THE DESIGN PROCESS THROUGH THE EYES OF A BERKELEY STUDENT

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ABSTRACT

As a leading institution, UC Berkeley needs to maintain the high caliber of its programs. To do so, it should be able to adapt to today's rapidly growing global economy. This paper will analyze the strengths and weaknesses of UC Berkeley's Mechanical Engineering curriculum, with an emphasis on design and innovation. The author addresses these issues through his experiences as a student (undergraduate and graduate) at UC Berkeley and as an intern at IDEO. The Design Process, as a non-linear and iterative method, is examined thoroughly by comparing academic models with actual industry practices. As a solution, a heavily iterative aspect of the Design Process model is suggested to change the status quo. Furthermore, disparities of teaching and practicing different disciplines of the Design Process are discussed. Subsequently, modifying the current curriculum as well as initiating collaborations between UC Berkeley and IDEO are recommended by the author.

I INTRODUCTION

In this age of global markets and information technology, the world has become a smaller place, especially for engineering students. After graduation, UC Berkeley engineering students are now competing, not only with fellow students from schools such as, MIT, or Stanford, but directly with the rest of the world. U.S. companies, as well as others, have been increasingly outsourcing their technical departments overseas due to high technical skills combined with lower wages. In the past decade, overseas manufacturing has already been a dominant strategy for businesses to reduce cost in response to fierce competition. It is only a matter of time that more companies will try to reduce cost on engineering programs. Therefore, technical skills acquired at the university level will not solely provide the edge engineers will need to succeed in the marketplace.

Engineers will be required to bring more than technical skills to the table: they will need to find opportunities to innovate. At the university level, innovation is often associated with research and technological breakthroughs. This sort of innovation is extremely important and universities should be at the root of it. However, many students find it more appealing to develop commercial products and services using their technical skills. The engineering curriculum should address and provide the necessary tools to those students as well. The ultimate purpose of this paper is to promote an engineering curriculum that prepares students for this changing industry and that encourages them to look at problem solving in a whole new way.

After spending a summer working at IDEO, one of the most innovative design firms in the world (www.ideo.com), I realized how powerful Design can be. Design, whether a technical discipline or a strategic business tool, should simply be about finding the optimal solution to a certain need. Engineers are often trained to solve difficult technical problems without actually taking a step back and considering a bigger perspective of the problem. Design combines science, art, and humanities to sometimes solve needs deep in human nature. Therefore, in order to innovate, engineers need to understand who they are designing for before they start applying theoretical engineering concepts.

Section II will look at the Design Process from a larger perspective to identify the key attributes engineers should possess to efficiently innovate.

Section III will cover into more details the different stages of the Design Process—Need Finding, Concept Generation, Prototyping, Concept Selection, and Testing. This paper will look at these sub-disciplines and reflect back on the differences between material instructed in academia and techniques used in industry. The Design Process being so fuzzy and non-linear, the IDEO process will be assessed specifically through the eyes of a Berkeley engineering student. I worked on developing an advanced engineering project for a major commercial company in a three-month period and this experience will be used as an example to support the main points of this paper.

Section IV will look at the lessons learned throughout this process and make recommendations on how the UC Berkeley Mechanical Engineering Department can adapt its curriculum to promote a Design Culture within and outside its department to prepare students for this new economy of innovation. Furthermore, this section will also offer some insight on how IDEO and UC Berkeley can potentially join forces and collaborate in a long-term relationship.

II THE DESIGN PROCESS

A. ON DESIGN CULTURE

The Design Process is not a simple linear process that one can apply and automatically reach successful results. As experienced, it is a long, fuzzy, and iterative process that requires more than sequential actions to take. Consequently, a process cannot be perfect in essence and this paper will not attempt to claim otherwise. Having the best process in the world without the right people to apply it will merely result in failure rather than success. Innovation calls for innovation within the process; thus, a good designer needs to understand that adapting the process to specific projects is essential as long as the philosophy behind it stays intact. Design is not an exact science and the process is constantly polished and altered to adapt to the industry's needs. Oftentimes, engineering students take a product development class and feel they will come out of it with a solution for success; they usually come out confused and not quite sure if they would be able to apply the same process to another project with another team. Hence, bringing the Design Culture to students would assure their understanding of the philosophy behind the process.

The Design Culture is the essence and foundation of innovation. Although this culture cannot be acquired overnight, one can grasp the basic concepts that promote the culture of creativity and innovation, and thereafter it is only a matter of practice and experience. From experience, the most important behavioral attributes a student should possess and exercise when designing are:

Being open-minded

Innovation, by definition, deals with the unknown. It is human nature to feel uncomfortable when placed in an unknown environment. One tends to get defensive and redirect the discussion towards a place where one feels more comfortable and more willing to take risks. Unfortunately, creativity does not do well in an environment where people are criticizing wild ideas and trying to contribute to the project by pulling everybody else towards their preconceived ideas. People participating in the Design Process need to respect one another and instead of being judgmental, they should embrace wild ideas and try to build on them. Throughout my undergraduate and graduate years, I have seen how engineers use their technical skills to obliterate somebody else's ideas rather than trying to build on them. Many great ideas go to waste because they are not even given a chance by judgmental people, who are usually quick to show their apprehension of failure.

Willing to risk failure

IDEO's philosophy is built around accepting failures and building on the lessons learned from them: ***"Fail early to succeed early".*** This is a great statement since it effectively captures the complexity and the iterative nature of the Design Process. Many companies and most students see failure as a consequence of bad decision making through the course of the project. However, IDEO sees failure as an opportunity to get a better understanding of the problems they are trying to solve. Designers from the project team, as well as the rest of the company, will benefit from the lessons learned from a failed prototype, or even a failed project. Obviously, failed prototypes have less serious consequences than failed projects; thus, early prototyping leaves more room for early failure and iteration in the process. Section III will discuss the role of prototyping in more detail. Students are often pressured to get the right answer on the first try or at least have a specific direction in mind when starting a project. Time constraints, grades, peer and faculty pressure, push students in a dynamic route that does not leave much room for error, therefore little room for creativity. If anything, academia should be a place where students can feel free to fail and learn from their mistakes in a safe environment rather than in industry where the consequences have greater impacts.

Willing to take a step back

Engineers tend to focus on a specific problem so much so that they forget about the bigger spectrum of the project. Good design requires taking a step back every now and then and looking at the problem from a new perspective. In fact, innovation starts at the point where you are willing to take that step back and revisit the problem in a more general context. It also introduces iteration into the process, which is essential for good design. It might be helpful to associate a story to the product one is designing. This story should be based on the user needs that have been gathered and the stakeholders' corporate philosophy. As the design process goes on, one needs to constantly refer back to this story and make sure that the design is conveying the right message to the users. The best products are the ones that people are willing to purchase, not only because of the great product itself, but because of the positive experience it brings to them. Taking a step back allows designers to broaden their perspectives before making important decisions. Concept selection is one the most crucial and difficult phases of the product development process and oftentimes decisions are made without having considered a broader range of concepts. Most students, whether technical or non-technical, tend to have difficulty diverging and they usually try to converge as quickly as possible to remain in their safe zone.

In summary, the Design Culture is about accepting the fact that innovation is not a linear process and is dependent on lots of different variables that cannot always be predicted or controlled. However, designers have control over their own behaviors and if they stay committed to the Design Culture, they will be able to adapt themselves, and the process, to different sorts of projects.

B. CONSEQUENCES OF NON-ITERATIVE PROCESSES

Although it is well-known that the Design Process is non-linear and iterative, many companies have a more linear, engineering approach. The lack of iteration in their process, a result of not willing to take a step back, leads to designs that do not reflect the initial goals of the project.

