

## Benchmarking: A Process Basis for Teaching Design

J.L. Fridley, J.E. Jorgensen  
University of Washington

and

J.S. Lamancusa  
Penn State University

### Abstract

Benchmarking is a business management tool that has been employed for many years to search for 'best practices' in, for example, business operations, customer relations, product design and manufacturing. To our knowledge, its application to the process of teaching design in a university setting is novel. As part of the Manufacturing Engineering Education Partnership (MEEP) we have attempted to restructure how we teach design to emulate an industrial setting and to provide more 'hands on' experience for the students.

Our implementation of benchmarking relies on product dissection to enable students to establish a database for analysis of the product design in terms of its function, performance, and manufacture. We have introduced the concept in our Junior level course, Introduction to Design, as a means for the students to experience working on real commercial products. Examples of such products are the electric drill, the hand held mixer, the food blender, and the oscillating cooling fan. The selection of the product and its complexity, or simplicity, in design and manufacture is less important in comparison to the process the students have to perform in order to arrive at the desired results and conclusions. The process we have employed, the resource requirements, and the educational benefits we have observed from using this process over the last two academic years are described.

### Introduction

Engineering design education has been receiving increasing attention nationwide over the past decade. At the University of Washington design education became an important focal point with the initiation of the ECSEL Coalition in 1991 (Jorgensen & Reagan, 1991). Through ECSEL the engineering faculty began to re-emphasize the potential benefits associated with having students doing more engineering design and distributing it throughout the four year curriculum. For example, a new Freshman course, Introduction to Engineering Design (Calkins et. al, 1993), was introduced in which students do design, work on teams, engage in hands-on activities, and in general, learn through highly participatory and interactive processes. Additionally, faculty have begun to include more design activity and design related material into existing courses (Miller et. al, 1995 and Peterson et. al., 1992), and developing new courses, such as Product Liability, with a design bent.

The Manufacturing Engineering Education Partnership (MEEP) was formed by the Pennsylvania State University, the University of Puerto Rico @ Mayaguez, the University of Washington, and Sandia National Laboratories in 1994 (Lamancusa et. al., 1995). The MEEP program focus was on design in relation to manufacturing with a recognized emphasis on issues involving enterprises producing multiple units, primarily in commercial endeavors. We fully subscribed to the "hands on" approach that was being advocated by the ECSEL coalition although, in MEEP, our attention was primarily on Junior and Senior level professional courses. Design education, coupled with hands-on implementation, remained the real emphasis. Through MEEP we implemented the "Integrated Learning Factory" (ILF) as a theme facility for education in concurrent engineering. The ILF embodies a design is a team sport and a learn-by-doing philosophy. The facility includes a design studio / teleconferencing center, a computer aided design and analysis laboratory, a product dissection or 'tear down' center, and a 'factory floor.' The physical layout intends to accommodate design as a team based activity.

The product dissection / tear down center was included in the ILF in response to our commitment to hands on learning, design-by-discovery and design-by-imitation. Product dissection (Lamancusa et. al., 1996) was identified early on as a specific activity that could allow design parameters to be related to product performance for a wide variety of manufactured products.

The Mechanical Engineering department at the University of Washington serves an undergraduate program of primarily Junior and Senior level students with approximately 200 receiving the B.S.M.E. each year. In the past, a sequence of stand alone courses lead up to a 10 week capstone design activity. The design sequence, which consisted of a “machine element design” course, an “introduction to mechanical design” course, and the capstone project course, tended to be concentrated in the last 3 or 4 academic quarters of each student’s residence. Design activity, as encountered by the students, tended toward individual or very small team projects, frequently with minimal supervision. We are now implementing an integrated sequence of courses and experiences that start in the freshman year and culminate with two or three quarter long team design projects that are either industry or competition driven. We see the design sequence as being predominantly learn-by-doing and product dissection has a critical role. We have had concerns however about integrating product dissection into the engineering curriculum in a way that is substantially more than taking things apart to see how they work. We wanted to include product dissection as a meaningful element in the students’ design project activity.

### **Benchmarking**

In contemporary business and quality improvement language benchmarking refers to the formal and systematic process of continually measuring and evaluating the performance of your own and other’s (ideally the best of all the others) products or processes and using the results to make informed business and engineering decisions.

We believed, primarily as a result of our involvement in ECSEL and MEEP, that the benefits of hands-on product dissection (Lamancusa, et. al., 1996) would be desirable outcomes of our design courses. But, it seemed that exercises in ‘take it apart and see what’s inside’ were inappropriate and that ‘take it apart and see how it works’ was only marginally better. In formal benchmarking we saw promise for incorporating product dissection as part of a design process appropriate for design education. It became our belief that through benchmarking we could utilize product dissection to not only derive its benefits as a hands-on learning exercise but to integrate it into the context of concurrent design.

