistical Summary of Responses (n=24), (α=0.05)		
	LOWER Confidence Interval	MEAN Value	UPPER Confidence Interval
1. The Guide was easy to use, even without a tutorial or previous training.	0.22	0.75	1.28
2. I found the Guide to be intimidating.	-1.26	-0.63	0.01
3. It would have been easier to have had just a lecture on this subject instead.	-1.56	-1.00	-0.44
4. The approach used by the Guide is a poor method for communicating this material.	-1.73	-1.21	-0.69
5. I had trouble finding what I needed.	-0.18	0.50	1.18
6. I would have done much better if I had completed a tutorial before I used the Guide.	-0.74	-0.04	0.65
7. I needed a lecture on the subject first.	-0.77	-0.13	0.52
8. I believe that I learned more working in teams than I would have working alone.	0.95	1.50	2.05
9. I would have learned more if a lecture had been used to present this material instead.	-0.89	-0.38	0.14
10. Using the Guide was better than reading the material from a book.	0.26	0.96	1.65
11. I don't think that I learned anything important about product development.	-2.23	-1.75	-1.27
12. Doing a problem assignment helped me to understand the material better.	0.90	1.42	1.93
13. I do not understand how the Guide is supposed to help me complete my design project later.	-1.86	-1.25	-0.64
14. Overall, I found the Guide to be an effective method for teaching this course material.	0.34	0.83	1.33

Two students saw the completeness as a negative; said one [student W06]: "This guide doesn't show me much promise with design in class because I felt the guide is more directed towards product development companies and most of the questions pertaining to them."

Colors. A near majority of students complained about the "vast use of unpleasant colors" [student W23] that were used within the Guide. Additional comments about colors included: "a bit extreme" [W07], "hard to look at" [W02], and "somewhat irksome" [W22]. Students reinforced these views during the class discussion.

Use of the Guide

Overall ease of use. Overall, students reported finding the Guide easy to use (67%, question #1), and at least eight students (33% of those surveyed) wrote specific comments about how easy the Guide was to use [students W02, W06, W07, W10, W11, W13, W14, W23]. Another student [W12] found the Guide to be "easily understandable", and particularly liked the use of "bullets" throughout.

Intimidation factor. Student response to question #2, "I found the Guide to be intimidating," was technically neutral under the defined analysis, but just barely. With a mean response of -0.63 and an "upper confidence interval" ending at +0.01, students came just short of concluding that the Guide was *not* intimidating. Additionally, only 25% of respondents indicated that they found the Guide intimidating, at least to some extent. However, one student [W21] did comment that he found the Guide "overwhelming." Interestingly, neither of the two students who indicated that the Guide was a poor method for communication said that they were intimidated by the Guide.

Finding Needed Information. Students in this survey were statistically neutral regarding how much trouble they experienced finding information in the Guide (question #5), although over 60% reported at least some trouble finding what they needed to complete their assignments.

The biggest problems noted by students [W01, W10, W11, W18] in their comments were all related to locating desired information: students would descend into a topic, then "lose their place"; or, students would recall seeing certain information, but have trouble finding it again. Other students said that they had some difficulty in distinguishing one section from another.

One student [W16] recognized that part of this problem was related to their lack of knowledge about the product development process: "In hindsight, the layout seemed good and logical. While doing the assignment we had to hunt, but I think that was the idea - familiarize."

Information density. Several students commented on the amount of information and how it was accessed from the Guide. Two students [W17, W22] specifically suggested that screen displays carry too much information and need to be "less cluttered". Unfortunately, to do this may very well aggravate the complaint of another user [W12] who complained that the Guide requires "too many screen changes". One also might anticipate that more display screens (so that less information can be presented on each screen) might increase users' tendencies to "feel lost", as described above.

Learning Experience

Perceived Effectiveness in Learning. Questions #4 and #14 were structured to test the same basic characteristic, that of whether the Guide is an appropriate educational tool, but asked that question differently. Question #4 asked students to agree/disagree that the "Guide is a poor method for communicating the material", while question #14 asked them to agree/disagree that they "found the Guide to be an effective method for teaching". Since communication is a significant element of teaching, one might expect students who say that the Guide is an effective communication method to also report it as effective in teaching. Thus, the combination of student responses to questions #4 and #14 were investigated.

The "combination" responses to questions #4 and #14 are shown in the "bubble" graph, Figure 3. On this graph, the sizes of the bubbles reflect how many students answered with that particular response combination. Given the phrasing of the two questions, students who found the Guide to be both a "good communication method" (#4) and "effective for teaching" (#14) are located in the upper-left quadrant of the graph. The graph clearly shows that most found the Guide to be both communicative *and* effective for teaching, and the statistical tests for both questions support this conclusion.

However, the graph clearly shows significant variation in the students' relative "ranking" of the Guide through the two questions. Many students ranked the Guide differently as "effective for teaching" than how they ranked the Guide as "a good communication method". Enough variation in the combinational response occurred that an attempt to fit a linear regression line to the responses failed (r^2 of correlations < 0.15). This failure suggests either that students either do not equate "communication" with "learning" this material, or that they are somewhat unsure of their perceptions of the Guide.

This uncertainty among some is evident in the two students [W06 and W23] who said that the Guide was not effective for teaching, but then said that it was a good method for communication (two bubbles in the lower-left quadrant of Figure 3). Another [W11] found the Guide to be a poor "communication method" but also found it to be "effective", as shown by the bubble in the upper-right quadrant of Figure 3.

Evaluation of Contents. Students were asked to comment about the contents of the Guide. Several students [W02, W05, W14, W23] stated that they overall had found the Guide to be "well presented", "useable", or "well written." Two students [W11, W23] noted that some questions and language were unclear to them, while another [W20] said that the "graphics (used in the Guide) were not that pleasing." That students would find the Guide's graphics disappointing is not surprising, considering that the Guide currently supports only rudimentary "box-like" and horizontal-vertical line graphics.

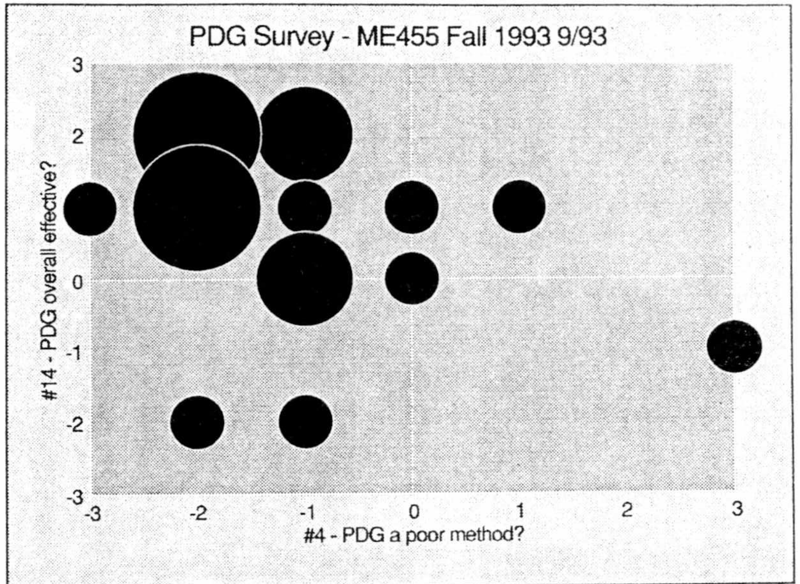

Figure 3: Bubble graph showing the combination student responses to Question #4, "... Guide is a poor method for communicating ...," and Question #14, Guide is "an effective method for teaching ...".

Students immediately perceived the Guide's contents as "important" [student W10] for "highlight(ing) important design considerations" [student W15]. Others noted that the contents "give an idea of (and that there is) a structure to a design process" [W16], and that "it show(s) you all the things you should think about when developing a product" [students W13, W18].

Many students recognized and described the rationale for the "critical questions" used throughout the Guide: said one, "It will make the design more thought out from the beginning" [W14]. Two students [W03, W13] specifically mentioned that the questions asked about issues that they would have otherwise "overlooked". One student [W16] noted that the questions "gave good ideas" about what must be resolved during the design process, and another [W08] even extended the concept to "allow me to develop my own questions to problems or given situations before they occur."

Quite a few students [W01, W02, W05, W11, W24] noted the "examples" residing in the Guide, and suggested that these had been important to their learning process. At least three students (12%) specifically asked for more examples in the Guide, and one of these [W01] thought that he "could have done better" on the assignments if there had been "more examples of what was wanted."

Several of the "problems" reported by students may actually indicate some real lessons learned from the Guide. For example, one student [W08] complained, "The paper (Product Design Specification) that (our team) turned in could have been a ten page document, if each question was answered that applied properly." Another complained, "One could spend days on these questions" [W20]. These statements suggest that students may have learned (even not explicitly realized by the students) that products must address many different needs simultaneously and that successful product development requires a sustained effort. One [student W11] did comment that the fact that the questions seem endless "is a good thing."

Students apparently were somewhat disturbed by the nature of some questions, which appeared to them to be "redundant" [student W23] or "overlapping" [W11]. This issue was also brought up during the class discussion. Another student [W21] reported a slightly different problem: "I would get stuck on one question, which seemed to have an endless answer." These comments suggest that some of the questions within the Guide have not been constructed precisely enough for students to distinguish the subtle differences in them. While many of the same development issues must be attacked iteratively and repeatedly throughout the process, the team's focus of how (and what) to attack changes during development.

Value Perceptions. Students strongly believed that they learned something of importance (question #11) from using the Guide, registering the highest mean response of all the questions in the survey. One student [W07] commented, "The guide did a fairly good job of describing the processes involved in product design and manufacturing. After using the Guide, I know more than I did about the processes explained in the Guide." Another [W17] stated that, "The material is good and the Guide is definitely worth having."

Three students (representing 12.5%) [W05, W15, W20] were neutral on the question, while only one student [W06] of the 24 surveyed indicated that he had not learned anything important from the Guide. This student commented that he had had a "bad experience in finding the material I needed to review," and also (as reported above) was one of the three that indicated that the Guide was not effective in teaching the material.

Role of Problem Assignments. Students clearly indicated that completing the problem assignments as part of the Guide's use assisted their learning (83%, question #12). Over 50% of students said strongly (through a +2 or +3 response) that the assignment was very helpful. One student [W16] complained that "the assignment at times seemed a bit like busywork."

Student Application. Students also said that they understood how the Guide is to help them with their subsequent design project (question #13), with fully 25% of students saying (through a "-3"

response to a "negative" question) that they knew "strongly" how it would help them. One-sixth admitted that they did not know.

One student [W16] commented generally that the Guide "could be a useful reference in the future." Even the student [W06] noted in the "completeness" section who did not think the Guide had much promise in the class thought that the Guide would apply to commercial development activities.

Comparison to Lecture and Text Resources

During the class discussion, students said that they thought it easier to access information from the Guide than from other sources. The strength of this conclusion was analyzed using the survey questions that compared use of the Guide to books and class lectures.

Guide versus Text. Students concluded that using the Guide is better than reading the material from a book (question #10), registering a mean of nearly +1 on the -3 to +3 scale. Fully 42% of students strongly ranked the Guide better than a book, as indicated by a +2 or +3 response.

The class discussion indicated that students felt that they were able to access information faster with the Guide than with a book, and one student [W02] wrote that the "Guide was helpful and laid out better than the Pugh book." (It should be noted that the topics for the Guide's Product Design Specification were derived from the Pugh text). Interestingly, one student [W12] who scored the Guide highly (+3) compared to a book commented that "a (condensed) handbook a few pages long would beat the heck out of the computer format."

Guide versus Lecture. Students were asked to compare their use of the Guide to having a class lecture on the same topic in two aspects: (a) whether it would be "easier" to have a lecture on the topic instead of using the Guide (question #3), and (b) whether students thought they would "learn more" in a lecture instead of using the Guide (question #9). The two questions were asked on this subject to evaluate whether students who say that they prefer a lecture do so because they believe that a lecture would be more effective for learning, or simply think that a lecture would require less effort/participation.

Students solidly indicated that using the Guide was easier than having a lecture over the same material (question #3). At the same time, they were statistically neutral regarding which was more effective for learning (question #9), even though twice as many of those expressing a preference said that the Guide was better.

The combinational student response to these two questions is shown in Figure 4. The phrasing of the two questions locates students who believe that the Guide is both easier and better for learning in the lower-left quadrant of the figure.

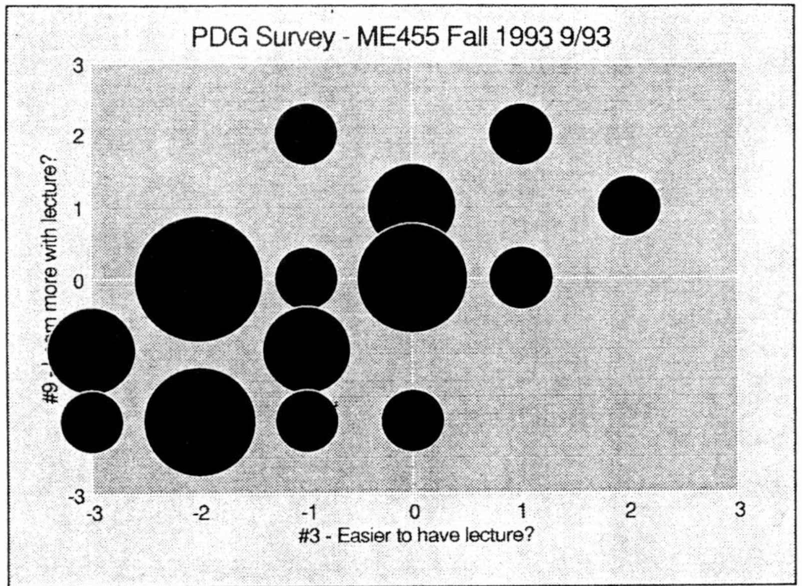

Figure 4: ME 455 class (Fall 1993) combinational response to statement (#3), "It would have been easier to have had just a lecture ..." and statement (#9), "I would have learned more if a lecture had been used ... ."

Introductory Tutorial or Lecture

The version of the Guide used with this survey did not contain any tutorial material, and students were intentionally given very little written or verbal instruction on how to use the Guide. Even though they received very little assistance, students nonetheless were almost evenly split about both the need to complete a tutorial (question #6) and the need to have an introductory lecture before attempting to use the Guide (question #7).

