Benchmarking: A Process Basis for Teaching Design

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Abstract *- Benchmarking is a 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 restructured the way we teach design by providing more 'hands on' experience for the students by more closely emulating an industrial setting and by incorporating a benchmarking process approach.*

Our implementation of benchmarking relies on product dissection to enable students to establish a database for analyzing a design in terms of its function, performance, and manufacture. We have introduced the concept in our Sophomore/Junior level Product Dissection and Junior level Introduction to Design courses 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 actual selection of the product and its complexity, or simplicity is less important in comparison to the process the students follow 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 [1]. 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 [2,3], was introduced in which students 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 activities and design related material into existing courses [4,5], 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 [6]. The MEEP program focus is to integrate design, manufacturing, and business realities into the engineering curriculum. 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. It includes a design studio / teleconferencing center, a computer aided design and analysis laboratory, a product dissection or 'tear down' center, and a 'factory floor' with advanced and traditional manufacturing and prototyping facilities. 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 [7] 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 led 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.

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. Benchmarking may involve both qualitative (e.g. ideas and overall approaches) and quantitative (e.g. costs and productivity) measurements and evaluations. We have provided some suggested benchmarking process models in the appendices.

Motivation

We believed, primarily as a result of our involvement in ECSEL and MEEP, that the benefits of hands-on product dissection [7] would be desirable outcomes of our design courses. But, we had concerns about including product dissection per se into the engineering curriculum. 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. We wanted to integrate product dissection as a meaningful element in the students' design project activity. Through 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.

Background

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 [8] suggested a definition for benchmarking: "benchmarking is the search for industry best practices that lead to superior performance." More recently, the Harringtons [9] 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. It succeeds, however, only when formally and systematically followed and only when viewed as a process as opposed to an event or a technique.

The Harringtons [9] 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 [10] 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 [11] 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 [12] 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.

Ethical Concerns

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., [9] pp7&35, [13] p48, & [14] pp197-

201). The authors, not surprisingly, make reasonable arguments for benchmarking as an ethical undertaking. Spendolini [14] 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 Baldridge Quality Award [15]. Benchmarking is also advocated as a valuable tool for educators to learn and implement best practices in the educational system [16].

Benchmarking Process Models

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 [8] described a four phase, ten step process:

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 Planning Phase		

An eight step benchmarking process model, tailored to examine manufacturing processes, is suggested by the Society of Manufacturing Engineers [17]:

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
Step 8	Measure results

Zairi and Leonard [18] 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 [14] 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. 'Competitive analysis' is a term that is frequently used synonymously with competitive benchmarking but the term itself, with its emphasis on analyzing the entities direct competition, connotes a subset of a benchmarking process. Similarly, 'reverse engineering', which is a method for retrospectively generating the technical specification of a product [19], is a useful tool within the continuous benchmarking process.

Benchmarking in a Design Course

We wished to adapt a process for 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 [20] in recent years. The course includes a progression of design projects over the duration of the quarter. The projects are intended to reinforce learning and allow tinkering with ideas introduced in the lecture/discussion/exercises, and at the same time, increase in scope and complexity. The progression often consists of a ‘lets 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 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 not withstanding, we felt that all of the important phases of a benchmarking project should be included in the course exercises.

We initially chose to approximately follow the benchmarking process model described by the SME [17] and have previously described those first experiences in some detail in Jorgensen et. al. [21]. 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 [22] as a ‘lets-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 [23] for a discussion of a stakeholder based approach to design). “Design for stakeholders” had been emphasized throughout the course, where stakeholders were defined (approximately) as those persons or groups of persons who can affect or be affected by the design. (Examples of stakeholders therefore can include the product user, various consumer protection and environmental groups, marketing and sales organizations, workers assembling the product, production managers, design engineers, stress analysis specialists, and on and on.) The stakeholder based approach was adopted in response to the student’s tendencies to want to concentrate on the end-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 (largely qualitatively) 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, however, 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 deep understanding (or 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 our 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:

Phase 1:	Plannning the Benchmarking Process and Characterization of the Item(s)	1. Identify what to benchmark 2. Obtain top management support 3. Develop the measurement plan 4. Develop the data collection plan 5. Review plans with location experts 6. Characterize the benchmark item
Phase II:	Internal data Collection and Analysis	7. Collect and analyze internal published information 8. Select potential internal benchmarking sites 9. Collect internal original research information 10. Conduct interviews and surveys 11. Form in internal benchmarking committee 12. Conduct internal site visits
Phase III:	External Data Collection and Analysis	13. Collect external published information 14. Collect external original research information
Phase IV:	Improvement of the Item's Performance	15. Identify corrective actions 16. Develop an implementation plan 17. Gain top management approval of the future-state solution 18. Implement the future-state solution and measure its impact
Phase V:	Continuous Improvement	19. Maintain the benchmarking database 20. Implement continuous performance improvement

Andersen and Pettersen (1996) describe the following approach:

Plan	1. Select the process to be benchmarked, based on the company's strategy (requires identifying and raising awareness of the strategy). 2. Form benchmarking team. 3. Understand and document the process to be benchmarked. 4. Establish performance measures for the process (quality, time, cost).
Search	5. Design list of criteria an idea benchmarking partner should satisfy 6. Search for potential benchmarking partners, i.e., companies that are better htan oneself at the process in question. 7. Compare the candidates and select the best suited benchmarking partner(s). 8. Establish contact witht he selected partner(s) and gain acceptance for participation in the benchmarking study.
Observe	9. Assess the information needs. 10. Select method and tool for collecting information and data. 11. Observe and debrief
Analyse	12. Sort the collected information and data 13. Quality control the information and data 14. Normalise the data 15. Identify Performance gaps 16. Identify the causes of the performance gaps
Adapt	17. Communicate the findings from the analysis and gain acceptance through participation and information. 18. Establish functional goals for the improvements that match the other improvement plans of the company. 19. Design and implementation plan for the improvements. 20. Monitor the progress and adjust deviations. 21. Close the benchmarking study with a final report.
Recycle	22. Recalibrate the benchmarks, i.e., adjust the goals/benchmarks as "best practice" changes/improvements. 23. Recycle the benchmarking process, i.e. perform new benchmarking studies for new areas/processes

Appendix A-2

Project Phase	**Camp's Tasks**	**Student's Tasks**	**Instructor's Tasks**
Planning Phase	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.	
Analysis Phase	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.	
Integration Phase	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.	
Action Phase	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		