Benchmarking, as a formal and systematic process for quality improvement, was developed in the business community in the late 1970’s and early 1980’s. In one of the original texts on benchmarking, Camp (1989) suggested a definition for benchmarking: “benchmarking is the search for industry best practices that lead to superior performance.” More recently, the Harringtons (1996) describe benchmarking as “a systematic way to identify, understand, and creatively evolve superior products, services, designs, equipment, processes, and practices to improve your organization’s real performance.” Although individual authors writing about benchmarking tend to indicate that their own short definitions are not terribly satisfying it is quite evident that benchmarking is consistently viewed as a widely accepted, documentable, and effective learning process that succeeds only when formally and systematically followed and only when viewed as a process as opposed to an event or a technique.

The Harringtons list a set of reasons why organizations undertake benchmarking. Many of the reasons appear to be fully consistent with the needs of a design team functioning in a “concurrent engineering” style. Examples include:

- To set challenging but realistic goals,
- To define how goals can be accomplished,
- Because a breakthrough improvement is required,
- To uncover emerging technologies or practices,
- To improve stakeholders’ satisfaction level, and
- Because there is a need to supplement...ideas with fresh thoughts.

Carey (1992) describes benchmarking as one of nine “quality tools for today’s engineers” that can be employed to “design, develop, build and service products that: work better, last longer, are lighter, cost less, are safer (and) do not disturb the environment.” Kobe (1993) discusses examples of benchmarking in the automobile manufacturing industry including the role it played in Chrysler’s design of their minivan. He

also discusses cooperation between automobile companies on benchmarking projects. There appears to be some concern about the legality of “sharing of the implications of what is found” through benchmarking and concern about protecting the “science of how to conduct a benchmarking session” when cooperating with competitors. (This latter concern seems to illustrate how highly benchmarking is valued by some companies.) A 1995 article in the trade magazine *Machine Design* (Anon., 1995) describes how the Product Design and Manufacturing Technology Group at Digital Equipment Corp. has devised methods for estimating competitor’s costs for labor, material, and contract manufacturing and how new design trends can be revealed through benchmarking.

Even though benchmarking has been widely practiced within the engineering profession, a question, concerning the ethics involved, arose as we considered including benchmarking in our course. Were we considering a legitimate process for achieving better designs or were we talking about introducing, into a University course, a discussion of how to steal someone else’s ideas or even perform industrial espionage with a trendy name? Ethical and legal issues are discussed in some of the benchmarking related texts (e.g., Harrington, 1996 pp7&35; Boxwell, 1994 p48; Spendolini, 1992 pp197-201). The authors, not surprisingly, make reasonable arguments for benchmarking as an ethical undertaking. Spendolini (1992) advises that companies “develop a formal position on ethical and legal issues” and gives examples of ethical and unethical behavior that could be encountered in a benchmarking exercise. We were further persuaded that benchmarking can be done in an ethical manner upon learning that it has become an expected component of a company’s portfolio of quality related “core values and concepts” when being considered for the prestigious Malcom Baldrige Quality Award (Hodgetts, 1993). Benchmarking is also advocated by one author (Tucker, 1996) as a valuable tool for educators to learn and implement best practices in the educational system.

To begin using benchmarking in an engineering design course we reviewed several benchmarking process models (see appendix) and concluded that, as with engineering design, there are probably as many process models described as there are book authors. Camp (1989) described a four phase, ten step process:

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|---------------------------------|---|
| Planning Phase                  | 1. Identify what is to be benchmarked                 |
|                                 | 2. Identify comparative companies                     |
|                                 | 3. Determine data collection method and collect data  |
| Analysis Phase                  | 4. Determine current performance “gap”                |
|                                 | 5. Project future performance levels                  |
| Integration Phase               | 6. Communicate benchmark findings and gain acceptance |
|                                 | 7. Establish functional goals                         |
| Action Phase                    | 8. Develop action plans                               |
|                                 | 9. Implement specific actions and monitor progress    |
|                                 | 10. Recalibrate benchmarks                            |
| Return to the<br>Planning Phase |   |

An eight step benchmarking process model, tailored to examine manufacturing processes, is suggested by the Society of Manufacturing Engineers (SME, 1995):

- |        |  |   |
|--------|--|---|
| Step 1 | Determine process to benchmark                         |   |
| Step 2 | Select team members                                    |   |
| Step 3 | Develop process measurements                           |   |
| Step 4 | Identify benchmark partners                            |   |
| Step 5 | Identify practices and measure performance of partners | and Identify practices and measure your own performance |
| Step 6 | Specify programs and actions to close the gap          |   |
| Step 7 | Implement changes identified                           |   |

Zairi and Leonard (1994) benchmarked fourteen benchmarking process models and highly rate Camp's model (which they identify as the "Xerox" methodology). They state that all of the processes they examined contain planning or preparation, analytical, integration and action phases.