Of those suggesting that an introduction was needed, several [W01, W03, W14] complained that they had found it "hard to get started". These students apparently did not immediately comprehend the role of the Guide in completing the assignments.

Tutorial. About 38% of the students indicated that they would have performed better had they completed a tutorial before attempting to use the Guide (question #6).

Introductory Lecture. Students were essentially neutral on the need for a lecture before using the Guide (question #7), with over 60% registering responses between (-1) and (+1) and an equal number of students responding positively (needing a lecture) and negatively (not needing a lecture).

Composite Response to Guide

Assessments of the overall student response to the Guide were constructed by combining each student's individual responses of specific questions into a "composite score" for that student. This composite measure was based on eight survey questions considered to be the most reflective of the overall "goodness" of the Guide: questions #1-#4, #9-#11, and #14. These questions evaluate the Guide's "ease of use", intimidation factor, communication and learning effectiveness, perceived importance, and usefulness versus books and lectures. Two different scores were created: an "unweighted" composite response and a "weighted" composite response.

Unweighted Response. The unweighted score was computed by assigning a "+1" to responses considered favorable, "-1" to unfavorable, and "0" to neutral responses. A score of "±1" was assigned to any non-neutral response, regardless of the actual response (hence the term, "unweighted"). Thus, a student response of "+3" to a question was assigned the same credit as a "+2" response. With eight total questions under review, the highest possible favorable opinion is +8, while the least favorable composite response is -8.

The unweighted composite score results were quite encouraging, as shown in Figure 5. The mean unweighted response is +4.04, indicating that the "average" student was "net positive" about at least four of the Guide's eight composite characteristics. The 95% confidence interval about the mean ranges from +2.64 to +5.44, indicating that the overall "positive" response is statistically significant. Only two students (8%, students W08 and W21) rated the Guide negatively, while two others (also 8%, students W14, W24) rated the Guide neutrally with a "0". The remaining 83% of the class ranked the Guide with a +3 or higher on the -8 to +8 scale.

Weighted Response. The "weighted score" was computed similarly to the unweighted score, except that the "magnitudes" of the responses were also used. Scores to negatively phrased questions were reversed so that favorable responses (as to the "goodness" of the Guide) yielded positive scores. With eight total questions under review and a maximum rating of ±3 for each question, the largest possible composite responses are +24 (most favorable) and -24 (least favorable).

The weighted composite score is shown in Figure 6. The mean weighted score is +7.50, with a 95% confidence interval of +4.75 to +10.25. Thus, the weighted overall "positive" response is also statistically significant.

As might be expected, the same two students (8%, students W08 and W21) who rated the Guide negatively on the unweighted scale also rated it negatively on the weighted scale. The same two others (8%, students W14 and W24) again rated the Guide neutrally with a "0". Other than one

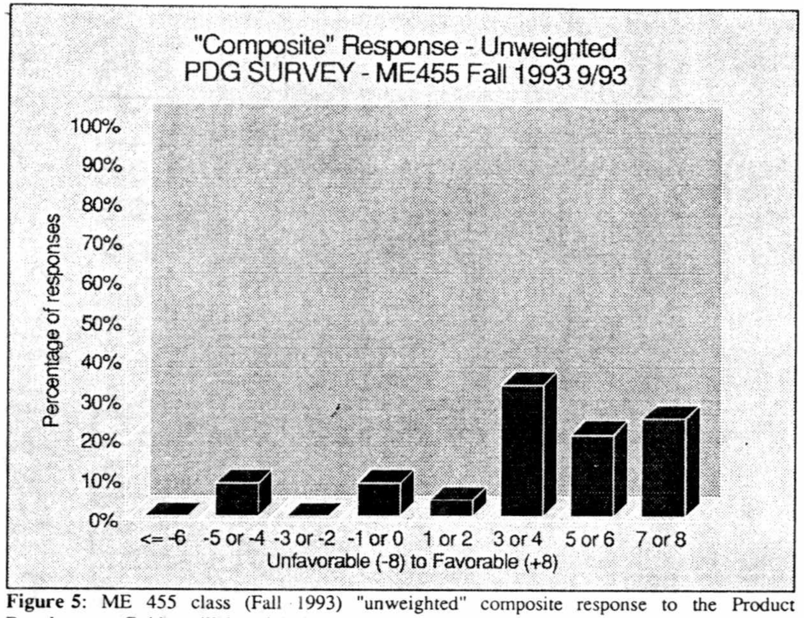

Figure 5: ME 455 class (Fall 1993) "unweighted" composite response to the Product Development Guide, utilizing eight key survey questions. The maximum favorable score is +8.

additional student [6%, student W10] who ranked the Guide at +1, all other students generated a composite score of at least +5. Over 40% of students ranked the Guide as a "+10" or higher on the -24 to +24 point scale.

Comparison of Results to 1992 Class

A similar exercise and survey was administered to 27 students taking the ME 455 course in 1992. Nine questions in the 1992 survey were either essentially or exactly the same as questions asked in this survey. Students in 1992, of course, used an earlier, less complete version of the Guide, but completed essentially the same assignments. The students in the earlier class were generally provided with more instruction on the use of the Guide.

Statistical tests were performed on the nine common questions (questions #1, #5-#7, #9-#13) to investigate potential differences in response between the two classes. Statistically significant differences in opinion between the two classes were found in three areas; students in the 1993

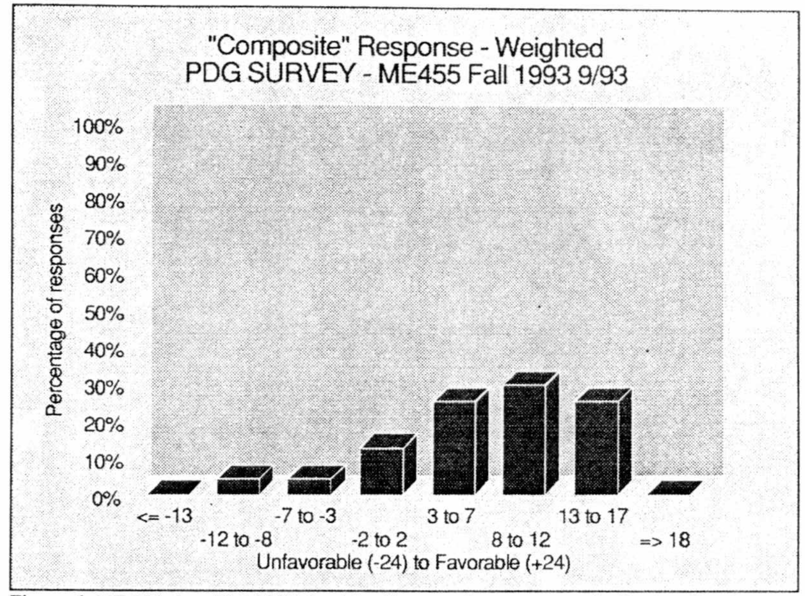

Figure 6: ME 455 class (Fall 1993) "weighted" composite response to the Product Development Guide, utilizing eight key survey questions. The maximum possible favorable score is +24.

class, when compared to the students in the 1992 class, reported that:

- the Guide was less easy to use (question #1)
- they had more trouble finding the desired material (question #5)
- they had more of a need for an introductory lecture (question #7)

Also, while the difference was not quite significant statistically, 1993 students tended to be less enthusiastic in their belief that using the Guide was better than using a textbook (question #10).

It should be noted that the 1993 students still reported the Guide as easy to use (mean +0.75, question #1); they simply did not report it as strongly as did the the 1992 students (mean +1.85). Also, while 1992 students reported that they did not have trouble finding needed material, 1993 students were technically neutral but were generally inclined to have more trouble (question #5 and Figure 7). These two factors are likely the result of the Guide's significant increase in overall size, discussed below.

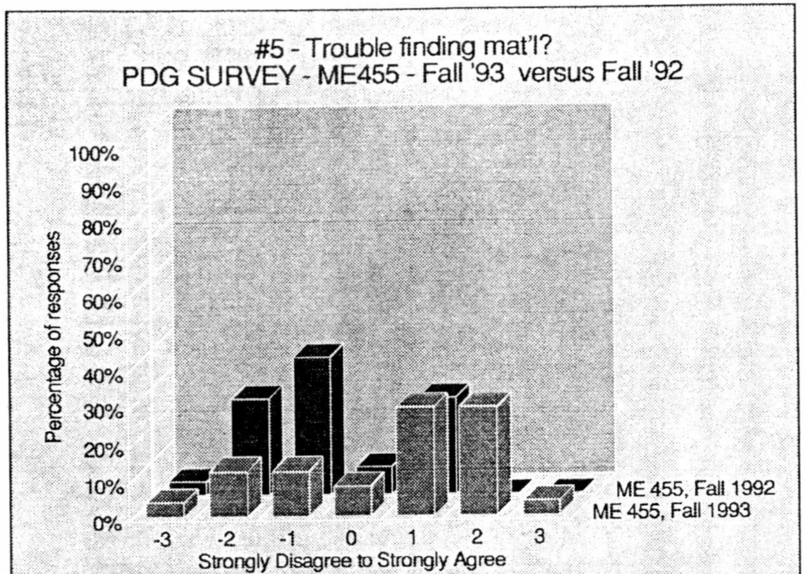

Figure 7: Comparison of ME 455 classes, Fall 1993 and Fall 1992, regarding response to the statement, "I had trouble finding what I needed." (question #5).

The general increase in students' need for an introductory lecture (question #7) and observed (but not quite statistically significant) increase in the need for a tutorial be may partially due to the Guide's increased size, but may also be associated with differences in how the Guide was presented to the classes. The 1993 students were intentionally provided with less instruction, to evaluate how well the Guide would fare as an independent team study effort.

Many students in the 1993 class still reported strongly that they thought the Guide was better than a book, but the number of students reporting that it was not increased, resulting in an net decline for the overall response.

Little difference was observed between the 1993 and 1992 classes regarding students' perceptions that they learned something important (question #11), that an assignment assisted their learning (question #12) and that they knew how the Guide would be useful in their design project course (question #13). Both student groups concluded that they learned something important, that the assignment helped their learning, and that the Guide would prove useful in their design project.

Comparison of Results to 1993 ME 553 Class

The Guide was also used (in a different role) during the Spring 1993 course ME 553, "Development of Superior Products and Processes". These students were asked to compare development process concepts shown in the Guide to those presented in class, and also were encouraged to use the Guide as a reference "text" throughout the semester. Fifteen (15) of the 19 students in the class were graduate students in engineering.

Nine questions from the survey administered to that class matched questions asked in the current survey. Students in the Spring 1993 ME 553 class utilized a version of the Guide which was less complete than that used for this survey, but more advanced than that used in the 1992 ME 455 class. Statistical tests on the nine common questions (questions #1-#4, #6-#7, #9-#11) revealed differences of opinion among five of the questions. The 1993 students in ME 455, when compared to the ME 553 students, reported that:

- the Guide was less easy to use (question #1);
- using the Guide was easier than having a lecture on the same material (question #3);
- the Guide was more effective for learning than a lecture (question #9);
- they were *less* intimidated by the Guide (question #2);
- they were *less* likely need to a lecture first before using the Guide (question #7).

While not quite statistically significant, the ME 455 students were also generally more enthusiastic in their belief that the Guide was an effective communication method (question #4).

It was surprising to find that the ME 553 graduate students, using a smaller version of the Guide, reported being much more intimidated by the Guide than did the 1993 ME 455 seniors using a larger version. Figure 8 shows the clear difference in these levels. It should be noted that these "equivalent" questions were worded somewhat differently; the ME 553 students were asked, "I was intimidated by the large amount of data contained in the Guide," while the 1993 ME 455 students were simply asked, "I found the Guide to be intimidating." Nonetheless, the difference is still quite dramatic.

ME 553 students were also more likely to prefer lectures and to say that lectures were more effective for learning than ME 455 students. The ME 553 class also reported a higher need for an introductory lecture before using the Guide. These differences may be due to differences in the courses and in the nature of the class assignment used with the Guide. A former ME 553 student later used the Guide in conjunction with designing a device for his master's thesis; he reported that he found the Guide much more valuable to him once he had a specific need for it than when he had used it as a general reference in the ME 553 class.

The 1993 ME 455 students responded similarly to the ME 553 students regarding the need for a tutorial before using the Guide (question #6), whether the Guide was better than a book (question #10), and whether they had learned something important from the Guide (question #11).

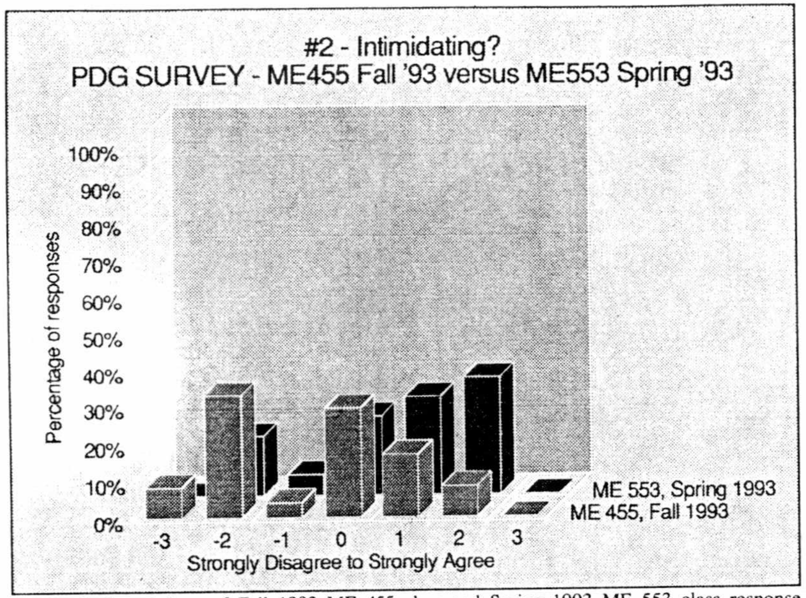

Figure 8: Comparison of Fall 1993 ME 455 class and Spring 1993 ME 553 class response regarding the statement, "I found the Guide to be intimidating." (question #2).