The client came to IDEO with a concept, we will call Concept A, and they wanted IDEO to refine their design to turn it into a commercially viable product. They had built a high level prototype (Prototype A) to show how serious they were about this concept. However, it seemed that this concept was not consistent with the story they were trying to tell. In fact, after identifying the important user needs and the corporate direction they needed to pursue, it was agreed that this product needed to convey a message of simplicity. An existing competitive product on the market, we will call Product X, was doing extremely well, but most users complained about the complexity of use of the product. The client had been a leader in this market for generations, but because of recent changes in the market's demographics and fierce competition, they had suffered considerable losses in the marketplace. They needed to design a product that would be functionally similar to the competitor's version, while avoiding developing a "me too" product. A "me too" product is one that attempts to mimic a successful product on the marketplace to take some of the market share away from competition. However, they could not afford jeopardizing their leadership status by validating the competitor's product with a "me too" version. Therefore, to differentiate these two products, IDEO needed to tell a whole new story, a whole new experience, one of simplicity.

Many designers, and most students do not include enough iteration in their processes and the results often show it. For instance, the client that was mentioned had spent a lot of time developing different concepts; however, they abandoned all of them due to technical difficulties, and without further iteration. **Figure 1** shows the client's product development process, as it was perceived. It seemed that they had promising ideas before Concept A, but they were not explored to their full potential because of technical challenges. The client's approach was engineering-based and they seemed to use durability as the main driver behind concept selection. They had started the project with a clear understanding of their users' needs, but as technical difficulties arose, they sacrificed many of those needs for technical functionality. **Figure 1** shows that they completely abandoned an idea when encountering a technical challenge and started exploring a whole new direction without trying to build on the previous ones. As discussed in Section II.A, engineers are not well-trained to deal with failures, and frustration tends to take over when they fail. **Figure 1** illustrates the fact that decision making is dependent on frustration and enthusiasm levels. Decisions made in any extremes of this spectrum may lead to undesired results. Frustration affects the designers' ability to be open-minded, to be willing to risk additional failures, and to take a step back and look at the problem from a new angle.

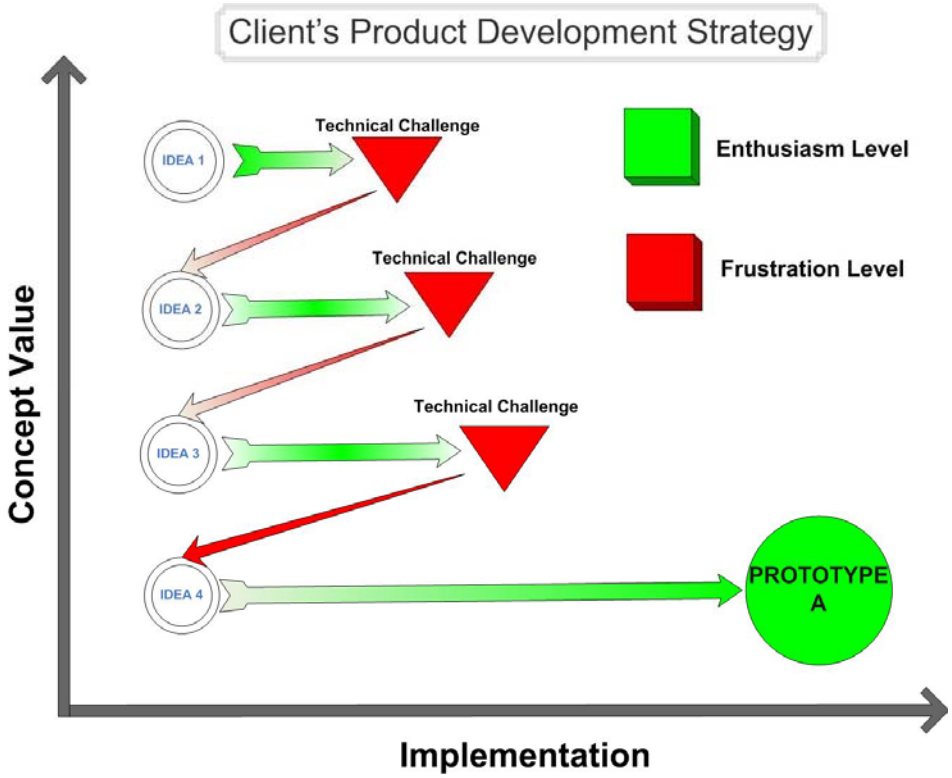
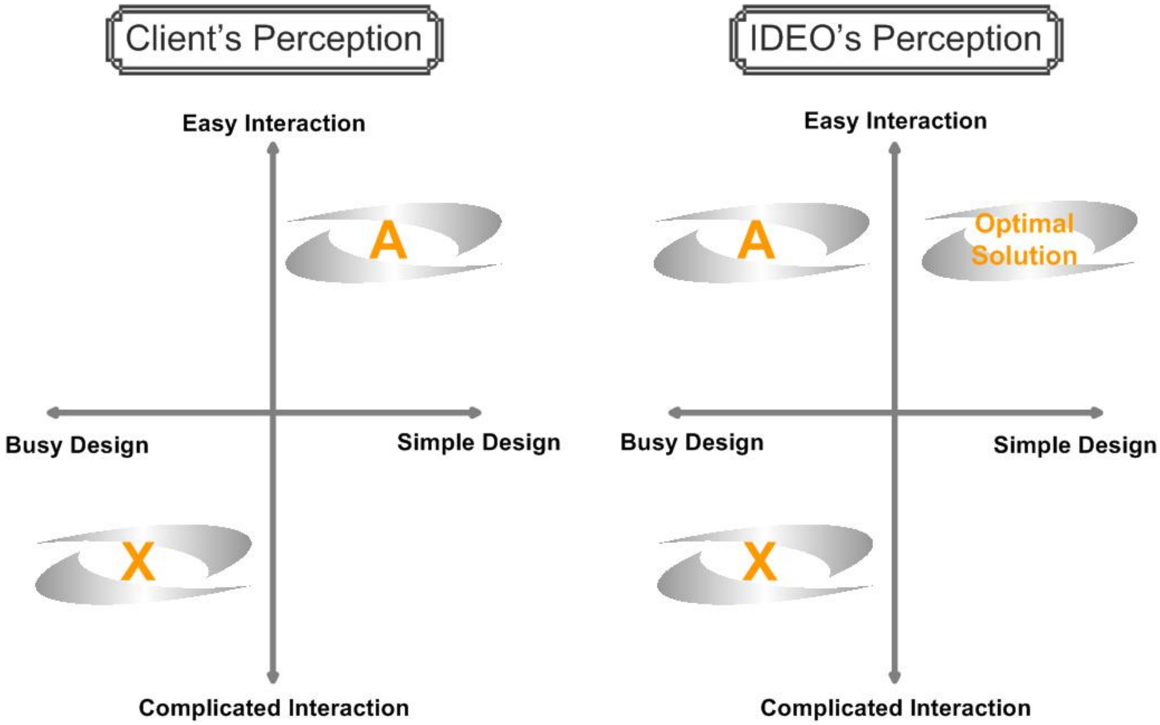