Spendolini (1992) suggests that there are three significantly different types of benchmarking. These are "internal," "competitive" and "functional." Internal benchmarking denotes a situation where all of the measurements and comparisons are being done with products and processes that are within the organization. This is suggested as a good let's-get-started step for a benchmarking endeavor. Competitive benchmarking focuses on the products and processes that are most similar to, and in direct competition with, those of the organization doing the benchmarking. Functional benchmarking indicates that the focus is on generic functions, such as using fasteners or processing customer orders. With functional benchmarking there is less emphasis on the competitor's practices but rather a search for the best practices that exist, regardless of the specific product or service in which they are being employed. In engineering practice, most of the emphasis seems to have been on competitive benchmarking.

### **Benchmarking in a Design Course**

We wished to adapt a process for competitive benchmarking to fit the needs of our Junior/Senior level mechanical engineering course "introduction to mechanical design." Typically the course consists of a series of lectures, discussions and exercises that serve to facilitate learning about a variety of design topics that are found in the multitude of engineering design texts that have been written. We have used the text by Dieter (Dieter, 1991) in recent years. In addition there is a progression of design projects over the duration of the quarter. The projects are intended to reinforce and allow tinkering with the ideas associated with the lecture/discussion/exercises and at the same time advance in scope and complexity. The progression often consists of a let's get started project, a conceptual design project, and a design/build project.

Design courses are not companies but they do develop their own "corporate culture." Typically courses do not have responsibilities for producing products or providing services (beyond the education of the students). The students' tenure in the 'organization' is relatively short and the variety of competencies represented by the students is somewhat narrow. (We like to say that the students are all equally over-qualified and under prepared for even the simplest the design projects that we assign to them). As a result the 'culture' and the projects usually lack the rich history that is found outside the classroom. But, the differences in the classroom and the commercial settings notwithstanding, we felt that all of the important phases of a benchmarking project be included in the course exercises.

We initially chose to approximately follow the benchmarking process model described by the SME (SME, 1995) and have previously described those first experiences in some detail in Jorgensen et. al. (1996). In summary, we undertook a classroom/design laboratory project that consisted of benchmarking and redesigning hand held kitchen mixers. Step 1 and step 2 of the exercise consisted of the instructors selecting hand held mixers as the product for benchmarking and assigning the benchmarking teams. Step 3, developing process measurements, was completed as a class exercise that emphasized customer expectations (CE's). In step 4, the 'benchmarking partners' were ultimately determined by the instructors when we purchased 12 units of varying brands and prices, after receiving input (homework) from student "shopping" teams. Step 5, identify practices and measure performance, was done as another class exercise and resulted in a "design database" that was provided to all design teams. Steps 6, 7 and 8 were completed by the individual design teams as they all sought to improve the design of some of the mixers by meeting or exceeding the best practices found in the set of mixers that had been benchmarked.

The exercise was highly effective for classroom learning about design at the conceptual, implementation, and detailed design stages. However, the students demonstrated a strong tendency for equating "customer" to "consumer" and therefore designing for the CE's was translated by them to mean designing for the consumer (as opposed to, e.g., including 'manufacturing' or 'vendors' in the set of customers). We may have encouraged this when we provided them with a copy of Consumer's Report (Anon. 1991) as a let's-get-

started step for Step 3 of their benchmarking process. But, it was more likely due to the students having better access to information about the product consumers than about, for example, the product manufacturing personnel and facilities.

More recently, we repeated the exercise with a set of 15 different kitchen blenders, ranging in price from \$15 to \$120, in a class of about 40 students. We followed the same benchmarking / product redesign process model that we had used with the hand held mixers but we attempted to emphasize a “stakeholder based approach” that focused design issues on stakeholder expectations or SE’s (see Dooley and Fridley, 1996, for a discussion of a stakeholder based approach to design). “Design for stakeholders” had been emphasized throughout the course, where stakeholders were defined as those persons who can affect or be affected by the design. The stakeholder based approach was adopted in response to the student’s tendencies to want to concentrate on the user as the only customer in our earlier experience.