Three-Way Comparison of Results

Six questions in the current survey (questions #1, #6-7, #9-11) matched inquiries asked in the earlier surveys from both the 1992 ME 455 class and the 1993 ME 553 class. Responses to these common questions were reviewed to assess differences among the three classes. All three classes of students reported that:

- the Guide was easy to use (question #1), although the extent declined in this survey versus the earlier two;
- using the Guide was superior to using a book to obtain the same material (question #10), although the extent declined after the 1992 survey;
- they had learned something important from using the Guide (question #11)
- they were "neutral" on the need to complete a tutorial before using the Guide (question #6)

Except for the noted decline in ease of use, the most significant differences between surveys were observed between the graduate ME 553 class versus the two senior ME 455 classes:

- While the ME 455 classes claimed that the Guide was either better than or equivalent to a lecture in terms of effectiveness for learning, the graduate students nearly said that the lecture was better (question #9);
- the ME 553 class expressed a much higher need for an introductory lecture than did the senior students (question #7).

Ease of Use. Figure 9 shows student opinion about the Guide's ease of use (question #1) for all three surveys. The most significant decline occurred between the ME 553 survey (Spring 1993) and the current one (ME 455, Fall 1993). The mean response between these two surveys declined almost 0.90 points, from +1.63 in Spring 1993 to +0.75 in Fall 1993.

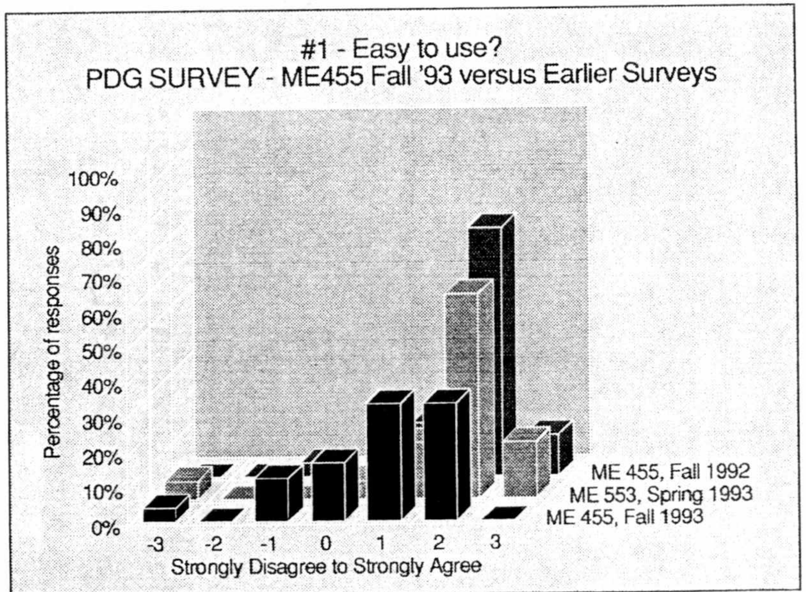

Figure 9: Comparison of responses from three classes regarding the statement, "The Guide was easy to use, even without a tutorial or previous training." (question #1).

Perceived Importance. Student perceptions of whether they learned something important from the Guide (question #11) is shown in Figure 10. Since this question was phrased negatively, "minus" answers are considered better. The magnitude of the mean response increased from 1.52 in Fall 1992, to 1.58 in Spring 1993, to 1.75 in Fall 1993, although it should be noted that the differences between classes were not statistically significant. All three classes strongly believed that they had learned something important about product development.

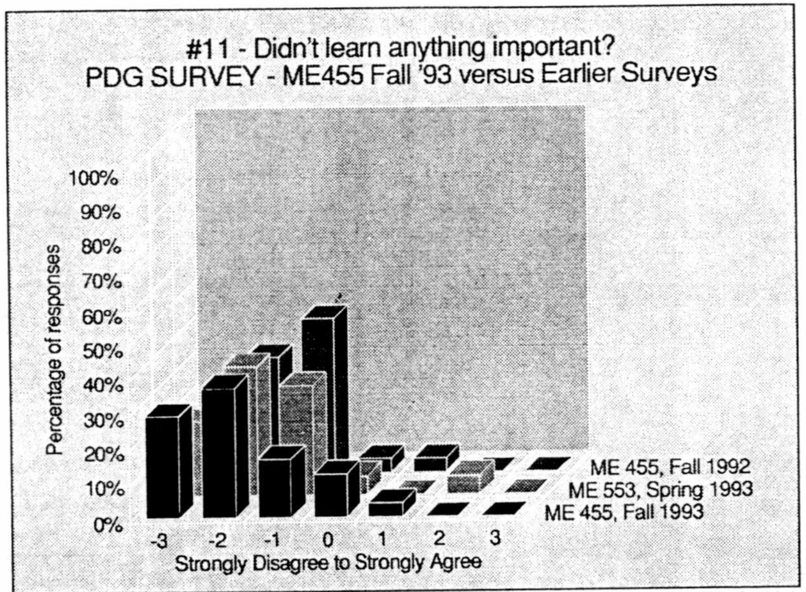

Figure 10: Comparison of responses from three classes regarding the statement, "I don't think that I learned anything important about product development." (question #11).

Need for Introductory Lecture. Unexpectedly, the ME 553 graduate students expressed a much stronger need for an introductory lecture (question #7) than did either of the ME 455 classes, as shown in Figure 11. This figure plots the "confidence interval" for each class on the agree-disagree (-3 to 3) scale, with the "tick" representing the mean response. The figure clearly indicates that the 1992 ME 455 class said that it did not need a lecture, while the Fall 1993 ME 455 class was essentially neutral. The ME 553 result stands in sharp contrast, reflecting that classes' expression of need.

Guide versus Alternative Instruction. All three classes said that using the Guide was better than using a book (question #10 and Figure 12), although the Fall 1992 class tended to rank the Guide

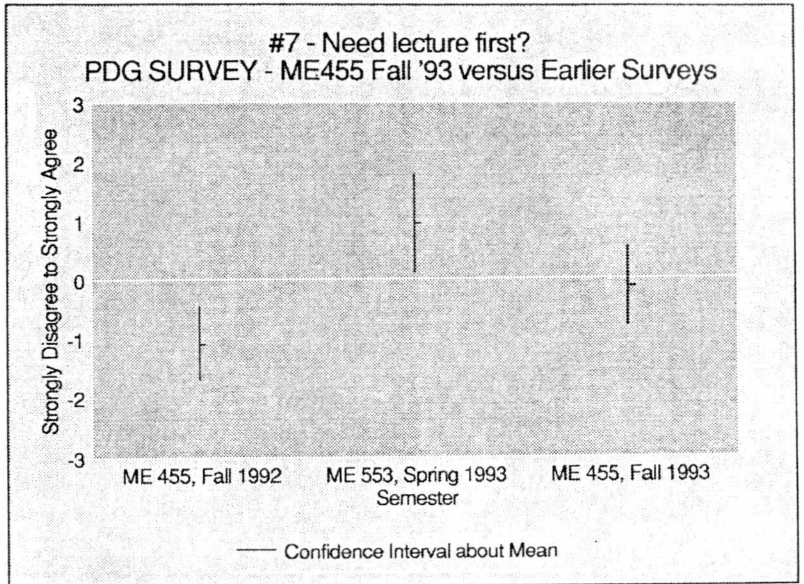

Figure 11: Comparison of responses from three classes regarding the statement, "I needed a lecture on the subject first." (question #7). The "tick" and vertical bars show the mean response and the confidence interval about the mean.

higher than subsequent classes. The figure also shows how the variation in opinion within the class has increased over time, with current responses spanning the entire -3 to +3 range.

When comparing the Guide to a lecture (question #9), a significant difference between the graduate course and the two senior classes can be seen (Figure 13). The ME 455 classes claimed (or almost claimed) that the Guide was better than a lecture for their learning, while the graduate students nearly said that lectures were more effective.

Possible Factors. The "size" of the Guide (as measured by the number of information displays or "screens" contained within it) has increased from about 190 screens in Fall 1992, to about 430 "screens" in Spring 1993, to approximately 725 screens in Fall 1993. One might reasonably expect increasing size to have an effect on the Guide's perceived ease of use and related indicators. Some deterioration in the results could be the effect of providing the later classes with less instruction on how to use the Guide.

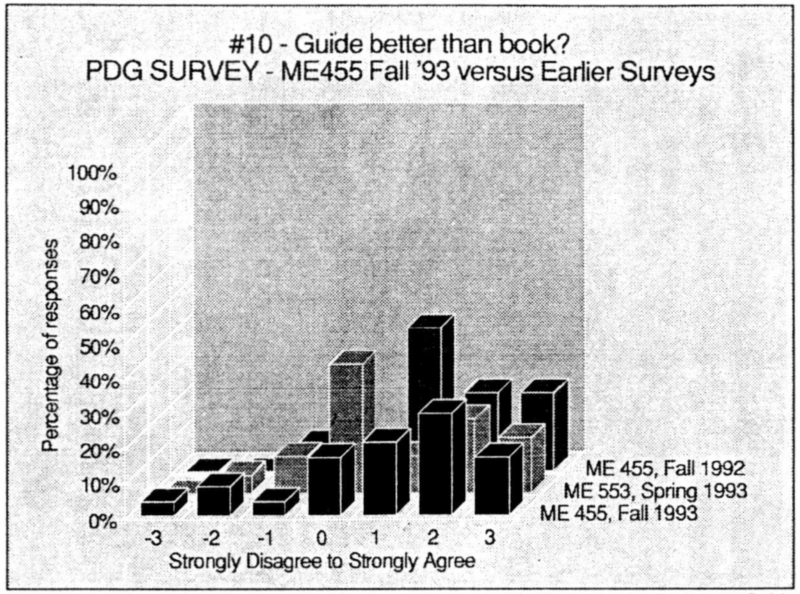

Figure 12: Comparison of responses from three classes regarding the statement, "Using the Guide was better than reading the material from a book." (question #10).

However, size alone cannot explain the differences, since the "worst" scores did not always occur in the latest survey. Indeed, several appear to be more related to which particular course (the ME 455 senior course or the ME 553 graduate course) was surveyed than to the raw size of the Guide. Thus, it may be useful to consider what significant differences in the two courses might have led to the differing results.

One potential difference is the type of assignment that accompanied the Guide. ME 455 students completed much more-highly structured assignments than did the ME 553 students. While ME 455 students were given two fairly specific tasks, ME 553 students were essentially assigned to review an entire phase, then compare the Guide with concepts presented in class. Thus, the ME 455 students may have rated the Guide higher because it directly assisted them with their assignments. Indeed, the ME 553 class' desire for an introductory lecture may reflect a need for some guidance as to how to use the Guide to complete their much broader assignment.

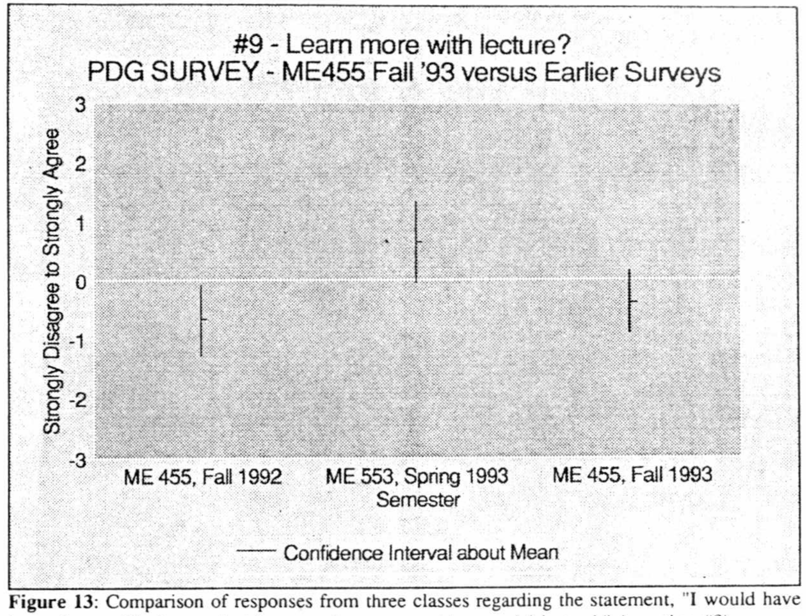

Figure 13: Comparison of responses from three classes regarding the statement, "I would have learned more if a lecture had been used to present this material instead." (question #9).

That ME 553 students tended to prefer lecture over the Guide is not all that surprising in retrospect, considering the format and content of that class. Lectures by the course professor and visits by guest speakers present a comprehensive vision of the development process; the items presented are real development projects and the class sessions are highly interactive. Given this environment, it is reasonable that students would like the "lecture" format. Their comparison, then, is not necessarily a negative impression of the Guide, but may more reflect the effectiveness of the ME 553 class format.

Suggestions for Improvement and Comments

General. Several students expressed satisfaction with the Guide as they experienced it, describing the Guide as "very effective and well planned." [student W24] These students suggested that the Guide "just needs some completing - finish the blank screens." [students W03, W18] One dissatisfied student [W17] said to "redesign the presentation," but did not make any specific recommendations.

Some students did make specific recommendations. Some of these included providing more directions [W01], using more examples [W05], and revising sections that are too wordy or ambiguous [W22]. Several students recommended making information screens less cluttered and the text easier to read [W01].

Reference/Locator Techniques. As noted earlier, students reported some difficulty in determining "where they were" within the Guide; students said during the class discussion that the Guide needs some type of screen identification technique.

Some students suggested potential remedies to this problem. One student [W07] recommended that "a line across the bottom of the screen" would help users determine "how deep (one is) into a menu," while another [W23] suggested that a "map" of the potential paths, separate from the Guide itself, would be adequate. Creating "obvious differences" in presenting different sections was also proposed [student W11]. The class discussion yielded ideas for "screen layers" or a "flow-tree chart".

Another student's suggestion [W10], "put the main headings of where you are up top or somewhere," is already used extensively throughout the Guide, but apparently was not adequate for this user.

Color. Many students [W02, W07, W13, plus others below] recommended changing the color schemes to make the Guide more appealing to users. One student [W06] was particularly emphatic: "Get rid of some of those damn colors." Two students [W07, W24] suggested that a "standard" color should be used throughout, with only key words highlighted in a different color.

One purpose of using color for different information screens is to "separate" sections visually, and thus reduce the feeling of "being lost" in the Guide. Apparently, this has not been managed consistently enough to be effective; part of the difficulty is related to the large number of sections, limited number of "acceptable" colors, and the fact that many displays have been moved to different sections after they were created.

One student [W23] clearly recognized the other purpose of using different colors: "I realize that the complexity of the text required many different shades of colors to help separate sections of the text. I think (that) a desirable color range ... (is) using only one color per paragraph."