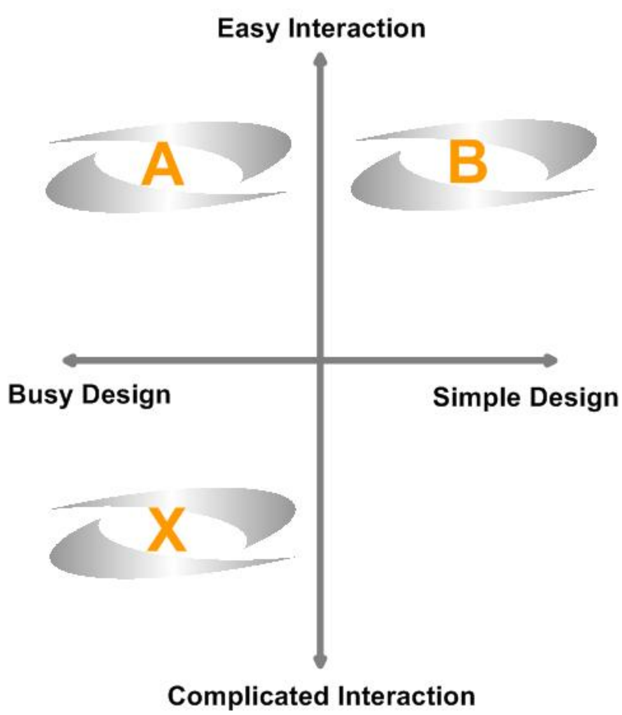
Figure 1. Client's Product Development Strategy
Lionel Mohri. *October 2005*

Concept A had been generated at the highest level of frustration and as the implementation did not seem to hit any technical challenges, the client prototyped it at the highest level of enthusiasm. These extreme feelings do not create an optimal environment for innovation. Consequently, the client convinced themselves that Concept A was the perfect answer to Product X (the competitive product); whereas, IDEO did not think it was the optimal solution that would convey the message of simplicity. Although Concept A was simple in user interaction, the design was busy and complicated, contradicting the story that was going to be told. **Graph 1** illustrates how subjective design can be, and that taking a step back can bring objectivity back into the process and remind designers of the users' needs that initiated this innovation opportunity in the first place.



Graph 1. Difference in Perception on Prototype A
Lionel Mohri, October 2005

Concept A did not properly address the user needs that were initially set to satisfy; therefore, the client was encouraged to take a step back and revisit the problem from a new angle. Sure enough, we were able to identify opportunities for innovation. It turned out that many of the concepts they had generated before Concept A had great design values. They were telling the right story, but because of technical challenges, they had been instantly dropped without attempting to build on them. A promising direction was identified, we will call it Concept B. **Graph 2** illustrates the fact that Concept B offers the optimal solution, a simple design combined with simple usability. IDEO was able to convince the client to get a two-week extension to look at the different designs to solve the technical difficulties they had previously encountered.



Graph 2. Concept B, the Optimal Solution

This previous section suggests that the design process needs to be iterative and that processes in which feedback loops are scarce will have fewer opportunities for innovation. The next section will attempt to model the "fuzziness" of the Design Process and compare it to the Design Process instructed in academia.

C. THE DESIGN PROCESS: A FUZZY AND ITERATIVE PROCESS

1. ACADEMIC MODEL

Design is probably one of the most difficult disciplines to teach in academia. Many students expect professors to teach them a formula for innovation as they would get from theoretical classes such as, heat transfer, or fluid dynamics. A linearization attempt of the Design Process is often illustrated in the first chapter of a design textbook and although it illustrates the different phases of the process, it does not emphasize nearly enough the complexity and fuzziness of the process. Consequently, academic design process models have been modified to show more iteration in the process, while trying to maintain an overall linear behavior (see **Figure 2**).

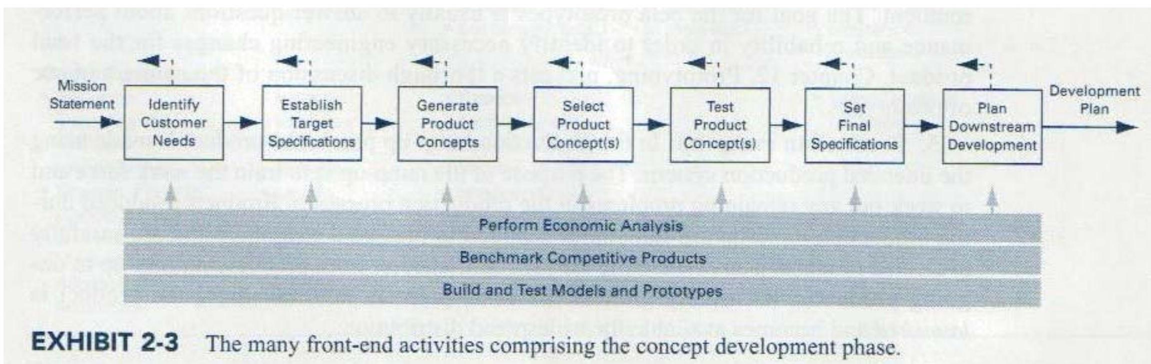


EXHIBIT 2-3 The many front-end activities comprising the concept development phase.

Figure 2. Design Process Academic Model
Product Design and Development, Ulrich and Eppinger, 3rd Edition, p.16

Figure 2, a design process model found in the textbook used for product development classes at UC Berkeley, divides the Design Process into successive stages while attempting to show that iteration is required and that prototyping, competitive analysis, and financial analysis should be performed throughout the whole process. Although this model compactly describes the iterative aspect of the process, students will not grasp the importance of iteration and prototyping in the design process. Most students will actually remember the main stages and will move forward in a linear fashion.

2. IDEO'S PROCESS

As previously discussed, IDEO's process is one that promotes iteration and prototyping. **Figure 3** summarizes the IDEO process in a clear and efficient way, putting special emphasis on the iteration that needs to take place in the Idea Generation and Prototyping phases. It is essential for designers to spend a considerable amount of time on the Learning side of the process before moving forward. IDEO is known for its efficient methods of gathering and understanding user needs; they are also known for their brainstorming and prototyping techniques that are constantly used throughout the process. Need finding should be seen as the foundation of the entire process, and designers must make sure to have a great understanding of the user needs they are trying to design for and that all members of the team are consistent in doing so.

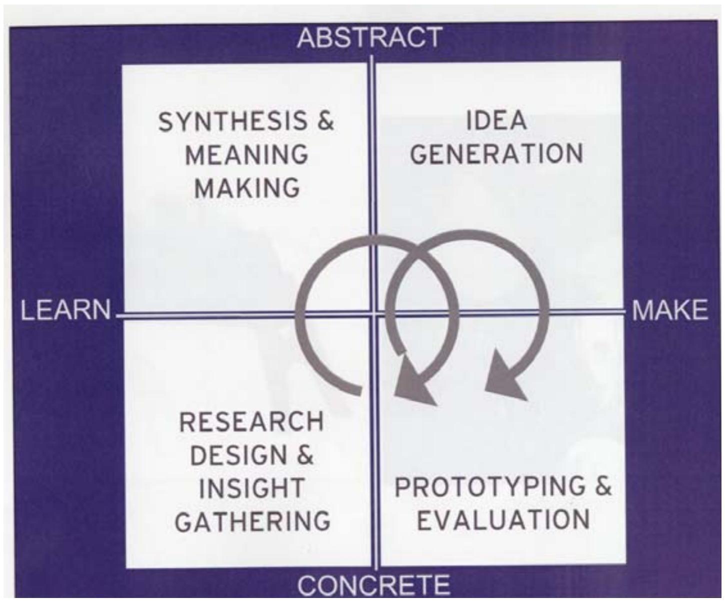


Figure 3. IDEO's Design Process

On an academic level, most students go quickly through the Learning phase and get to the Idea Generation part without actually having a great understanding of the problem they are trying to solve for. Oftentimes, students use the Idea Generation phase as their foundation and go back to revisit the user needs and accordingly modify them. It is extremely dangerous to approach the Design Process this way since now an idea is driving the user needs, rather than the other way around. Furthermore, since the team does not have a good understanding of the user needs, they will waste time deciding which idea to select for further implementation. Unfortunately, this debate will not be based on solid arguments, i.e. user needs and prototyping, and team members will "campaign" for their favorite ideas rather than base their concept selection on actual data. This dynamics does not leave much room for prototyping and user feedback. Furthermore, students usually do not go through more than one cycle of the process, making their first prototype their final one. Although a few UC Berkeley product development classes encourage multiple rounds of prototyping, most design courses encourage students to start building when they are completely sure that their designs will work. The latter approach prevents iteration and leaves little room for error, therefore, limiting the innovation opportunities.