When the students performed steps one through five of the benchmarking process, to search for the best practices, it was done in the context of their limited knowledge and beliefs of how a blender’s functions and features relate to how well some stakeholder expectations will be satisfied. They did pay particularly close attention to part count, the ease of and estimated time required for final assembly, and product packaging in their attempt to consider stakeholders other than the consumer.

Upon completing Step 5, “identify practices and measure performance,” each of the benchmarking teams were assigned a specific blender. Their goal was to improve its design with respect to the best practices that had been identified. Each team selected four or five SE’s and set out to “meet or exceed the best practices” that they had discovered through their earlier efforts. Working prototypes were not produced but teams provided a written design report and oral presentation in the form of a proposal requesting the “go-ahead” for their “new” product. The results, which still included a very strong tendency to focus on the consumer as the stakeholder, were approximately similar to what we observed with the hand held mixers.

### **Observations and Conclusions**

Benchmarking provides an appropriate context for product dissection and it is applicable to a variety of products/projects. Benchmarking is a desirable topic for an engineering design course. Contemporary approaches to quality improvement, in the context of product and process redesign and new product development, make study and experience in benchmarking valuable. We now have experience incorporating benchmarking into design class activities involving hand held mixer and food blender redesign and bird feeder design. Recently, some of our colleagues have begun to try exercises that have involved oscillating fans and hand held vacuum cleaners.

There are three key challenges when trying to get the most educational value from the benchmarking process in design education, these are: 1) having students apply their newly engineering analysis skills in combination with their creative design abilities to their design projects, 2) expanding the design class’ “corporate culture” to enable students to better address a wide variety of stakeholder interests in product improvement through redesign, and 3) developing a benchmarking process model that is tuned for the classroom design project.

There are probably many aspects that must be addressed to meet each of the three challenges but we believe that the first, combining analysis and creative design, can be met through attention to the second two. The students do not lack in their ‘how to’ competencies but they lack the knowledge and access to the knowledge and data that they need in order to decide ‘what to’ and ‘when to’ bring their analytical capabilities to bear on a problem.

Expanding the design class’ ‘corporate culture’ probably requires reaching out and involving practicing engineers and business managers from companies that manufacture, market, or provide inputs to the manufacturing, of products similar to the products that we use in class. The practicing engineer, even at the entry level, soon learns how their company “likes to do things” and who in their company “knows about that.” A rich picture of the stakeholders and their concerns needs to be created. The rich picture must

provide the knowledge and data about the business in which the product exists so that the students can begin to make rational decisions that go beyond maximizing the products' physical performance.

Many benchmarking process models have been generated for the purpose of guiding businesses and other organizations. But a design course is a unique organization in regards to project time frame, severely limited resources, potentially large number of people doing essentially the same thing, the lack of diversity of talent available for teams, and the fact that the real goal is education rather than product development or production or some other business function.. We initially used the eight step SME model to guide or classroom exercises but it does not provide discrete activities in each the four phases: planning, analysis, integration and implementation. Most of the published benchmarking process models include these phases and indicate that they are critical for success. Camp's model is presented as ten specific tasks that are clearly identified with the four phases. Using it along with the experiences we have gained so far we developed the benchmarking process model given in Appendix A-2. The model provides specific student activities in each of the four benchmarking project phases.

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## Appendix A-1

Spendolini (1992), in what has become staple reading on the subject of benchmarking, describes a 5 stage process without specifying detailed steps or actions:

1. Determine what to benchmark
2. Form a benchmarking team
3. Identify benchmarking partners
4. Collect and analyze benchmarking information
5. Take action

The Harringtons (1996) suggest a 5 phase, 20 step process:

- |   |  |
|---|--|
| <i>Phase I: Planning the Benchmarking Process and Characterization of the Item(s)</i> | <ol style="list-style-type: none"> <li>1. Identify what to benchmark</li> <li>2. Obtain top management support</li> <li>3. Develop the measurement plan</li> <li>4. Develop the data collection plan</li> <li>5. Review plans with location experts</li> <li>6. Characterize the benchmark item</li> </ol>   |
| <i>Phase II: Internal data Collection and Analysis</i>                                | <ol style="list-style-type: none"> <li>7. Collect and analyze internal published information</li> <li>8. Select potential internal benchmarking sites</li> <li>9. Collect internal original research information</li> <li>10. Conduct interviews and surveys</li> <li>11. Form in internal benchmarking committee</li> <li>12. Conduct internal site visits</li> </ol> |
| <i>Phase III: External Data Collection and Analysis</i>                               | <ol style="list-style-type: none"> <li>13. Collect external published information</li> <li>14. Collect external original research information</li> </ol>   |
| <i>Phase IV: Improvement of the Item's Performance</i>                                | <ol style="list-style-type: none"> <li>15. Identify corrective actions</li> <li>16. Develop an implementation plan</li> <li>17. Gain top management approval of the future-state solution</li> <li>18. Implement the future-state solution and measure its impact</li> </ol>   |
| <i>Phase V: Continuous Improvement</i>  | <ol style="list-style-type: none"> <li>19. Maintain the benchmarking database</li> <li>20. Implement continuous performance improvement</li> </ol>   |