Tutorial Contents. Earlier classes responding to similar surveys were specifically asked to recommend contents for the Guide's tutorial. To assess how much a tutorial is really needed, students in this survey were not specifically asked about a tutorial, but were provided opportunities to mention one if they deemed it important. Few written comments were received, although students apparently mentioned the need for a tutorial was during the class discussion. Tutorial suggestions were focused in two areas: (1) helping students to locate specific contents in the Guide [student W06], and (2) helping students "get started" in utilizing the Guide.

Advanced Features/operation. Several users suggested that using a different program to "run" the Guide would improve its operation. Three students [W08, W21, W24] specifically recommended a "Windows"-type environment. Another student [W11] saw the potential for "supplemental multi-media" information to be added to the framework of the Guide.

Other Comments

The Product Development Guide, as tested by this class, was an incomplete version, dated September 1993.

The responses from all of the surveys are being used to improve the PD Guide and its presentation. Additional surveys and evaluations may be performed as the Guide is completed.

Student response distributions, relevant statistics, and compiled student comments are available from the research files. Bar graph plots of the response distributions are also available.

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Original draft 2/94

APPENDIX Q

Student Survey Report, ME 469 Course, Spring 1994

PRODUCT DEVELOPMENT GUIDE

Results of ME 469 Student Survey - May 1994

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The University of Tennessee

SUMMARY

Thirty-two (32) University of Tennessee mechanical engineering students in two separate sections of the "capstone" design course ME 469 (spring semester 1994) answered a survey concerning their use and impressions of the Product Development Guide ("PD Guide"), a computer-based aid for product development, and its associated tools, "PDG Tools".

The survey was conducted primarily to assess student reaction and use of PD Guide and PDG Tools within the capstone design project, and to identify needed improvements. While not specifically constructed to demonstrate educational efficacy, the survey did solicit student opinions concerning the relative effectiveness of PD Guide as a supplement or replacement to lecture instruction and textbooks.

The survey consisted of several sections: personal data, 17 "agree-disagree" questions, 11 inquiries regarding the use and usefulness of PD Guide and PDG Tools and 4 short-answer questions. The "agree-disagree" and "use/usefulness" responses were tabulated and analyzed statistically. Student comments on PD Guide's presentation, contents, and other issues were compiled and grouped by subject.

CONCLUSIONS

Students' overall response to PD Guide was moderately positive. Student use of PD Guide was "moderate", with students reporting an average use of 1.75 on a "0 to 4" scale. Students rated the usefulness of Product Development Guide as a mean score of 1.94 on a "0-4" scale. Some PDG Tools, such as the final design report template and the CAD drawing frame, achieved usefulness mean scores in excess of 3.0. Students' relative value rankings of PD Guide and specific PDG Tools were higher than their use ratings, which suggests that students find value in PD Guide and PDG Tools, once they can be convinced to use them.

Students generally, albeit moderately, indicated that:

- using PD Guide is a worthwhile experience (question #3), and it contributes to learning something important about product development (question #11);

- PD Guide can be used successfully to help student teams complete their design projects (question #14);
- using PD Guide is better than obtaining the same material from a book (question #7);
- they would not object to using software such as the PD Guide in place of a course textbook (question #9).

Comments from students who said that PD Guide was not useful or worthwhile suggest that these students perceived PD Guide as "extra tasks" requiring more time, rather than as "an project assistant".

Based on their experiences in the design course (and their corresponding use of PD Guide), students said *very strongly* that:

- they learn *much* more in teams than they would by working alone (question #6);
- they now have a much *stronger* interest in pursuing a career in design or product development than they did before taking the course (question #17);
- a structured approach is critical to completing a design project successfully (question #8), and that they were generally able to apply a structured approach when completing their design problem (question #4).

Students in the two separate course sections (a morning "AM" session and an afternoon "PM" session) differed in opinions regarding several aspects of PD Guide and the design class:

- students in the PM session expressed a higher need for some type of resource to help them with the course than did students in the AM group (question #1);
- the AM session instructors encouraged students to use PD Guide much more than did the PM instructor (question #2);
- AM section students reported higher average use of PD Guide and PDG Tools than did PM students;
- AM students were more likely to claim success in using an organized approach in solving their design problem (question #4), but PM students more strongly indicated that, after their design experience, using an structured approach is important for solving a design problem (question #8).

The differences between sections are believed to be due to specific differences in how those sections were managed. The PM instructor intentionally conducted a more "laissez-faire" class than did the AM instructors. Also, a stronger effort was made to inform AM students of the available PDG Tools and their use in a design project.

Comparison of results versus previous surveys revealed that students remain essentially neutral on whether PD Guide is more effective than an equivalent lecture (question #10), but also continue to believe that using PD Guide is better than attempting to find equivalent material from a textbook (question #7). Although still positive, student opinion as to whether they learned something important about product development declined sharply. Use of PD Guide over a longer period, compared to earlier surveys, may have altered students' perception of their own learning from PD Guide (question #11).

DISCUSSION of METHODOLOGY

Background and Goals

A survey was administered to senior-level capstone design course students to capture their perceptions of Product Development Guide ("PD Guide"), a computer-based aid for learning product development. The survey was conducted primarily to assess student use and value perceptions of PD Guide and PDG Tools within the capstone design course and to identify desirable improvements. It specifically was *not* constructed to prove the educational efficacy of PD Guide as a teaching aid. Nonetheless, student views were solicited concerning the relative effectiveness of PD Guide as a supplement or replacement to alternative instructional methods, such as lectures and textbooks.

Student Group Composition and Assignment

Thirty-two (32) University of Tennessee mechanical engineering students in two separate sections of the spring 1994 senior-level "capstone design" course (course number ME 469) completed and returned the survey after they completed the course. Twenty (20) of the 24 students in the AM section returned the survey; all twelve (12) of the PM section students returned the survey. All students in both sections were mechanical engineering seniors.

The basic purpose of ME 469 is to give students experience in the product design process. Students work in 2 or 3 person teams. The two sections were taught by different instructors, and had somewhat differing course objectives and operations. Students in the afternoon ("PM") section were all assigned to complete the same design project; students in the morning ("AM") section were assigned one of three possible projects. The AM section students were assigned to "design, build, and test" a working prototype of their project; the PM section designed a large system which was not constructed. Students in the PM section generally experienced a more "laissez-faire" environment than did AM students, who were required to meet with their professors twice per week.

Survey and Analysis

The survey utilized a variety of questions to reveal student opinion. Students were asked to provide some basic personal data, such as their team name, GPA, whether they owned a computer, and if they had some co-op or similar experience. Students then answered seventeen (17) "agree-disagree" questions, shown in Figure 1. Questions were provided as statements, with which student were asked to agree or disagree on a seven point scale (-3 to +3). Students circled the number that best represented their opinion on that statement.

Next, inquiries regarding the use and usefulness of PD Guide and its tools were asked through the use of two five-point scales (using a "0" to "4" scale). The use/usefulness questions are shown in Figure 2.

YOUR DESIGN PROJECT and PD GUIDE EXPERIENCE:

Please indicate how much you agree or disagree with the following statements; read questions carefully.

(NOTE: the -3 to +3 scale has been removed for clarity.)

1. Some type of resource (textbook, forms, etc.) is needed to help students complete their design projects more effectively.
2. My instructor(s) encouraged our team to use the PD Guide and/or the PDG Tools.
3. Using PD Guide in ME 455 was very important to our team being able to use the PD Guide and Tools in our design project.
4. Our team used an organized approach to solve our design project problem.
5. The lessons, techniques, etc. that we learned from the PD Guide in ME 455 were useful in our design project.
6. I believe that I learned more working in teams than I would have working alone.
7. Using the PD Guide is better than finding equivalent material from a book.
8. In retrospect, I believe that a structured approach is critical to completing a design project successfully.
9. I would disapprove of using software, like the PD Guide, in place of a course textbook.
10. Lectures would be more effective than using the PD Guide.
11. I believe that I learned something important about product development from using the PD Guide.
12. The PD Guide can be used by design teams without additional instruction/guidance.
13. Overall, PD Guide and PDG Tools did *not* affect my team's design project effort.
14. Based on this class experience, I believe that PD Guide can be used successfully to help student teams complete their design projects.
15. The PDG Tools that we used in our project are clear and easy to use.
16. Even if it did not affect my project directly, use of the PD Guide in the course was a worthwhile learning experience.
17. Based on my experience in the senior design course, I now have *less* interest in pursuing a career in design or product development.

Figure 1: "Agree-disagree" questions used in the survey used to assess Product Development Guide, ME 469 course, Spring 1994.

USE / APPLICATION OF THE PD GUIDE:

Please indicate how much you used the following; if used, also indicate how useful each was in helping your team to complete your project. If you were NOT AWARE that the item exists, circle the (na) option:

Tool or Item	NOT Aware	USE of ITEM: NOT Used				HIGHLY Used	USEFULNESS of ITEM: NOT Useful				VERY Useful
Product Development Guide	na	0	1	2	3	4	0	1	2	3	4
PDS Module of the PD Guide	na	0	1	2	3	4	0	1	2	3	4
Project Schedule Worksheet	na	0	1	2	3	4	0	1	2	3	4
Parts List Worksheet	na	0	1	2	3	4	0	1	2	3	4
Parts Cost Worksheet	na	0	1	2	3	4	0	1	2	3	4
Product Profit Worksheet	na	0	1	2	3	4	0	1	2	3	4
PDS Format Template (wp)	na	0	1	2	3	4	0	1	2	3	4
Progress Report Template (wp)	na	0	1	2	3	4	0	1	2	3	4
Final Report Template (wp)	na	0	1	2	3	4	0	1	2	3	4
CAD Drawing Templates	na	0	1	2	3	4	0	1	2	3	4
CAD "Critical To" Symbols	na	0	1	2	3	4	0	1	2	3	4

Figure 2: Use-usefulness portion of survey used to assess use of Product Development Guide, ME 469, Spring 1994.

Four "open-ended" questions at the end of the survey solicited comments regarding students' largest needs for help in the course, their use of PD Guide, learning, and needed PD Guide improvements. These questions are presented in Figure 3.

Responses to the agree-disagree and use-usefulness questions were tabulated and analyzed statistically. Lotus and Quattro spreadsheets were used extensively to tabulate data, generate statistics, and create graphs. Statistical tests were used to decide when student opinion was sufficiently strong (from a neutral opinion) to make a conclusion. In general, a 95% confidence interval (using a t-distribution) was constructed for each statement. Student opinion regarding the agree-disagree questions was deemed significant when the confidence interval did not include "0", or the neutral opinion. This procedure is equivalent to a one-sided t-test, using an alpha of 0.025. Similar confidence intervals were constructed for the use-usefulness questions.

Differences in response between different groups (such as between the AM and PM sections of the course) were evaluated by computing a confidence interval for the difference between the two

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Comments: Please provide your thoughts on the following topics. You may attach an extra sheet for your comments, if needed:

Need for Help: With what in the *design course* did you need the most assistance? What advice, tools, etc. would you have liked to have received during the semester that would have helped you?

Use of Guide: How do you think PD Guide should have been able to help you and your team with your design project? How did it actually help? In areas where the Guide did not help you as much as you thought it should, why did the Guide not help enough?

Learning: What do you believe is/are the most important thing(s) that you learned from the PD Guide and its associated PDG Tools?

Improvements: How can the PD Guide be made more useful for completing the senior design project?

(original survey included more space between questions)

Figure 3: Short-answer comments portion of survey used to assess use of Product Development Guide, ME 469, Spring 1994.

groups' means, using an alpha of 0.05. Response differences for a particular question were deemed significant when the confidence interval did not include "0", or "no difference". This procedure is equivalent to a one-sided t-test, using an alpha of 0.025.

Small alphas were used in the evaluation to be conservative in making conclusions about PD Guide. Confidence intervals were used in place of standard t-tests because they were more easily computed using the spreadsheet format.

Comments in the survey's short answer section were compiled and grouped by subject. These results were used to gain additional insight into the conclusions derived from the numerical analysis and to gather ideas for improvements.

STATISTICAL SUMMARY of RESULTS

Student Characteristics

A summary of student reported characteristics is shown in Table I. The breakdown of students responding to the question concerning whether students have accepted a job upon graduation is

Table I: Summary of student characteristics and survey response, ME 469 survey (spring 1994).

Category	Number or Percentage
Total Number of Students in ME 469 course:	36
Number of students responding to survey:	32
Percentage of students in course responding:	89%
Number of separate class sections:	2
Total Number of Design Teams (all sections):	12
Average GPA (of those reporting):	3.02/4.00
Percentage of students reporting that they own a computer:	50%
Percentage of students reporting co-op/similar experience:	52%

shown in Table II. The "employment acceptance" rate of these students is low; unfortunately, the question was not worded precisely enough to distinguish among the possible causes. Some known causes for the low rate include: some students who are still at least one semester from graduation; failing to respond to the question; and, of course, not yet obtaining employment.

Student Opinion Summary Data

The frequency distributions of student responses to the "agree-disagree" portion of the survey are shown in Table III (for questions 1-10) and Table IV (for questions 11-17). The numbers to the right of each statement define how many students responded to that statement with the scale value defined for that slot. Thus, the left-most number for each statement defines how many students responded with a "-3" (strongly disagree), while the right-most value is the number of students who strongly agreed (+3) with that statement.

The mean responses to the "agree-disagree" survey questions, along with 95% confidence intervals about the mean, are shown in Table V (for questions 1-10) and Table VI (for questions 11-17). The response means and confidence intervals were used to decide when overall student opinion could be considered "significant" or "non-neutral".

Use and Usefulness Summary Data

Student responses regarding their use of PD Guide and the PDG Tools, and their opinion as to the usefulness of those items in their design project, are shown in Table VII.

Table II: Summary of student response to question pertaining to their post-graduate employment, ME 469 survey (spring 1994).