Figure 3 is a simple and friendly illustration of the process. It efficiently shows the iteration aspect of the product development process, while clearly segmenting the different stages of the process. Of course, the actual implementation of this process is challenging and much more chaotic, but the diagram shown in **Figure 3** is a good representation of the philosophy behind the process.

3. PERSONAL PERCEPTION OF THE DESIGN PROCESS

Before joining IDEO, I had already been exposed to the diagrams discussed in the previous sections. Once I finished my internship and looked backed at my experience, I felt that none of these diagrams actually felt as fuzzy and complicated as my experience had been as a UC Berkeley student. I had been taught that the Design Process was iterative and non-linear, but I was not aware of how iterative it actually was.

Figure 4 illustrates my perception of the Design Process. It shows the Design Process as a large spiral made out of smaller spirals. The large spiral represents the general Design Process, where one starts off wide and narrow down to a final process. The smaller spiral represents the iteration cycles that are needed to advance through the process. As the process progresses, the iteration cycles get larger, characterizing the level of iteration needed for concept selection and advancement towards a final solution. These iteration cycles can be seen as sub-processes—brainstorming, prototyping, detailed design, testing—one needs to go through before concept selection.

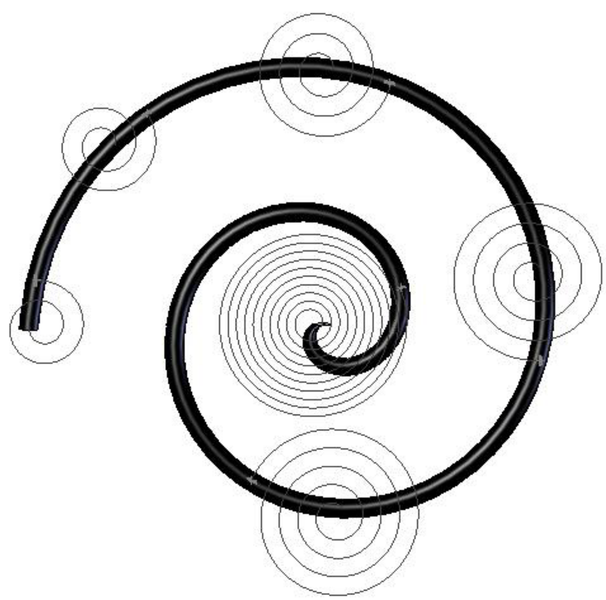


Figure 4. The Fractal Design Model
Lionel Mohri, November 2005

Figure 4 suggests that the Design Process is a sequence of sub-processes that address corresponding concept selection stages. As the overall process is going forward, those concept selection stages become more critical, hence more iteration is required to select the best concept(s). For instance, at the beginning of the process, lots of concepts are generated and concept selection can be conducted without getting into the smallest details of the design. However, as the final concept is getting closer to confirmation, designers need to take a step back and go through a large amount of iteration before claiming the final design is the optimal solution for a certain problem. Many students and even professional designers do not, or are not willing to, take this final step back and go through another round of iteration before reaching their final design. In fact, students usually bypass that last iteration altogether and directly prototype the final solution the team agrees on. Unfortunately, this last iteration phase is extremely important and is one of the main reasons why many products fail.

III STAGES OF THE DESIGN PROCESS: COMPARATIVE STUDY OF ACADEMIC THEORIES AND INDUSTRY PROCESS

The Design Process being extremely fuzzy and iterative, it is difficult to look at it as a whole and understand what needs to be done in each stage of the process. Therefore, it can be helpful to look at sub-disciplines rather than stages. This section looks at these sub-disciplines—Need Finding, Concept Generation, Concept selection, Prototyping, and Testing—and will compare the lessons learned from working in industry to theories taught in academia. **Figure 5** reminds us of the complexity of the process and that these sub-disciplines have more influence on each other than often assumed. Further references will be made to **Figure 5** as this paper will look in more details at each of these sub-disciplines.

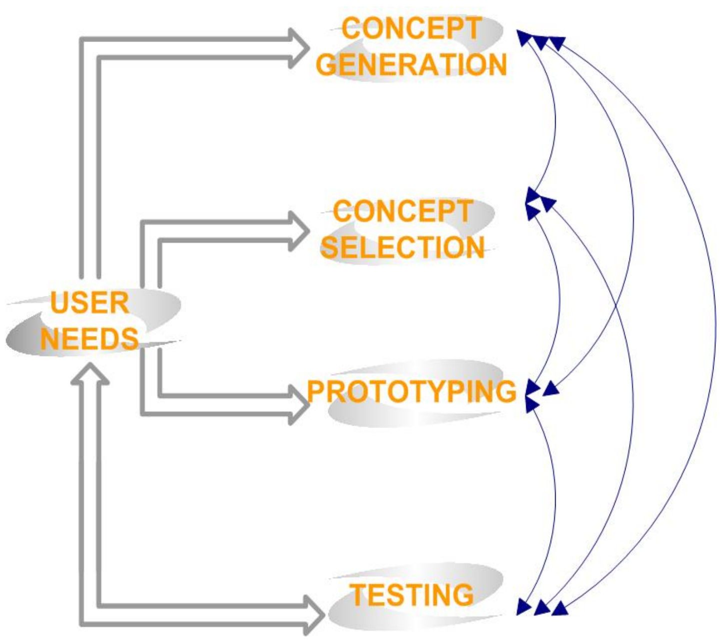


Figure 5. Relationships within the Design Process
Lionel Mohri, November 2005

Table 1 describes in more detail how the stages of the Design Process influence each other.

Users' needs influence

Other influence

	USERS' NEEDS	CONCEPT GENERATION	CONCEPT SELECTION	PROTOTYPING	TESTING
USERS' NEEDS					Observing users interact with prototypes leads to reassessing and refining users' needs
CONCEPT GENERATION	Brainstorm topics should be a direct results of need finding results		After selecting a few promising concepts, the team needs to go wide on each one of them to generate multiple design directions	Different sorts of prototypes require different brainstorming approachs (detail design)	Testing results start another concept generation cycle
CONCEPT SELECTION	The design process is user driven and not product driven. A good concept is one that satisfies users' needs	Once concepts are generated, the team needs to make a decision on which concepts to pursue (prototyping/testing)		Prototypes illustrate concepts and facilitate concept selection	User feedback from testing drives concept selection
PROTOTYPING	A good prototype is one that effectively communicates how a concept satisfies users' needs	Once concepts are generated, the team prototypes promising concepts to determine their design values	Promising concepts must be quickly prototyped		User feedback from testing lead to revisiting and adjusting prototypes
TESTING	A good test is designed to determine to what extent a concept satisfies users' needs	Concept Generation principals can be used to design an appropriate test	Selected concepts require specific testing conditions	The level of prototyping considerably affect the results of testing	

Table 1 Explanation of Relationships within the Design Process

A. NEED FINDING

As **Figure 5** shows, the Design Process is, or at least should be, entirely based on user needs. As previously mentioned, many students start concept generation without having a great understanding of users' needs; consequently, they use a few good ideas they generated during brainstorm sessions to drive the rest of the project and accordingly modify the user needs. Many design classes are actually conducted in this precise way. Unfortunately, some professors are responsible for pushing their students to come up with ideas in a short amount of time merely based on technological tools that are taught in the class. Academic design is often technology-based rather than need-driven, considerably constraining creativity and innovation. It is therefore crucial to expose students to some techniques they can use early in the process to gather information about the users they are targeting, and to get a good understanding of the problem they are solving for. During my project at IDEO, I did not work on the need finding element; nevertheless, our team was provided with user data that were gathered by another IDEO team, and we based our entire project on the user needs they had determined. References will be made to some of the techniques that had been used to gather this information and show how they were used in a design project for ME290P (Graduate Product Development class).