Andersen and Pettersen (1996) describe the following approach:

- |         |  |
|---------|--|
| Plan    | <ol style="list-style-type: none"> <li>1. Select the process to be benchmarked, based on the company's strategy (requires identifying and raising awareness of the strategy).</li> <li>2. Form benchmarking team.</li> <li>3. Understand and document the process to be benchmarked.</li> <li>4. Establish performance measures for the process (quality, time, cost).</li> </ol>  |
| Search  | <ol style="list-style-type: none"> <li>5. Design list of criteria an idea benchmarking partner should satisfy</li> <li>6. Search for potential benchmarking partners, i.e., companies that are better than oneself at the process in question.</li> <li>7. Compare the candidates and select the best suited benchmarking partner(s).</li> <li>8. Establish contact with the selected partner(s) and gain acceptance for participation in the benchmarking study.</li> </ol> |
| Observe | <ol style="list-style-type: none"> <li>9. Assess the information needs.</li> <li>10. Select method and tool for collecting information and data.</li> </ol>  |
| Analyse | <ol style="list-style-type: none"> <li>11. Observe and debrief</li> <li>12. Sort the collected information and data</li> <li>13. Quality control the information and data</li> <li>14. Normalise the data</li> <li>15. Identify Performance gaps</li> <li>16. Identify the causes of the performance gaps</li> </ol>   |
| Adapt   | <ol style="list-style-type: none"> <li>17. Communicate the findings from the analysis and gain acceptance through participation and information.</li> <li>18. Establish functional goals for the improvements that match the other improvement plans of the company.</li> <li>19. Design and implementation plan for the improvements.</li> <li>20. Monitor the progress and adjust deviations.</li> </ol>   |
| Recycle | <ol style="list-style-type: none"> <li>21. Close the benchmarking study with a final report.</li> <li>22. Recalibrate the benchmarks, i.e., adjust the goals/benchmarks as "best practice" changes/improvements.</li> <li>23. Recycle the benchmarking process, i.e. perform new benchmarking studies for new areas/processes</li> </ol>   |



Appendix A-2

Project Phase	Camp's Tasks	Student Task	Instructor Task
<b>Planning Phase</b>	1. Identify what is to be benchmarked		Select product and inform students
			Assign students to initial benchmarking teams
		1. Identify stakeholder expectations (SE's) that could be important. Identify corresponding features and functions (F&F's) that could be benchmarked.	
	2. Identify comparative companies.	2. Develop a generic list of products with similar F&F's.	
		3. Identify (through "shopping") specific brand and model numbers of products and recommend which to acquire.	
			Select, acquire and provide products to students.
		4. Identify specific F&F's to benchmark (some product disassembly may be required)	
			Summarize specific features and functions selected for benchmarking
	3. Determine data collection method and collect data	5. Devise metrics that are appropriate for each feature or function to be benchmarked	
		6. Use product dissection to determine performance of each product.	
<b>Analysis Phase</b>	4. Determine current performance "gap"		Assign "ad hoc" reconciliation teams
			Summarize performance data and provide to reconciliation teams
		7. Identify best performers for each function or feature that was benchmarked. Call these best in class.	
			Create "design database" that provides performance ratings for each product
			Assign a specific model, one to each design team, for improvement through redesign
	5. Project future performance levels	8. Estimate performance that would be achieved if best-in-class performance were reached to the fullest extent possible for the team's specific product.	
<b>Integration Phase</b>	6. Communicate benchmark findings and gain acceptance	9. Document the current performance gap and possible performance level in a benchmarking report.	
	7. Establish functional goals	10. Select a small number of F&Fs and call these the critical success factors (CFS's). Agree to meet or exceed the best in class performance for each CSF.	
<b>Action Phase</b>	8. Develop action plans	11. Develop a written proposal to redesign the assigned product so that the goal (step 10) is met.	
			Accept proposals
	9. Implement specific actions and monitor progress	12. Engineering design to satisfy the contract	
	10. Recalibrate benchmarks		