Area of Employment	Number of Students
Total number of students responding to survey:	32
Total number reporting employment:	8 (25%)
Design/Project	4
Manufacturing/production	1
Technical Sales	3
Other	0
Not employed, did not report, or not yet graduated:	24 (75%)

DISCUSSION of RESULTS

Use of PD Guide and PDG Tools

Student use of PD Guide. Student use of PD Guide during their capstone design project can perhaps best be described as "moderate". On a "0 to 4" scale, students reported their use of PD Guide to be an average of 1.75. Three students [S02, S07, and B12] commented specifically that they did not use PD Guide except for required assignments. Students overall reported that they had been encouraged to use PD Guide (question #2), although there was a significant difference between the two class sections. Students in the morning (AM) section reported both higher encouragement to use PD Guide and higher average use. This result corresponds with the observations of the author and the course instructors that students must be encouraged to use PD Guide in their design project. Two students [B08 and B10] went so far as to suggest that use of PD Guide should be "required", and not just "made available". These students postulated that their results might have been better had they been required to turn in intermediate results from PD Guide throughout the semester.

Student use of PDG Tools. Student-reported use of Product Development Guide Tools (PDG Tools) varied dramatically, based on the specific tool under consideration. Again, a "0 to 4" scale was used. The most-highly used tools were the part drawing templates (3.94 mean) and the design project schedule worksheet (2.06). The product design specification (PDS) module (1.77) and its associated "starter" document (1.81) were the next-highest used tools.

Table III: Frequency distribution of responses to ME 469 survey (spring 1994), questions #1-10.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Frequency Summary of Responses (n=32)						
	-3	-2	-1	0	+1	+2	+3
1. Some type of resource (textbook, forms, etc.) is needed to help students complete their design projects more effectively.	0	2	3	3	10	6	8
2. My instructor(s) encouraged our team to use the PD Guide and/or the PDG Tools.	0	0	3	2	7	10	10
3. Using PD Guide in ME 455 was very important to our team being able to use the PD Guide and Tools in our design project.	0	3	4	9	11	5	0
4. Our team used an organized approach to solve our design project problem.	2	1	2	3	8	10	6
5. The lessons, techniques, etc. that we learned from the PD Guide in ME 455 were useful in our design project.	1	5	4	6	10	6	0
6. I believe that I learned more working in teams than I would have working alone.	0	0	0	1	3	7	21
7. Using the PD Guide is better than finding equivalent material from a book.	0	3	2	6	7	12	2
8. In retrospect, I believe that a structured approach is critical to completing a design project successfully.	0	0	0	2	3	12	15
9. I would disapprove of using software, like the PD Guide, in place of a course textbook.	1	7	7	7	6	4	0
10. Lectures would be more effective than using the PD Guide.	2	3	5	12	7	3	0

The Product Profitability Analysis, or "Business Plan", was reported by students to be the least-frequently used tool (mean use of 0.34). The Parts Cost worksheet (0.65) and the Parts List worksheet (0.81) also were not used much by students.

Table IV: Frequency distribution of responses to ME 469 survey (spring 1994), questions #11-17.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Frequency Summary of Responses (n=32)						
	-3	-2	-1	0	+1	+2	+3
11. I believe that I learned something important about product development from using the PD Guide.	0	1	6	6	14	4	1
12. The PD Guide can be used by design teams without additional instruction/guidance.	1	4	8	1	11	6	1
13. Overall, PD Guide and PDG Tools did *not* affect my team's design project effort.	1	3	10	7	5	4	2
14. Based on this class experience, I believe that PD Guide can be used successfully to help student teams complete their design projects.	1	1	2	9	9	10	0
15. The PDG Tools that we used in our project are clear and easy to use.	2	4	4	5	11	6	0
16. Even if it did not affect my project directly, use of the PD Guide in the course was a worthwhile learning experience.	0	4	1	8	11	7	1
17. Based on my experience in the senior design course, I now have *less* interest in pursuing a career in design or product development.	15	3	6	8	0	0	0

Students in the AM section reported higher average use of all Tools except one, although it must be noted that differences for most of the questions individually were not statistically significant. The exception involved the interim progress report template, which was a required task in the PM section but was not used in the AM section. AM section students were provided information in class on the existence and use of PDG Tools; PM students were generally not reminded. It thus appears to be important to prompt students about PDG Tools at specific points throughout the term to maximize their use.

Table V: Response statistics for the ME 469 survey (spring 1994), questions 1-10.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Statistical Summary of Responses (n=32), (α=0.05) LOWER Confidence Interval	MEAN Value	UPPER Confidence Interval
1. Some type of resource (textbook, forms, etc.) is needed to help students complete their design projects more effectively.	0.69	1.22	1.75
2. My instructor(s) encouraged our team to use the PD Guide and/or the PDG Tools.	1.24	1.69	2.13
3. Using PD Guide in ME 455 was very important to our team being able to use the PD Guide and Tools in our design project.	-0.08	0.34	0.76
4. Our team used an organized approach to solve our design project problem.	0.54	1.13	1.71
5. The lessons, techniques, etc. that we learned from the PD Guide in ME 455 were useful in our design project.	-0.36	0.16	0.68
6. I believe that I learned more working in teams than I would have working alone.	2.21	2.50	2.79
7. Using the PD Guide is better than finding equivalent material from a book.	0.41	0.91	1.40
8. In retrospect, I believe that a structured approach is critical to completing a design project successfully.	1.94	2.25	2.56
9. I would disapprove of using software, like the PD Guide, in place of a course textbook.	-0.82	-0.31	0.19
10. Lectures would be more effective than using the PD Guide.	-0.59	-0.13	0.34

All three members [students S02, S07, S13] of one AM team reported high use and satisfaction from the PDG Tools that they used, but reported that they did not use PD Guide.

Table VI: Response statistics for the ME 469 survey (spring 1994), questions 11-17.

NUMBERS AT RIGHT: (-3 = Strongly Disagree) to (+3 = Strongly Agree) QUESTION	Statistical Summary of Responses (n=32), (α=0.05) LOWER Confidence Interval	MEAN Value	UPPER Confidence Interval
11. I believe that I learned something important about product development from using the PD Guide.	0.13	0.53	0.93
12. The PD Guide can be used by design teams without additional instruction/guidance.	-0.34	0.22	0.77
13. Overall, PD Guide and PDG Tools did ***not*** affect my team's design project effort.	-0.53	0.00	0.53
14. Based on this class experience, I believe that PD Guide can be used successfully to help student teams complete their design projects.	0.24	0.69	1.13
15. The PDG Tools that we used in our project are clear and easy to use.	-0.39	0.16	0.70
16. Even if it did not affect my project directly, use of the PD Guide in the course was a worthwhile learning experience.	0.13	0.59	1.06
17. Based on my experience in the senior design course, I now have ***less*** interest in pursuing a career in design or product development.	-2.24	-1.78	-1.32

Student Assessment of Value

In almost every case, students' relative value rankings of PD Guide and specific PDG Tools were higher than their use ratings. This finding suggests that students find value in PD Guide and PDG Tools, once they can be convinced to use them.

Students found the CAD drawing templates to be the most valuable (as well as the most highly used) Tools, scoring a 3.75 on the value scale. Other highly-valued PDG Tools were the final report guidelines and template, "critical to" symbols for drawings, interim report template, and the Product Design Specification (PDS) template. It is instructive to note that these tools are all "project deliverables" of some type, related to part/assembly drawings (CAD templates and

Table VII: Frequency summary of PD Guide use and usefulness, ME 469 survey (spring 1994).

NUMBERS AT RIGHT: (0 = Not Used/Useful) to (+4 = Highly Used/Useful) QUESTION	Freq. of Response: *Use* of Item					Freq. of Response: *Usefulness* of Item				
	0	1	2	3	4	0	1	2	3	4
Product Development Guide	1	10	16	3	1	1	6	18	6	0
PDS Module of PD Guide	4	9	10	6	2	3	4	13	7	1
Project Schedule Worksheet	1	8	13	8	2	4	7	9	7	3
Parts List Worksheet	19	6	2	4	1	0	1	5	5	2
Parts Cost Worksheet	22	3	2	3	1	0	1	5	2	1
Product Profit Worksheet	24	6	1	1	0	0	0	6	2	0
PDS Format Template (wp)	8	·6	6	6	5	2	2	6	7	6
Progress Report Template (wp)	17	1	3	4	6	2	0	3	4	5
Final Report Template (wp)	11	4	5	6	5	0	1	5	5	·10
CAD Drawing Templates	0	0	1	0	31	0	0	2	4	26
CAD "Critical To" Symbols	14	3	7	3	5	0	1	4	4	8

NOTE: Column "0" total for "use of item" includes those who responded "not aware" of the item; totals for usefulness do not add up to sample size total, because students answering "0" to the use of that item did not (could not) judge the that item's usefulness.

"critical to" symbols) or direct product documentation (PDS template, final report guidelines-template, interim report template).

All PDG Tools achieved mean value scores of 1.93 or higher. Only three PDG items failed to achieve a value score above 2.00: the project schedule worksheet (mean value 1.93), the PD Guide itself (1.94), and the PDS module (1.96).

In spite of relatively good average value scores, five students in the survey (16%) specifically commented that they had not found PD Guide or specific PDG Tools to be very useful. Students making these comments also were more likely to say that some type of resource was *not* needed to complete their project (question #1). Another [S18] said that PD Guide was good for providing "exposure" to some topics, but did not help otherwise. One student [S12] complained

that he found PDG tools to be "trivial" and that students should have been left to work these out for themselves.

Learning Experience

Perceived Effectiveness in Learning. Students indicated that their use of PD Guide was a worthwhile learning experience, even if it did not directly affect their design projects (question #16). While the mean response was not particularly strong (0.59 on the -3 to +3 scale), the number of students who said PD Guide was worthwhile outnumbered those who did not 19 to 5. Eight students (25%) indicated strongly, through a +2 or +3 response, that their use of PD Guide was worthwhile.

Students similarily indicated that they had learned something important about product development from PD Guide (question #11). Students commenting on how PD Guide had helped them mentioned most often that it had helped them to "get started", specify product requirements, or increase their awareness of the many issues involved in a product design.

As might be anticipated, there was a general correlation beween those who said that they had learned something important about product development and those who considered using PD Guide to be a worthwhile experience. The combinational student response to these two questions is shown in Figure 4. On this graph, the sizes of the "bubbles" reflect how many students answered with that particular response combination. The phrasing of the two questions locates students who found PD Guide to be worthwhile *and* learned something important in the upper-right quadrant of the figure. Only 25% found fault with their learning from PD Guide, their perception of how worthwhile it was to use PD Guide, or both. These 8 students were members of just 4 different teams. Their written comments suggest that they perceived PD Guide as an "extra task" to do rather than as something to assist them in their design project (also, see section on "mismatch in needs...", below).

Impact on Design Projects. Disappointingly, students recorded a mean score of exactly 0.00 to the question asking whether PD Guide and PDG Tools had affected their design project (question #13). Fourteen students (43%) reported some effect on their projects, while 11 others (34%) disagreed that PD Guide had any effect.

AM students responded to this question across the entire -3 to +3 scale, with 20% indicating that PD Guide and Tools had strongly affected their project (-3 or -2 response) but 25% indicating just as strongly (+2 or +3 response) that they did not. (The phrasing of this question is such that negative answers reflect a higher effect on the design project.) PM student answers were less varied, clustering from -1 to +2 . The means for each class, however, were not significantly different.

Project Organization. Students were asked the extent to which they were able to apply an organized approach to solving their design problem (question #4). While the overall mean score for the question reached a relatively well-organized +1.13 on the (-3 to +3) scale, the difference

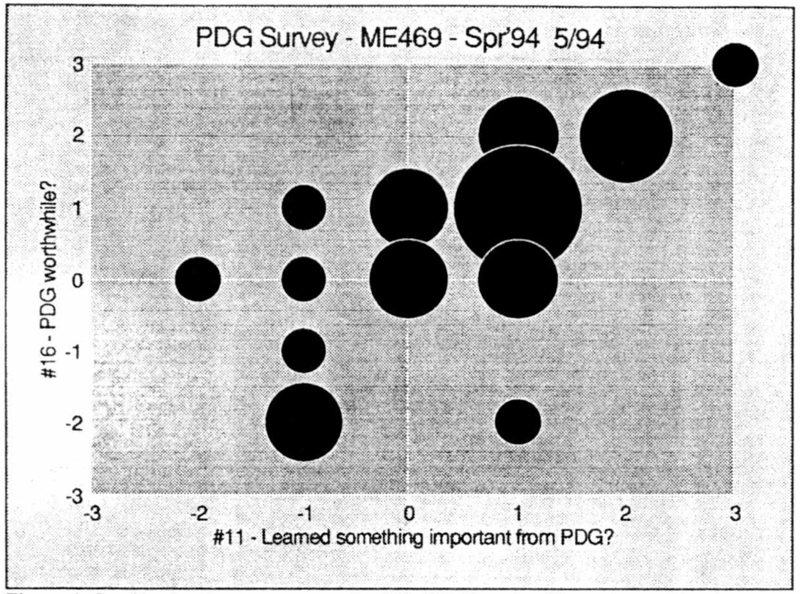

Figure 4: Combinational response to question #11, "I believe that I learned something important from using PD Guide," and question #16, ".. use of PD Guide in the course was a worthwhile learning experience." ME 469, spring 1994.

in the means of the AM and PM sections was almost statistically significant. When reviewed separately, AM students solidly reported using a organized approach (mean +1.55), while PM students scored statistically neutral. The "by section" breakdown to this question is shown in Figure 5.

Interestingly, the difference how the two sections were able to apply an organized approach affected how they answered the related question asking how important they now believe a structured approach is to solving a design problem (question #8). While the overall response indicates quite strongly (mean score 2.25) that all students believe a structured approach is important, PM students answered the question much more strongly. Every PM student responded with a +2 or +3 to the need for structure in finishing a project, suggesting that they learned from the problems that they experienced in their project.

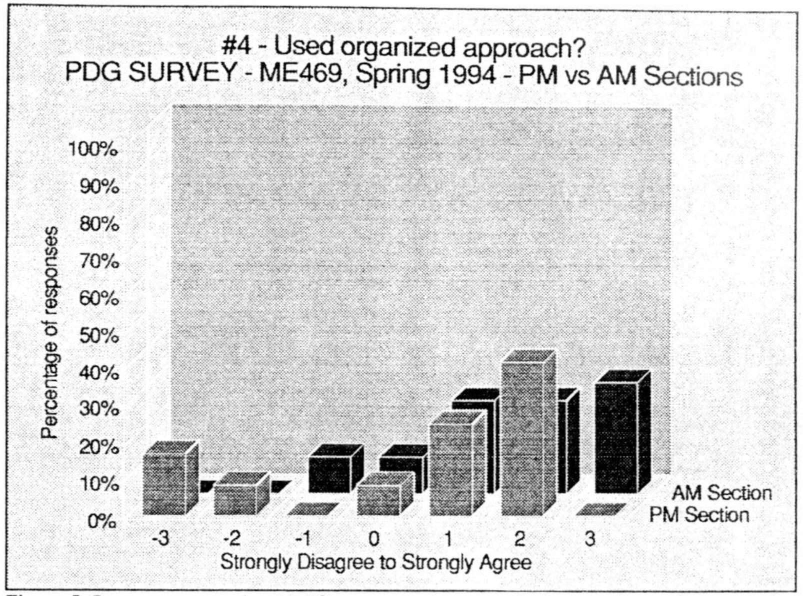

Figure 5: Response to question #4, "Our team used an organized approach to solve our design project problem," ME 469, spring 1994.