The most difficult element of need finding is to determine who will form the sample group that the design team will observe and interview. Obviously, a design team cannot interview a large number of users to statistically determine what the prominent needs are. It can be difficult to find trends if all users are randomly chosen and designers try to make sense out of random feedback. It is therefore crucial to cleverly find a small number of people (less than twenty if possible) who can quickly and efficiently share their knowledge and experience. This group should include a certain number of people who are either experts in the field of interest or users at the extreme of the target market spectrum—called lead users. Once data is collected from lead users, designers need to test the validity of these needs on "regular" users.

The choice of lead users can be an innovation opportunity in itself since different companies approach this exercise differently and might bypass some promising directions. Again, Design is about looking at a problem from a different perspective to find opportunities for innovation. This section will illustrate how lead users can be helpful in understanding user needs by looking at some examples from a project I worked on at UC Berkeley.

1. OBSERVATION & INTERVIEWS

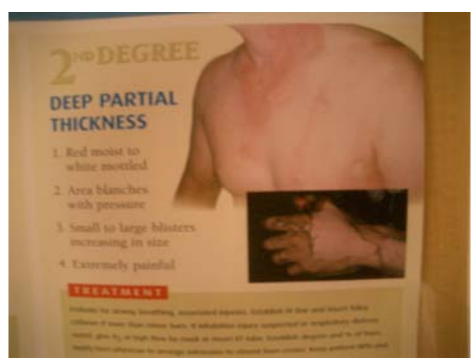
Observation has become an anthropological exercise that engineers are increasingly required to practice. It is extremely difficult to understand human behavior when only looking at data and statistical analyses. Many users are not aware of their needs and if designers only rely on interviewees to tell them what their needs are, there would not be much room left for innovation. Although it is important to hear what are some of the problems users express, it is essential to observe their interaction with their environment, and the product of interest. Indeed, most users are not always aware of what their primary needs are. For instance, I spent some time observing preschool kids for a playground project I was assigned to, and it was really interesting to see how much one can actually learn just by observing and not asking any questions. After an hour of observation, I started noticing a few principal trends on how kids play and interact with their environment and with each other. This information can never be fully obtained from interviewing every single one of them. However, observation is only efficient and powerful if observers are as objective as possible and do not choose to only record pieces of information that would reinforce their preconceived ideas. Although it is difficult, and probably impossible, to be completely objective, there are techniques that can be used to minimize introducing bias in the data.

It is always a good idea to conduct observations with somebody else from the team. If each person thoroughly records the events they observe, even the seemingly most insignificant ones, the team can share their findings afterwards and seek general trends that can be translated into user needs. Another good observation tool is to videotape the users, and once the team gets together to share information, everybody can take a look back at the occurrence on video and collectively understand the user's behavior. Finally, if the design team does not have a video camera, they can document their observation with a simple camera. Although pictures can be pretty subjective, they are also really powerful in demonstrating specific events. **Picture 1** was taken while observing people with physical limitations interacting with their oven system. In this picture, the lady was talking about her needs while demonstrating how she interacted with the oven. As the picture shows, she had to use the oven door as a support to bend forward; fortunately, the oven was cold and that's probably why she was using it as a support point. Nevertheless, this picture showed us that support was a major need and that there existed a risk of unconsciously using a hot oven door for support if the user was distracted enough.

Picture 1. Observation of Woman cooking with Disability

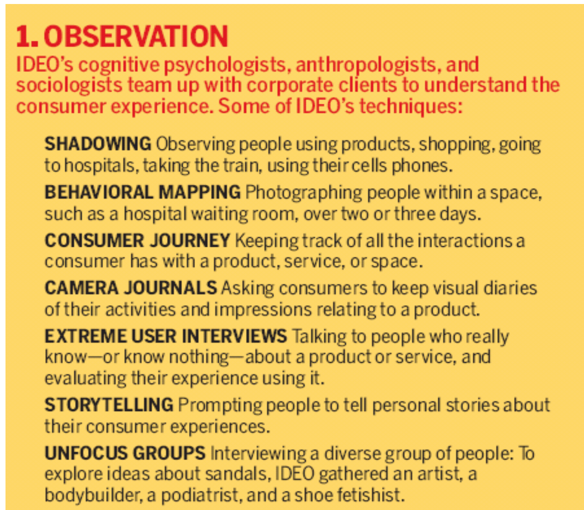
Although observation is a great tool to gather and understand users' needs, it is not enough to entirely grasp the problem. Interviews allow designers to dig into the user's mind and get explanations for some of the behavior they observed. Interviewing users is an art in itself, and this paper will not attempt to describe the details of the techniques that are used during interviews. From experience, the questions need to be seemingly open-ended so that interviewees feel comfortable sharing their experience, even things they might think are useless, but are in fact the things the interviewer is trying to understand. Good interviewers know how to ask open-ended questions first and as the conversation progresses, they redirect it with follow-up questions to make sure the interview is not losing value.

As for observations, interviewing lead users is extremely useful in approaching the problem from a new perspective. For instance, our team interviewed the director of the Burn Unit at a major hospital to get a better understanding of safety issues in kitchens. **Picture 2** shows a poster on the hospital wall, describing second degree burns that can occur while reaching for the back burners. Knowing the consequences of the problem can lead to generating interesting and innovative concepts.



Picture 2. Burn Unit Educational Poster

Figure 6 summarizes some of the methods that IDEO uses to efficiently understand users' needs. As **Figure 6** illustrates, IDEO utilizes a diverse array of methodologies to recreate the consumer experience. This diversity allows them to approach the user experience from multiple angles to get a better and more complete understanding of the users' needs.



1. OBSERVATION

IDEO's cognitive psychologists, anthropologists, and sociologists team up with corporate clients to understand the consumer experience. Some of IDEO's techniques:

SHADOWING Observing people using products, shopping, going to hospitals, taking the train, using their cells phones.

BEHAVIORAL MAPPING Photographing people within a space, such as a hospital waiting room, over two or three days.

CONSUMER JOURNEY Keeping track of all the interactions a consumer has with a product, service, or space.

CAMERA JOURNALS Asking consumers to keep visual diaries of their activities and impressions relating to a product.

EXTREME USER INTERVIEWS Talking to people who really know—or know nothing—about a product or service, and evaluating their experience using it.

STORYTELLING Prompting people to tell personal stories about their consumer experiences.

UNFOCUS GROUPS Interviewing a diverse group of people: To explore ideas about sandals, IDEO gathered an artist, a bodybuilder, a podiatrist, and a shoe fetishist.

Figure 6. IDEO's Need Finding Techniques
Business Week, May 2004

2. ORGANIZING AND INTERPRETING USERS' NEEDS

After gathering a considerable amount of information in such a short amount of time, one needs to efficiently organize the collected data so that the rest of the team can be on the same page and start translating the interview results into users' needs. Since each interview can be up to an hour and a half long, the interviewer has to objectively determine what the most important pieces of information are. **Picture 3** shows a technique of how data can be organized to efficiently communicate the interviewee's message. Users' needs are organized on big pieces of foam board and they are displayed around the project space. Multi-colored Post-its are great, and inexpensive tools that all design teams should use to organize their findings during the process. Important quotes are put down on individual Post-its and are organized into main categories. Visual cues bring data and ideas to life, helping with creative thinking and user-based design. For instance, in **Picture 3**, a photograph of the interviewee and a description of her background are included on the top left corner. These sorts of details allow the design team to easily refer back to a certain interview and remember who they are designing for. Keeping the color of the Post-its consistent across all interviewees makes it easier for the design team to consolidate the information and interpret the data into specific user needs.