Initial use in earlier course. Students indicated that their earlier use of PD Guide and PDG Tools in the predecessor course ME 455, "Introduction to Design", was not a large factor to their use of these items in their design project. The student average was essentially neutral to the question asking whether the lessons, techniques, etc. learned from their use of PD Guide in ME 455 were useful in their design project (question #3). Students were almost just slightly positive when asked if use of PD Guide/Tools in ME 455 has been important to being able to use PD Guide/Tools in the project (question #5). However, several students commented specifically that more use of PD Guide and PDG Tools in ME 455 would have made them easier to use later during the design project.

Need for PD Guide and PDG Tools

Need for a course resource. Students solidly expressed a need for some type of resource to support the execution of their design project (question #1), with two-thirds of students saying that some resource needs to be available. Students in the PM section indicated a significantly higher need for a resource than did AM students, as shown in Figure 6. This student reaction suggests that students' perceived need for a resource depends on the extent of instructor interaction in the class.

PD Guide use in design course. Based on their experience, students concluded that PD Guide can indeed be used successfully to help student design teams complete their projects (question #14, mean score +0.69). Those who believe that PD Guide *can* be used in the design course outnumbered those who did not by a margin of 19:4. AM student responses varied more than the PM answers, as AM respondents were responsible for all of the "negative" answers and had a higher percentage of more-strongly positive "+2" answers.

Need for building awareness. Students generally commented (both in the survey and personally) that they were unaware of the many features and Tools related to PD Guide, and thus did not use them. PM students were especially likely to note that they did not know about these items, and this would correspond to their lower reported use of the PDG Tools. One student in the AM section [student S15] suggested that awareness of the items could be built in the fall semester course.

Difficulties in Student Use

Mismatch in needs/expectations. The students who thought that PD Guide was not worthwhile and/or who said that they did not learn something important about product development generally commented on the lack of a connection between PD Guide and their design project. A typical comment from a half-dozen students concerning this included, "Once we got started on the project no one really wanted to take the time to understand the Guide." [student S15] One student [S03] specifically saw a mismatch in scope between PD Guide and his project: "for a project with narrow scope as we did, (PD Guide) was more of a hindrance than help." This suggests that these students saw PD Guide in terms of extra work rather than as an aid to product development.

"Not enough time". Five students (16%) wrote comments indicating that they felt that they did not have enough time to use PD Guide.

Finding Needed Information. Some students in this survey reported in their comments some typical problems that have been expressed in other PD Guide surveys: PD Guide provides too much information to sort through [student B11]; it "sometimes ran off too many questions at once" and seemed repetitive [student B10]; PD Guide was "difficult to follow and when looking for a specific topic it became difficult to search through all of the modules." [student B12]

Overall ease of use. As opposed to previous surveys, measurement of ease of use was not a top priority for this survey. Nonetheless, students were asked whether design teams need additional instruction or guidance to use PD Guide (question #12) and whether they had found PDG Tools easy to use (question #15).

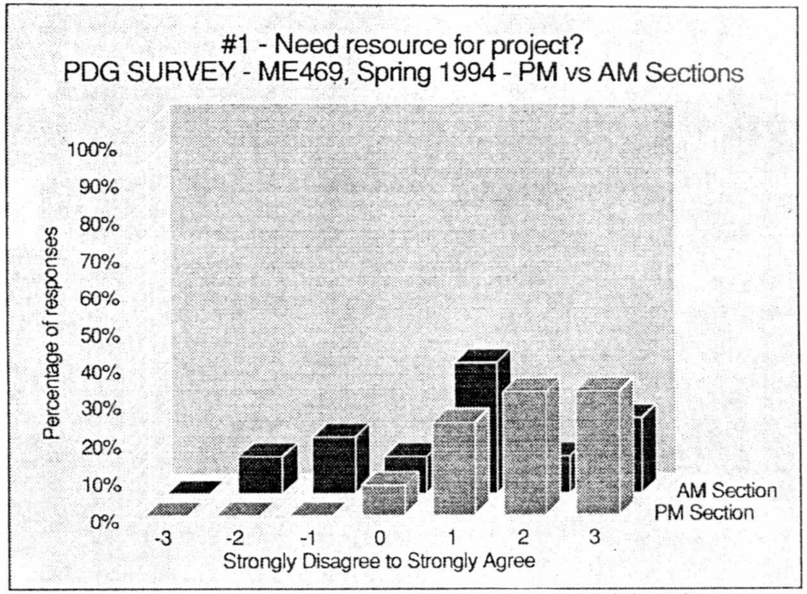

Figure 6: Response to question #1, "Some type of resource is needed to help students complete their design projects more effectively," ME 469, spring 1994.

Students in both sections were essentially neutral as to whether design teams need additional instruction or guidance to use PD Guide (question #12). Students were also neutral regarding whether PDG Tools are "clear and easy to use" (question #15), although some 40% indicated that the tools were generally *not* easy to use. Part of the difficulty may be due to the "timing" of their use: the tools were available, but the corresponding sections in PD Guide explaining the purpose and use of the tools were not yet available.

Comparison to Lecture and Text Resources

PD Guide versus Textbook. Students indicated that using PD Guide is better than finding equivalent material from a textbook (question #7), registering a mean of +0.91 on the -3 to +3 scale. Over 43% of students ranked PD Guide as much better than a book, as indicated by a +2 or +3 response. Only 16% preferred a textbook, as reflected by a -1 or -2 ranking; about half of these student commented they preferred a textbook with a very-complete index than to use PD Guide [students S02, S06, S07].

Students were generally neutral on whether they would approve of using software, such as PD Guide, in place of a regular course textbook (question #9), although the number of students who approved of using software as a replacement for a textbook outnumbered those opposed by a 3:2 ratio. Interestingly, student response did not depend on whether the student had a computer at home; the percentage of students who owned a computer in the group that disapproved of using PD Guide in place of a textbook was about the same as for the group that preferred PD Guide.

As might be expected, students who preferred PD Guide to a textbook were more likely to accept its use in place of a course textbook. The combinational student response to the two questions is shown in Figure 7. On this graph, the sizes of the "bubbles" reflect how many students answered with that particular response combination. The phrasing of the two questions locates students who believe that PD Guide is better than a text and is acceptable as a replacement for a text in the lower-right quadrant of the figure. The "bubbles" in the upper-right quadrant indicate that four students (12%) preferred PD Guide, but still disapproved of its use as a replacement to a textbook. These four students were on just two different teams in the PM section of the course, but did not appear to share any other common characteristics. Still, three of these four indicated that using PD Guide had been a worthwhile experience (question #16).

PD Guide versus Lecture. Students were asked to assess the effectiveness of PD Guide compared to obtaining the same information through class lectures (question #10). Students were essentially neutral on the relative effectiveness of PD Guide versus a lecture (mean score -0.13, in favor of PD Guide).

Conclusions Pertaining to Design Course

In addition to their discussion of PD Guide and PDG Tools, students also revealed other factors and needs related to their learning.

Importance of teamwork. Students emphatically stated that they learned more working on the projects in teams than they would have be working alone (question #6), scoring a survey-high mean of 2.50 on the (-3 to +3) scale. Almost two-thirds of students indicated the maximum score (+3), only one student was neutral, and none was negative. Thus, not only have the professors observed increased productivity from students working in teams, but students perceive the method as superior for learning.

Student interest in design / product development. Students enthusiastically reported that their participation in the design course had increased their interest in pursuing a career in design or product development (question #17). No student reported that the course had decreased his or her interest. Fifteen (15) of the 32 students in the survey scored the question as a "-3", the highest possible (the question was phrased negatively, so a minus score indicates increased interest in design). Clearly the capstone design course is serving to increase student interest in design and product development.

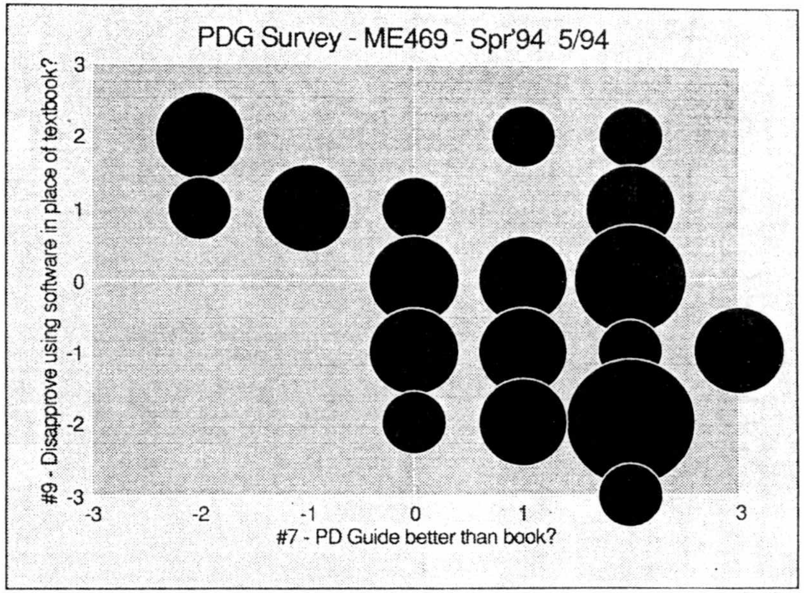

Figure 7: Combinational response to question #7, "Using PD Guide is better than finding equivalent material from a book," and question #9, "I would disapprove of using software, like PD Guide, in place of a course textbook." ME 469, spring 1994.

Engineering Design Center resources. When asked to define advice, tools, and other items that would have been helpful in the design project, several students commented about the UT Engineering Design Center facilities. Most complaints centered on problems that the students experienced with IBMCAD, the facility's computer-aided drawing program; about one-quarter noted it as a problem. Suggestions for improved learning/use of IBMCAD generally involved more, shorter, and/or earlier tutorial sessions.

Two students said that it would be useful to have more reference texts/materials and textbooks available. Specific topics with which students expressed a need included engineering drawing conventions, welding and fasteners, tolerancing, and materials/manufacturing.

Comparison of Results to Previous Classes

During the development of PD Guide and PDG Tools, several other surveys have been administered to students taking other courses. In particular, surveys were collected from students in the fall semester introduction course (ME 455) in 1992 and 1993, as well as from students in a graduate course in product development. It should be noted that the students in the fall 1993 ME 455 class were largely the same as those in the AM section group of this survey.

Comparisons of the current survey to the previous ones are more difficult to make, because the focus of this survey is different. Previous surveys concentrated on students' perceptions of ease of use while completing a structured, limited assignment; this survey attempted to measure the extent of use and the usefulness of items throughout an entire semester.

Because of the difference in focus, only 3 of the 17 questions in this survey closely matched those asked in previous surveys. Students in earlier surveys, of course, used an earlier, less complete version of PD Guide, and used PD Guide for a different assignment.

Comparison of the results from these common questions (questions #7, #10, #11) revealed that:
- students remain essentially neutral on whether PD Guide is more effective than an equivalent lecture (question #10);
- students continue, on average, to believe that using PD Guide is better than attempting to find equivalent material from a textbook (question #7);
- when used over the long term (as opposed to being used for a specific assignment), the self-perceived impact on the student's own learning is not nearly as dramatic (question #11).

The overall difference in student perception as to whether they learned something important from PD Guide is shown in Figure 8. While still positive, the current result is significantly less than that achieved in previous surveys.

Suggestions for Improvement and Comments

Interestingly, improvement comments focused as much on how PD Guide and PDG Tools are used in class as they did on how to improve the items themselves. Other than some "general" items, PD Guide improvement suggestions focused on users' need to "know where they are" when working through PD Guide and in narrowing the "scope" of contents to be covered. Use in class suggestions emphasized earlier introduction of the materials and its required use in student projects.

Location feature. Similar to earlier surveys, many students [S02, S04, S07, S08, B03, B05] commented that they needed help in knowing "where you are in the program menus" [student S02], because "it is easy to lose sight of where you are in relation to the overall Guide." [student B05] These students said that a "map" or "background listing" was needed; student S08 suggested that this guidance did not necessarily have to be in PD Guide itself, but could be a

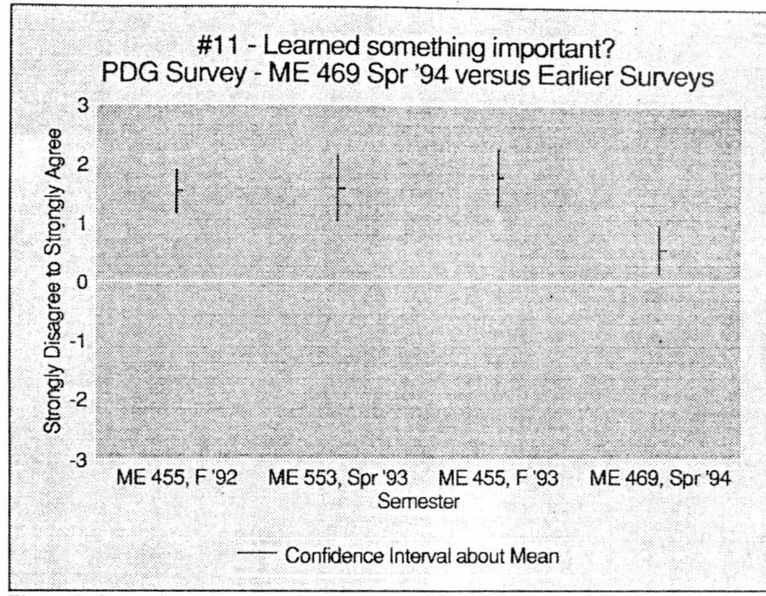

Figure 8: Comparison of mean student response (with confidence interval) across several surveys to a question asking students if they "learned something important from using PD Guide" (question #11 on ME 469 survey, spring 1994).

couple of well-drafted reference sheets. Student S07 identified MS Windows "Help History" and "Bookmark" commands as features that would be useful for locating one's place and of marking sections that are found to be of interest.

Narrow the scope/focus of use. Several students said that PD Guide was too large or "too involved" for students to use effectively, and that its size/complexity was "intimidating" and discourages its use. In response to this need, one students suggested that a subset of PD Guide would improve its use: "Have it focus on *project management* instead of product development. Only include Business Plan, PDS, and conceptual development parts of the PD Guide." [student S17] This subset suggestion supports the "modularization" of PD Guide, such as putting the PDS material in its own module. Another approach might be to assign students to complete specific sections as assignments throughout the course.

One student [B11] suggested use of a "system setup which would allow you only to call up the specific information your project required. I believe that this program could be *very* useful if it was easier to sort through." This comment is strikingly similar to those made previously by academic reviewers who teach design courses and an industrial reviewer. The "sorting" process, and the questions used to determine how they are sorted, could be a significant and high value research area.

Time for Introduction. Questions #3 and #5 in the survey indicates that the introductory course, ME 455, was not used as effectively as it could have been to introduce PD Guide and PDG Tools. Two students [S15, B03] specifically recommended "more exposure" to PD Guide/Tools in that class, so that students will already know how to use them in the design project. Two others [B01, S01] simply expressed the need for "more time" to understand what is available.

Required Use. As noted earlier, two students [B08, B10] remarked that PD Guide will not be used as frequently/effectively as it could unless its use is required as part of the course. One student [B08] used the cliche, "You can lead a horse to water, but you can't make him drink," to express his view that his team's result might have been better had they been required to use various features of PD Guide at specific times during the semester.

General Needs. A few "typical" suggestions also arose from the student comments. One student [B06] thought that the examples and schematics could be improved. Student B02 suggested that PD Guide ought to be made interactive with a word processor, presumably so that responses can be made immediately to presented questions. Two students [B09, S20] asked for a tutorial or a book that would explain/demonstrate PD Guide and PDG tools (students in this survey did not have access to the tutorial section).

Other Comments

The versions of Product Development Guide and PDG Tools used by these classes were incomplete versions, dated January and February 1994. The first "complete" version of the PD Guide was finished in May 1994.

The responses from all surveys are being used to improve PD Guide and its presentation. Additional surveys and evaluations may be performed as PD Guide is developed further.

Student response distributions, relevant statistics, and compiled student comments are available from the research files. Bar graph plots of the response distributions are also available.

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Original draft 7/94
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APPENDIX R

Expert Practitioner Review Comments

Responses to Survey - Industrial Experts - July 1994

This document is a summary compilation of comments made by the expert practitioners during their review of the Product Development Guide. While it is relatively complete, it does *not* include every comment. Specifically, it does not include all comments made in the correspondence that accompanied the survey or all of the notes that were made on display printouts.

The comments are "arranged" based on the topics/questions that were asked in the survey.

Tutorial: *List/describe any omissions in the tutorial.*

Did not notice any. [Randall]

I would suggest including discussion of "design review sessions" as a means to progressively evolve the PDS. [Eggert]

Many aspects on the "soft" side of product development such as interpersonal team relations and how to deal with conflicts should be addressed and time allocated for training. [Beck]

Environmental in mfg. systems. [Wittwer]

Human element - selection of team and team building [Wittwer]

Painfully complete - could it be arranged so that experienced person could skip to "3" - it is so intuitive that 1 and 2 aren't necessary for many people. There is so much detailed tutorial that it should be very clear how to use it. The amount of instruction is almost painfully complete, but perhaps necessary for your wide audience - student to those in practice. Is there a way to make an abbreviated version (of tutorial)? [Ward]

The purpose and intent of the program. [Allen]

"Best" Sections: *Of the specific topics/tools that you reviewed, please describe/list the "best" ones. Note briefly what makes that section best (eg. reflects particularly good practice, concise, in the "correct location", etc.).*

Description and illustration of operating space and, how to tolerance. [Randall]

Mfg. Systems Design - determining/computing process capability. "Best" because practice is right on target for modern IPDP ("integrated product development process"). Graphics illustrate the point easily. [Randall]

Product Configuration section - for the thoroughness of this section is good because this really *is the* most important step in product development. The quality of the work done here determines the cost/success of the overall project. PD Guide covers very well the many aspects of product configuration that need to be considered in a logical straightforward manner. [Foster]

Product Configuration - this area was very well done and complete. [Burdick]

It is hard to single out one section over another. I did like sections in which the guide encourages benchmarking. I also liked the use of sensitivity analysis to check plans. Both practices address the potential problem of "group think". They also both support continuous improvement. [Abbott]

No one best - all are well done. Topics #1-4 (of Market Prep phase) capture the most relevant aspects in a concise way. [Eggert]

sections and topics all flowed together very well. [Wittwer]

Comprehensive - liked risk factor and ranking on critical components. this portion tied in an important factor of the mfg. process, ie. modular, sequential, test. [Wittwer]

Setting targets for product costs, marketing and support costs, and profit. Good explanation of why market must set the targets and examples where different ratios apply. [Heard]

All consistent - expand on reasoned answers to questions, paint philosophy -> customer, economics, time to market. [Martin]

Comprehensive Test Plan well done. [Wesner]

PDS very comprehensive. [Wesner]

The idea generation section was quite complete in sources for initial concepts. Some items listed by topic would need explanation for the novice. [Allen]

"Poorest" Sections: *Please describe/list the "poorest" sections/topics/tools of the ones you reviewed, and what makes it poor. Be sure to indicate if you find it "unacceptable" for use in superior development practice.*

There is nothing unacceptable. [Randall]

Process selection - certainly these are the right questions, but how would anyone determine the answers? Sources, help, books, etc. [Randall]

(In process capability section), I prefer that $\pm 3\sigma$ be used instead of 6σ because 6σ can be misleading. For many, they see this as "Six Sigma" program ... [Randall]

I believe that much more emphasis on the establishment and use of datum systems is warranted in the parts design section (see letter). This provides a geometric framework on which truly superior designs can be built. Although it takes significant work to create this framework, the robustness and reduction in variability more than justify the effort. I do not consider this section "poor" - I just believe it would be improved by adding more emphasis as described above. [Foster]

I did not find any areas I would rate poor. My feedback is, in general, not in disagreement with the PD guide but in most cases additional building on what was already there. [Burdick]

The areas I have most interest in is the introduction of fundamental function and datum dimensioning thinking. these topics are references in the PD Guide, but I would like to see them given more emphasis since I believe they can have a *major* impact on arriving at a "world class" design process. [Burdick]

I found no "poor" sections. All critical comments are included in my attachment. [Abbott]

No sections were "poor". [Eggert]

If one was concurrently engineering, a portion of marketing planning would be inserted earlier in process (in Cust. Future Needs phase). Would recommend expanding "promotion" to a detailed advertising plan, developed in concert with sales staff. Also might add Fed and State regulatory agencies that regulate product (FDA, EPA, etc.). [Eggert]

There's always room for improvement - example essential elements in the product idea section a check list could go on to infinity - each product is unique in some way. [Wittwer]

Product cost estimating. (See related comment under key problems.) The cost spreadsheet tool seem more suitable for costing an individual part than for developing a cost for an entire product, with provision for showing that cost as a function of time or of production volume. [Heard]

(Overall), must emphasize economics more; more market analysis; limit reinvention; emphasize product, not technology [Martin]

"Design/Evaluation Schedule" could use a higher-level introduction. I was uncertain if this was dealing with the entire design schedule or just "evaluation" pieces. [Wesner]

Need some "Comprehensive Design Plan" words, similar to those provided for Testing. [Wesner]

I can imagine wanting to see the PDS part connected to the main part, to exchange data. [Wesner]

Screen colors - unacceptable. [Allen]

Got lost in tree of screens - need a roadmap. [Allen]

Product Development Fundamentals: *Assess the "match" (or lack of it) between the contents of PD Guide and what you believe are the major tenets for achieving successful product development. Does PD Guide contain what engineering students most need to know about product development?*

Yes, this contains what eng. students need to know about product development. But to be successful, the softer side of team, team development, common goal, common purpose are critical. The answers to the questions and criteria are a function of who answers them. In my experience the best answers come from a team that has reached consensus. this takes longer than one person/one question, but the results are deployed faster than the former. [Randall]

The guide is comprehensive and thorough, very well done. All the major elements of product development are adequately covered. There are no major omissions that I could see. The level of detail is well suited for an engineering student, or for students in other fields as well. [Abbott]

PDG provides an excellent comprehensive overview of the development process. Product development is an extremely convoluted and specialized process, highly dependent on the particular industry and the talent in the particular corporation. However, PDG really captures the essence of what happens in the "real world". [Eggert]

Pedagogically, PDG will make a *major contribution* to undergraduate and graduate engineering education. Its multiple menus can be explored individually or comprehensively as in a specific product development assignment, required in a course. [Eggert]

... must be remembered that it is a guide. Lots more information can be built in ... . the mind flashes through the sections ... often in parallel fashion. It is an intuitive process. With the ability to bring to light the critical processes or problems in short order, I think this is what will eventually prepare the student to achieve in a more expeditious manner. Like many professions, the student must serve an internship. I believe this guide will help the student shorten or be more effective during this apprenticeship phase as they go out into industry or start their own businesses someday. [Wittwer]

Overall, I believe that the match of content to what is needed to develop a product is good. [Heard]

Broaden, awaken more business reality in the engineer. [Martin]

Yes. It may overwhelm them, but it is very thorough. An excellent compilation of what it takes to develop/deliver an outstanding product. [Ward]

I looked at PDG not from a student viewpoint but a practitioner viewpoint. It begins to capture an idea that I have had for some years, of an "aid" for design engineers that would lead them through the basics. The need is great: engineering design is *sooo* complex (and becoming ever more so) that it is almost beyond the ability of a "mere mortal" to do it. An aid, maybe using an expert system, could help immensely - so, for instance, you don't forget to design and test for UL compliance. The ultimate system would look at the PDS and decide which UL requirement is appropriate for the particular product ... This work is a great start down the road I envision. [Wesner]

The important elements are there. I especially noted (because of my recent attention on *process*) the attention to Concurrent Engineering concepts and the use of teams of highly skilled people. While I did not examine every piece in full depth, I did not see any of the serious outages that would lead me to suspect other shortcomings. [Wesner]

In general I found the material to be representative of current industrial practice in product development. In this aspect, I found neither any major omission or extraneous portions. I feel comfortable with the approach. [Allen]

(Significant notes made on printouts of specific screens) [Burdick], [Foster], [Ward]

KEY Problems: *Describe any important criticisms that you have of PD Guide ...*

Certainly the questions are right and lead to more related questions, How would anyone find the answers? Deming taught me that there is no substitute for knowledge. Suggested sources would be helpful. [Randall]

One nit pickin error: in the section on design redundancy and Motorola's processor, the point is that by designing a redundant circuit, the chip functions even when one circuit does not function. This is because the process is not defect free the circuit did not fail, as in fail in use [Randall]

Emphasis on "Fundamental Function" and Datum Dimensioning (needed). [Burdick]

I found no major problems. My most significant observation relates to the treatment of team formation and performance. This is a subject of intense professional interest to me at present, as my organization is in the midst of a long term socio-technical redesign. I believe that successful teams share many common characteristics, and that the formation and nurturing of these teams is a critical success factor. Many of the individual factors are covered in the guide. Overall treatment of the subject is missing. Coverage of this subject in the guide is more than adequate for students. [Abbott]

Concurrent engineering - the trend in modern design, in my opinion, should be adopted as a "best practice" philosophy in the PDG. Marketing and manufacturing, therefore, should be part of the design team, involved right at the beginning. I would recommend this emphasis. [Eggert]

Design Reviews - Lots of them! Reviews provide progressive design refinement, process self-correction and help to build teamwork. I would recommend adding a few more phrases, or sentences. [Eggert]

Suggest some additional information needs to be added, Such as environmental processes that need state approval. and consideration to processes that need employee protection in the work place. And backup plans for critical components that may have shown feasibility, but at risk, to name a few. [Wittwer]

The point is well made that target cost must derive from the market. However, it is also necessary to continuously verify that the actual cost will be within the target. While one screen does ask for input on average manufacturing cost, the actual methodology for developing this is not introduced until (MSD phase). Estimates of actual cost are an essential element for sections (Prod Ideas, both Tech. Sel. phases) and are critical for go-nogo decisions based on the results of (Final Product Definition and Product Design). Therefore, cost estimating methodology needs to be introduced much earlier in the process and given more emphasis in the sections mentioned. A similar comment might also apply to reliability analysis. [Heard]

It is difficult to separate priorities among the items presented. Within the constraints of what can be presented on a screen, items tend to be perceived as of equal importance, especially where the quantity of items is large. There is a tendency to be overwhelmed by the amount of items and to treat them as all equal in importance. [Heard]

Need for navigation aids to avoid getting lost and to help access a specific area. I found it almost essential to display multiple copies of PDG (using Windows) ... easy to lose track since there is no highlighting of the current or last selection. ... there is no keyword search capability. [Heard]

to see an entire subtopic at once ... accompanying hardcopy (or at least a menu tree) will be essential. [Heard]

Emphasize product more, technology less. Economics are key to choices - time to market drives economics. [Martin]

Subcontracting choices may add "great value" if keys are protected. Subcontracting to minimize overhead is not a bad idea if it fits the overall plan while protecting the "jewels". [Martin]

(see detailed notes on screen printouts) [Ward]

(see comments on PDG Tools) [Beck, Roof]

Product Ideas phase lacks reference/use of "voice of the customer" and use of some of the QFD tools. [Mason - from phone conversation]

On launching, you get the prompt "PDGFILES", with no hint as to what to do. [Wesner]

While the use of color is excellent for guiding you around and for keeping things apart where needed and together where needed, there may be over-use of color in some places: simply too many colors on one screen. [Wesner]

Why is the PDS separate? Don't I want to swap data, and maybe refer to other parts? [Wesner]

Should "Aesthetics" (in the PDS) prompt you to engage an Industrial Designer on the team? Should "Ergonomics" prompt you to engage a Human Factors Psychologist on the team? [Wesner]