Picture 3. Organization of Users' Needs

A good users' needs organization facilitates the difficult task of interpreting and understanding users' needs, which ultimately lay out the foundation of the design process. After organizing the users' interviews and observations data, the design team should start noticing a pattern in the results and get a better understanding of the major users' needs. The aptitude to translate interview and observation results into users' needs is a matter of skills, but also a matter of experience. Students, who have less experience in product development, might consider using a table to methodically determine the main users' needs (see **Table 2**). Although many designers do not have enough time to fill-out a table such as **Table 2**, it might be beneficial for students to use it the first few times as an exercise to grasp the philosophy behind this discipline.

Customer:	Bill Esposito	**Interviewer(s):**	Jonathan and Lisa
Address:	100 Memorial Drive Cambridge, MA 02139	**Date:**	19 December 2002
Telephone:	617-864-1274	**Currently uses:**	Craftsman Model A3
Willing to do follow-up?	Yes	**Type of user:**	Building maintenance

Question/Prompt	Customer Statement	Interpreted Need
Typical uses	I need to drive screws fast, faster than by hand.	The SD drives screws faster than by hand.
	I sometimes do duct work; use sheet metal screws.	The SD drives sheet metal screws into metal duct work.
	A lot of electrical; switch covers, outlets, fans, kitchen appliances.	The SD can be used for screws on electrical devices.
Likes—current tool	I like the pistol grip; it feels the best.	The SD is comfortable to grip.
	I like the magnetized tip.	The SD tip retains the screw before it is driven.
Dislikes—current tool	I don't like it when the tip slips off the screw.	The SD tip remains aligned with the screw head without slipping.
	I would like to be able to lock it so I can use it with a dead battery.	The user can apply torque manually to the SD to drive a screw. (!)
	Can't drive screws into hard wood.	The SD can drive screws into hard wood.
	Sometimes I strip tough screws.	The SD does not strip screw heads.
Suggested improvements	An attachment to allow me to reach down skinny holes.	The SD can access screws at the end of deep, narrow holes.
	A point so I can scrape paint off of screws.	The SD allows the user to work with screws that have been painted over.
	Would be nice if it could punch a pilot hole.	The SD can be used to create a pilot hole. (!)

EXHIBIT 4-6 Customer data template filled in with sample customer statements and interpreted needs. SD is an abbreviation for screwdriver. (Note that this template represents a partial list from a single interview. A typical interview session may elicit more than 50 customer statements and interpreted needs.)

Table 2 Interpreting Users' needs
Product Design and Development, Ulrich and Eppinger, 3rd Edition, page 62

A. CONCEPT GENERATION

PEOPLE DEPENDENT

Concept generation is the exercise that connects users' needs to the rest of the product development process. It is the oxygen for innovation because it is dependent on people. In fact, two brainstorm sessions could never result in identical outcomes. Of course, many ideas will overlap, but because of statistical realities, two groups of people will probably not generate identical ideas concerning the same topic. Therefore, there is a great amount of value placed on the individuals who get together for a short amount of time to generate as many concepts as possible. Concept generation is a group effort since the team uses their dynamics to build on each other's ideas to approach a specific problem. It is crucial to emphasize the importance of the individual in this process. To promote innovation, it is crucial to have diversity—professional, cultural, personal, gender, social, etc.—within groups to increase the number of concept combinations possible. When people from all walks of life come together and try to solve a specific problem, innovation is more likely to succeed than otherwise.

From experience, as a student and a graduate student instructor for a mechatronics design course, I can strongly affirm that most students do not know how to properly conduct brainstorming sessions. Oftentimes, brainstorming sessions are controlled by extravert students who generate ideas without giving others a chance to participate in this group effort, hence reducing the opportunity for innovation. This kind of concept generation can only lead to one-dimensional results that do not reflect a collective effort. Being quite introvert myself, I always felt uncomfortable sharing my ideas without spending some time trying to make sure they were feasible; however, extravert people tend to take over brainstorms and feel comfortable defending their ideas. Unfortunately, they also tend to be extremely judgmental when it comes to other people's ideas. I have observed this behavior consistently as a student; many good ideas are instantaneously abandoned because of judgmental people who do not feel comfortable being away from their comfort zone. These ideas are usually at the root of innovation.

RULES OF BRAINSTORMING

Given the constant power struggle between extraverts and introverts, there ought to be brainstorming rules that all participants respect, creating an environment where all can collaborate towards a common goal. The more people are willing to apply themselves to these rules, the more efficient the concept generation will be. IDEO has a set of rules that promote a safe environment for everyone to be part of the concept generation exercise (see **Figure 7**). The individual who is running the

2. BRAINSTORMING

An intense, idea-generating session analyzing data gathered by observing people. Each lasts no more than an hour. Rules of brainstorming are strict and are stenciled on the walls:

DEFER JUDGMENT Don't dismiss any ideas.

BUILD ON THE IDEAS OF OTHERS No "buts," only "ands."

ENCOURAGE WILD IDEAS Embrace the most out-of-the-box notions because they can be the key to solutions.

GO FOR QUANTITY Aim for as many new ideas as possible. In a good session, up to 100 ideas are generated in 60 minutes.

BE VISUAL Use yellow, red, and blue markers to write on big 30-inch by 25-inch Post-its that are put on a wall.

STAY FOCUSED ON THE TOPIC Always keep the discussion on target.

ONE CONVERSATION AT A TIME No interrupting, no dismissing, no disrespect, no rudeness.

Figure 7. IDEO's Brainstorming Rules
Business Week, May 2004

brainstorming session, i.e. the person who is organizing the ideas on the board, should be seen as a debate mediator who enforces these rules and makes sure that participants are behaving within the boundaries of the rules.

Although many of these rules are intuitive, it is extremely difficult conditioning people to respect them. Therefore, this preparation should be acquired early through the undergraduate years so that students feel comfortable taking risks without facing embarrassment and judgment. School ought to be a place where wild ideas and risk taking are encouraged, and not frowned upon. Unfortunately, peer judgment is not the only barrier to concept generation; many professors are responsible for negatively responding to wild ideas. When students generate wild ideas, some professors are quick to dismiss the whole concept, rather than trying to build on them.

Concept generation sessions can be improved if teams have access to brainstorm-friendly infrastructures; however, no amount of money spent on that infrastructure can replace the influence faculty members have on their students. In fact, faculty should be exposed to the design culture so they can in turn promote it amongst their students.

A CREATIVE ENVIRONMENT

From experience, I have found brainstorming sessions to be more productive if the environment is relaxed and fun. A great way of relaxing the environment is to make the exercise a fun event, even a bonding experience. IDEO's brainstorms usually include lots of food and drinks. The brainstorm is still a serious and focused exercise, but by taking the pressure off the team, it will be easier to get the exercise started, and more importantly to engage everybody in the concept generation phase. It is a good idea to keep brainstorms not too long, up to an hour is good, so that the energy does not suddenly fall down. Ideally, you want an intense session where ideas flow quickly before losing the synergy that was generated. Food and drinks also provide the energy needed to revitalize the participants when fatigue starts taking over. At our ME290P brainstorm sessions, our team agreed to bring food and drinks to our meetings, and it was amazing to see how much difference it made: everybody was more relaxed, and consequently more willing to take risks. As a result of this fun atmosphere, we were able to generate approximately three hundred concepts in less than four hours of brainstorming.

Another important factor in efficient concept generation is having easy access to office supply, such as, foam board, Post-its, multicolored markers, white boards, and anything else that helps making the exercise visual. For one of the design projects at UC Berkeley, we were lucky enough to have access to BiD (Berkeley Institute of Design) facilities where we had a wide range of office supply selection. **Picture 4** illustrates the environment where we conducted our concept generation sessions. As **Picture 4** shows, we made good use of the space by displaying the results of our brainstorming sessions and our users' interviews. Unfortunately, not many students have access to similar project spaces, and they usually conduct

Picture 4. Brainstorming Results

brainstorming sessions in coffee shops or in the computer lab, considerably limiting the range of concepts that can be generated.

DIFFERENT TYPES OF BRAINSTORMING

Working at IDEO, I got to participate in different sorts of brainstorming sessions—multi-disciplinary, engineering, and social—all were following the same philosophy, but were quite different in process.

A multi-disciplinary brainstorming is one where people from different backgrounds gather for a certain amount of time and brainstorm around concepts to satisfy one, or several users' needs. This sort of concept generation is usually performed early in a project where designers try to go wide and consider as many concepts as possible. The level of details of the generated concepts can be rather low since the purpose of this exercise is to generate as many ideas as possible in a relatively short amount of time. Participants are asked to sketch each concept on a Post-it to communicate the ideas across to the rest of the team, but these sketches do not need to include technical details as long as they clearly demonstrate the main thought behind the concept.

Engineering-based brainstorming sessions are quite different since the participants usually come from technical backgrounds. The purpose of such a brainstorm is to find a specific solution to a specific technical problem. For instance, I've had many brainstorms where we were trying to design a customized fastener that would be used for a product. In these cases, the level of detail involved in sketching is critical since the design revolves around a really specific area of interest. Furthermore, many of the generated concepts might only differ by minor details, and that is exactly why participants have to make an extra effort and sketch at a higher fidelity level. Oftentimes, engineers need to invite other engineers to take advantage of their expertise in a certain field. Thus, the organizing engineers have to make sure to get as much as possible from their colleagues in that short amount of time. To do so, they can question the participants during the brainstorm whenever they are not completely sure of the intended meaning of a concept. They can also enforce detailed sketching so that they can refer to them in the future if needed. From experience, I have found these sessions to be extremely difficult at first since I was not able to quickly generate concepts at such a high detail level; of course, this process becomes easier as you gain a wider range of design experience. Finally, brainstorming techniques are not only used to generate ideas for commercial products and services; increasingly, design process principles, and especially brainstorming techniques, are applied to solving social issues. For instance, I attended a brainstorm session at IDEO where we were looking at different ways of bringing technical education to middle school kids who come from financially challenged backgrounds. The same brainstorming principals can be utilized to find innovative solutions to social problems. Consequently, the Design Culture does not only apply to designers, but also everybody else who is trying to find an innovative solution to a specific problem. I have found these brainstorming principals to be useful in many facets of everyday life.

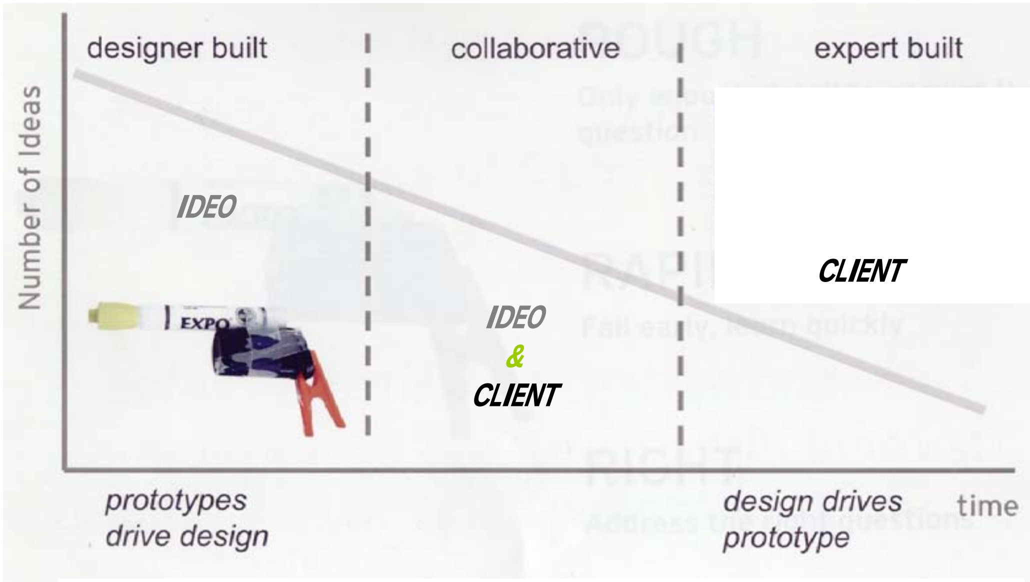
After a brainstorming session, design teams usually transition into a concept selection mode where they decide which concepts they will pursue for prototyping and testing. However, I would like to discuss the bigger picture behind concept selection after discussing prototyping and testing, a way that might be quite different from conventional academic models. Concept Selection is the most difficult stage of the design process and it is also the most difficult one to teach. I believe it can be made less difficult if we emphasize that prototyping and testing are ultimately driving the concept selection process.

B. PROTOTYPING

Prototyping is the stage of the Design Process where ideas are brought to life, at least are given a chance. Prototyping is the language that designers use to communicate their ideas in an effective method. Like any other language, prototyping has its own nuances, and it is therefore crucial to understand how different prototyping techniques address different design issues through the process. Traditionally, prototyping is performed late into the process when a final concept selection is expected; however, designers are increasingly integrating prototyping into different stages of the design process, making early prototyping a powerful concept selection tool.

THE DIFFERENT LEVELS OF PROTOTYPING

Different sorts of prototypes can be used to communicate different concepts, and it is important to grasp the level of prototyping that is required to correctly and efficiently convey the intended message. Having worked at IDEO, I have realized how powerful prototypes can be if used properly; conversely, they can also be extremely detrimental if used without a good understanding of the message you are trying to convey. Graph 3 summarizes the evolution of prototyping through the Design Process. As a general rule, IDEO (and others) relies on prototyping early to drive the design, and as concepts are refined, the design starts driving the prototypes. Traditionally, companies merely rely on design to drive prototypes, which implies that many concepts were selected without using prototypes. However, when IDEO and their clients collaborate on a project, they also collaborate and share the prototyping task. Both organizations use their prototyping expertise to complete each other, making prototyping a major factor in the design process. As mentioned earlier in the paper, IDEO sees value in learning from failures and their prototyping philosophy is absolutely at the root of their ***"fail early, to succeed early"*** approach of Design.



Graph 3. IDEO's Prototyping Philosophy
All rights reserved to IDEO

IDEO is known for integrating prototyping through all stages of its process. When collaborating with a certain client, IDEO uses different levels of prototyping to advance the project and reach important milestones (as shown in **Graph 3**). Conventionally, prototypes are categorized as:

- Rapid Prototyping vs. Prototyping Rapidly
- "Works Like" vs. "Looks Like"
- Low Fidelity vs. High Fidelity

Although these terms accurately describe the level of the prototypes, they do not actually suggest when and how they should be applied. In industry, many of these prototype forms are cross-linked and it becomes difficult to associate them to general situations. The following paragraphs will represent a survey of prototyping examples I have used throughout the process I went through.