Another level is needed, so that you can go from "Warning Labels may be needed" to illustrations of typical warning labels. (And, in my dream system, to illustrations of exactly the warning labels to the particular product ...) [Wesner]

I suffered from a lack of an introduction to the program. At least for a reviewer, there is a need to present the background, purpose, and intended application of the program. From the little I knew, I assumed it to be an educational tool to be used in academic design courses. I believe that an industrial version might need to be considerably different. [Allen]

The use of wild colors is distracting. Color should assist the user, this did not. [Allen]

Part way through (Product Ideas) I became concerned about the relationship between the case studies research and the screen presentations. In the screens I could not identify any results from the case studies. [Allen]

Lots of good questions and lists of items that are critical to the product development process. But I found no guidance or quantitative evaluations. ... I wanted some reference as to poor/good/better/best. [Allen]

... I got lost in some of the paths from sections, subsections ... and had no idea where I was or where I had been. A software programming problem that detracts from the engineering design accomplishment. [Allen]

***OVERALL Assessment:** Describe your overall "grade" of PD Guide, in terms of...*

- *it being reflective of, and consistent with, competitive product development practices*

It is consistent with modern design practice at TI DSEG. Give it an "A". [Randall]

PD Guide embodies much of the current practices of leading product developers. [Foster]

Yes- consistent with and ahead in many areas. [Burdick]

I found the overall quality of the guide to be excellent. It reflects my understanding of all the ingredients of successful product development. [Abbott]

PDG is the most comprehensive and real-life tool for product development that I have *ever* seen. Many texts or articles describe specific phases well. But none tie together the whole process with a unified language and methodology like the PDG. PDG is a contribution to the state of knowledge because it unifies, and interrelates the development process in a comprehensive and user-friendly fashion. [Eggert]

It appears to be consistent in that it contains the bulk of the essential elements related to being competitive. "World class" manufacturing includes a strong element of employee education and training. You touch upon that, and that is an area for future growth of the guide. [Wittwer]

Overall the guide seem to capture well the processes needed to develop competitive products. It does seem to be oriented to the environment of large companies with multiple products or product lines. These companies are likely to have their own internal procedures or guides (with even greater level of detail) which define the development process for them, so that the utility of PDG would be as a supplemental checklist or reference. Much of the content is inapplicable to a small company which may have only one product and therefore does not have or is willing to change its strategic focus, financial evaluation methods, manufacturing capabilities, customer set, etc. [Heard]

A bit too much of a scientific feel - gut plays a big role, willingness to risk. [Martin]

An excellent comprehensive piece of work - a massive effort. [Ward]

Home level and top process maps provide an appropriate framework for me, as an experienced person. I'm not sure I can evaluate how well it guides a novice student because one does not recognize how much they have learned in 17 years that the beginning student does not know. [Ward]

As I said in Sect. 1 above, you have made an excellent start at implementing a dream of mine. [Wesner]

It is obvious that this was a significant effort to structure the product development process to fit into this computer presentation format. Most of us have a difficult time making the product realization process appear logical just using transparencies for lectures. [Allen]

It is certainly up to date in many ways (eg. focus on Concurrent Engineering and teams), and does cover the needed steps in a Product Realization Process (PRP). [Wesner]

For this new and complex presentation format, the general structure has now been developed and proven -- and in the process several areas for future improvements have been identified. [Allen]

- *using the contents of PD Guide to teach product development ...*

The contents of the guide are good for engineering students to know. [Randall]

This is an excellent teaching tool for students of product design and development. [Foster]

Yes - should be an excellent teaching tool. [Burdick]

Areas for improvement do exist and are relatively minor, especially when considering use by students. [Abbott]

To use this guide most effectively - I believe it needs to be taught with case studies, and there are many that could be used to bring out the points in the guide. And hands-on simulation, and real industry student project work. [Wittwer]

I believe that the most effective use of the guide is in a teaching environment where the pace can be controlled to focus on individual sections and where additional materials (such as case studies and class discussion) can be introduced to support it. It is well suited for this purpose. The structure does not lend itself well to a "cover-to-cover" read, such as we reviewers must attempt to do. [Heard]

Grade "A" (undergraduate), "A" (graduate), "B" (professional). Needs more concrete direction to be useful for professionals. [Martin]

harder to assess if we know too much for the beginner. [Ward]

It probably would be useful in a design project class - although you might want to provide "shortcut" paths to keep the students from some of the details that will simply complicate things and lengthen their effort beyond what is really appropriate. [Wesner]

- *whether my dissertation committee should approve PD Guide ...*

I see no reason why it should not be approved. [Randall]

This Guide *is* a valid result and *should* be approved.

Yes - they should approve the Guide as a valid result [Burdick]

I would personally recommend approval of the PD Guide as a valid result of your research. [Abbott]

Definitely the dissertation committee should approve the PD Guide as a valid result from your research in competitive product development. The real test of the worthiness of this guide will be the number of students wishing to enroll in the class which uses this. [Wittwer]

Overall, I believe the guide to be a valid research result which will be useful for a variety of teaching and reference purposes. [Heard]

A+++ [Martin]

Approve for degree. [Ward]

YES (Emphatically!), your Dissertation Committee should approve PD Guide as a valid research result. [Wesner]

Improvements/Suggestions: *Please provide any input that you have ...*

We are now assessing manufacturability prior to production in a qualitative way. We are using process capability info, part info, system performance variation, to estimate defects that will happen during mfg. and test. It is a powerful analytical method that we have been perfecting for about 4 years. I think it would be good to show these principles to students. One could add a spreadsheet the listed requirements, capabilities, and summed the probabilities to get the expected number of defects per unit. [Randall]

Add fundamental function / Datum dimensioning [Burdick]

Cycle time to market is by far our most critical issue. We are investing heavily to improve in this key area. Our current thrust is called "process train engineering" by some. there isn't much written on the subject yet. HP is using it. We are just starting, beginning with two key corporate processes, Product Creation and Product Delivery, from which all other corporate processes are derived. All corporate quality improvement activities are aimed at improving these two high-level processes in some way. We are drawing heavily from Reintersen's book for concepts of product development team formation and effectiveness. [Abbott]

I would like to see the guide steer students toward references and standard tools more frequently. This is a minor point, but I have seen teams waste time and resources by trying to develop a tool or concept that is not critical to their project. Project Management software is an example. [Abbott]

The guide addresses the concurrent nature of many product development activities. Still, I found it a little rigid. Teams need to follow the underlying principles of the guide, while being flexible where appropriate to save time. [Abbott]

the terms "function" and "form" have conventional meanings; the concept of function versus form; and the correlated .. what (function) need the customer has versus how (form) the need is fulfilled ... should be stressed. [Eggert]

Also, you may wish to include "green" design. The environment, energy, hazard materials, and scarce resources are being factored into more and more product designs. [Eggert]

MSD phase - Some areas for future incorporation, environmental (state approvals), scale up production plans, and backup plan for components. [Wittwer]

many areas can be expanded upon and improved. No one should expect this guide to be completely comprehensive to start with. As an example, take automating the factory. Many decisions must be made prior to automation, scale up, the distribution, the marketing all tie in. But, once the decision to automate the manner to achieve automation is a chapter in itself. [Wittwer]

Some of the comments under key problems identify potential improvements. [Heard]

A possible future activity might be to develop a "PDG Lite" focused on development in a startup company. Some significant variations would include the interactions with fundraising activities needed in order to keep a company going so it can proceed with the development process. (Some of this would apply to large companies also, since it is often necessary to demonstrate an early version of the product in order to obtain the resources to progress to the final definition stage.) [Heard]

Need more concrete sources, less questions [Martin]

Delineate testing approaches, delineate ways of studying competition; time to market!, reliability, cost. Business plan checklist or outline. If engineers are to lead the process, they must grasp the essentials to the economics of the business and its processes. [Martin]

Technology sources - patent searches. attendance at trade shows - see competitive products / companies (get more in a day than a month of library work)

Economics - cost, cost, cost! Do not reinvent wheel; avoid NIH; features seldom overcome price; two successful areas in markets: cheapest adequate product and "cadillac" - middle approach always loses, because squeezed by "what if" from the top and by cost/benefit from the bottom. [Martin]

Make it work on the MAC - at least with SoftWindows emulation, but preferably directly. (Remember, many academics use MAC's so if you do intend this for educational use ...) [Wesner]

Find someone to sponsor continuing work, with closer ties to industry (But don't let anyone make it proprietary, except that they could take whatever there is and extend it in a proprietary fashion.) [Wesner]

(Notes provided on screen printouts) [Burdick], [Foster], [Ward]

APPENDIX S

Product Development Guide Technical Information

PRODUCT DEVELOPMENT GUIDE: Directory Names and Number of Files

File name: PDG_SIZ.R02 Date: 14 SEP 1994

Data shown is for PD Guide Version 940901P (Sept. 01, 1994) - dissertation version.

Product Development Phases - Number of Files:

Phase #	Phase Name	Directory Name	Total # of Files	# of Info. Displays
1	Product Ideas	PDG_PDE	74	69
2	Customer Future Needs Projection	PDG_CFN	78	73
3 & 4	Technology Selection & Development (Product & Process)	PDG_TSD	134	128
5	Final Product Definition & Project Targets	PDG_FPD	211	206
6	Marketing and Distribution Preparation	PDG_MDP	96	91
7	Product Design & Evaluation	PDG_PDE	443	438
8	Manufacturing System Design	PDG_MSD	223	218
9	Product Manufacturing, Delivery & Use	PDG_MFG	66	61
(base)	"Home" Directory (including Tutorial)	PDGFILES	109	80
(pds)	Product Design Specification (separate module)	PDG_PDS	65	61
(root)	Root directory starter files	..	2	0
TOTALS			1501	1425

NOTES: Total number of files include program-starting "batch" files, program files that "link" the phases to each other, and information display screen files.

Information Display totals include "duplicate" files - files of the same name and contents that appear in more than one phase. There are 14 files that are considered to be duplicates.

Product Development Guide - File Categorization Totals

Description	Number of Files
TOTAL Number of FILES in PDGUIDE	1501
Number of Control-Type Files	- 76
TOTAL Number of Information Display Files	1425
"Duplicate" Displays	- 14
NET Total of "Original" Displays	1411
Displays Not Used / to be removed	- 0
NET Total of Information Displays	1411

Explanation of Descriptions:

"Total Number of Files" is the total number of files transferred when PD Guide and Product Design Specification module (PDG-PDS) are installed to a fixed disk.

"Control-Type files" are those related to starting the PD Guide, switching directories, and other tasks that must be completed as part of PD Guide operations.

"Information Display files" are those used to create a visual display on the monitor.

"Duplicate Displays" are those information display files which appear in more than one development process phase. (Because of the way PD Guide is organized, duplicate copies of these files must be created for each additional phase in which the display appears.)

"Net Total of Original Displays" is the number of distinct PD Guide displays that exist.

"Displays not used / to be removed" are information displays that are not currently used in this version, but which still reside in the PD Guide.

"Net Total of Information Displays" is the total number of information displays which can be accessed from this version of the PD Guide and its associated modules.

PD GUIDE Disk Space Requirements

PD Guide Version 940901P (September 01, 1994) - dissertation version

PHASE or MODULE	"As-Listed" Size (kB)	Number of 512K Blocks	Actual Diskette Space (kB)	Number of 2048K Blocks	Actual Fixed Disk Space (kB)
"Home" Directory (including Tutorial)	259.7	568	290.8	194	397.3
Product Ideas	101.0	241	123.4	74	151.6
Customer Future Needs Projection	106.1	243	124.4	78	159.7
Technology Selection & Development (Product & Process)	192.7	443	226.8	136	278.5
Final Product Definition & Project Targets	296.7	675	345.6	212	434.2
Marketing and Distribution Preparation	133.0	306	156.7	96	196.6
Product Design & Evaluation	635.3	1444	739.3	446	913.4
Manufacturing System Design	304.4	713	365.1	224	458.8
Product Manufacture, Delivery & Use	85.2	198	101.4	67	137.2
PDS Module	88.6	202	103.4	65	133.1
Root	0.1	1	0.5	1	2.1
TOTALS	2202.8	5034	2577.4	1593	3262.5

Explanation of Table Headers:

"As-Listed" Size (kB) is the sum of the size of each file in that directory or module, as listed in the DOS directory listing.

Number of 512K Blocks is the number of 512K "blocks" that the files in this directory/module require. The "real size" of a file on a diskette must be assessed in these blocks, since the use of any portion of a block by any file makes that block unavailable to any other file. The number of blocks needed by each individual file is computed from its "as-listed" size; the total shown in the table is the sum of the number of blocks required by each individual file in that directory.

Actual Diskette Space (kB) is the number of 512K blocks required times 512K.

Number of 2048K Blocks is the number of 2048K "blocks" required by the files in this directory or module. The "real size" of a file on a fixed diskette must be assessed by the number of "blocks" required, since the use of any portion of a block by any file makes that block unavailable to any other file. The size 2048K was selected because it is a common block size on many fixed disks, including the computer used in the UT Engineering Design Cetner. The number of blocks needed by each individual file is computed from its "as-listed" size; the total shown in the table is the sum of the number of blocks required by each individual file.

Actual Fixed Disk Space (kB) is the number of 2048K blocks required times 2048K.

VITA

Michael Earl Kennedy is co-author of eight papers pertaining to product development and design education. He is co-author (with his major professor, Dr. Clement C. Wilson) of Chapter 18, "Improving the Product Development Process" in the 1991 book, *Competing Globally Through Customer Value*, and of an upcoming product development text, *Superior Product Development: Managing the Process for Innovative Products* (co-authored with Clement C. Wilson and Carmen J. Trammell).

After fifteen months as a controls engineer for Pratt and Whitney (West Palm Beach, FL), Mr. Kennedy was awarded an IBM Graduate Fellowship and returned to The University of Tennessee to pursue M.S. and Ph.D. degrees in mechanical engineering. His M.S. thesis project, the design and manufacture of a low-cost industrial robot, led to an M.S. in mechanical engineering in May 1991.

Mr. Kennedy earned a B.S. degree in mechanical engineering at The University of Tennessee in 1986. Mr. Kennedy was president of his Tau Beta Pi chapter, and was awarded two Chancellor's Citations for Extraordinary Academic Achievement. He was named "Outstanding Engineering Senior" and designated "Top Graduate" for the College of Engineering. As a Cooperative Engineering Program participant, he worked for IBM Corporation in Boca Raton, FL.

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