<u>Designer Built:</u>

In the first phase, IDEO is usually asked to look at an identified innovative opportunity and generate as many ideas as possible to determine the best direction(s) to pursue by the end of the phase. During this phase, IDEO heavily relies on designer built, which indicates the overall level of prototyping that is expected early in the process. Generally, by the end of the phase, the client expects several prototypes of concept designs (engineering, as well as industrial) from which one would be chosen for further implementation (see **Figure 8**). **Figure 8** illustrates the first phase our team went through at IDEO. By the end of the phase, four main mechanical engineering (ME) designs were considered for a specific concept (Concept B), as well as three main industrial design (ID) directions that could be associated to any of the four physical prototypes.

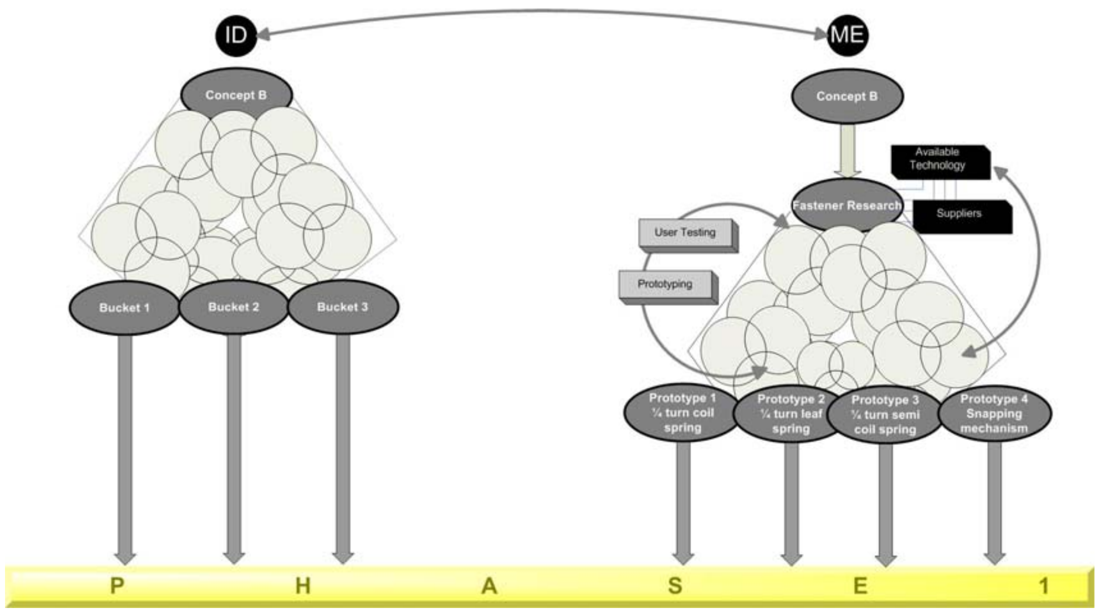


Figure 8. Example of Phase I Process
Lionel Mohri, September 2005

The level of prototyping for this phase is usually a "works like" rapid prototype, i.e. it is functional, but not robust enough for testing, and it has the general look of the product, without the high fidelity. The purpose of these prototypes is to demonstrate how the concept satisfies the main issues of the design.

Figure 8 largely illustrates a typical design process, where an innovation opportunity is identified (from users' needs), and designers start going wide before narrowing down to a few concepts that are prototyped in parallel. It is important to notice that the final prototypes were not the results of a single cycle, but of much iteration. What **Figure 8** does not show is the level of prototyping that was used to get to the final four prototypes. As previously discussed, concept generation is a stage where designers go as wide as they can to find the best solution to a specific need. However, lots of ideas are generated during brainstorming sessions (around one hundred per hour at IDEO), and it becomes extremely difficult to have everybody on the team to be on the same page. Since some of the generated ideas are wild and hard to illustrate to a multi-disciplinary team, prototyping becomes an important communication tool.

These prototypes are rough and they only address the right questions in a really short time. IDEO calls it the three R's of prototyping—rough, rapid, and right. (see **Figure 9a** for an example of a prototype that was used while brainstorming around a surgical tool). As **Figure 9a** shows, this prototype is a gun-shaped tool made out of office supply materials. The prototype was built in the middle of a brainstorm session to better grasp the feeling of performing surgery with a gun-shaped tool. To emphasize the importance of this sort of prototyping, this design was actually the one that was pursued for the final commercial version of the project. Had the team not built this simple prototype, the project might have gone in another direction that might have not addressed the users' needs properly.

Figure 9a. Surgical tool prototype built during Concept Generation

This sort of prototyping is simple, cheap, fast, and most importantly it could be easily implemented at the university level, i.e. the Mechanical Engineering department does not need to spend lots of money on building new prototyping infrastructures. As part of my teaching experience for a mechatronics course, I had the opportunity to observe how undergraduate students approached prototyping. The students had little time to come up with an idea and a corresponding design they would subsequently build. During this short period of time, most groups designed mechanisms on solid modeling software, without knowing whether or not it would work. Instructors were usually asked to check their designs and tell them whether or not their designs would work. Out of twenty-two groups, only one came to us with an early prototype to convince us how their mechanism would actually function. They used a coffee cup lid to demonstrate the functionality of their mechanism. It was pleasantly surprising to see that a group was willing to take such a risk to convince their instructors, without fearing embarrassment and judgment. Before investing in rapid prototyping infrastructures, faculty members and students need to be exposed to these techniques so that they are promoted through the department as a design tool.

Not all early prototypes have to be as rough as the one in **Figure 9s**. In fact, different levels of prototyping such as, machining parts, using FDM (Fusion Deposition Modeling) models or laser cutting, can be helpful in preliminary phases as well. Unfortunately, rapid prototyping machines (FDM, Laser cutting) have great barriers to entry in the Mechanical Engineering Department at UC Berkeley, especially to undergraduate students. Therefore, the machine shop becomes the main resource for students to prototype. Again, as part of my teaching experience, I have observed the dynamics surrounding the machine shop. The machine shop is usually empty for the first half of the semester, the time where students are concentrating on generating ideas for their designs. As expected, the second half of the semester gets much busier, especially during the last four weeks. Students should start building early prototypes out of scrap material available in the machine shop to help them refine their final design. Unfortunately, students have been conditioned to prototype only once, and they feel the pressure to get it right on their first attempt.

Although this "MacGyver" (rapidly building prototypes out of available material) approach should be encouraged in design, one needs to be extremely careful in using it. Such prototypes can have different impacts in different circumstances. The level of "roughness" of the prototype depends on who it will be exposed to. A prototype can be extremely rough if it is for internal purposes. For a superior or a client however, the prototyping philosophy should be comprehensible. If not, promising concepts can be dismissed quickly without even being given a chance.

<u>Collaborative Built:</u>

Collaborative built is at the heart of successful (and unsuccessful) collaborations between two (or more) organizations. In the case of IDEO, a company hires them to collaborate on a design project; consequently, both companies are involved and dedicated to the success of this project. In this phase, there is a greater dependency between both sides, and a feedback loop is necessary to advance the course of the project. IDEO generates ideas at a designer built level, and show higher fidelity prototypes to the client to get feedback on the promising directions they have found. The client then explores the feasibility (manufacturing, durability, cost, branding etc.) of the concept and accordingly points out the pros and cons of the concept and often makes changes that reflect their corporate philosophy. It is then IDEO's turn to reiterate on the findings of the previous concept and make the necessary improvements, while keeping the users' needs as the number one driver. This cycle goes on for the entire phase until an optimal solution, which addresses users' needs and that is feasible within the client's capabilities, is reached. Throughout this phase, the main channel of communication is prototyping and it is therefore essential for both parties to recognize each other's prototyping capabilities and philosophies. This collaborative phase, indeed, requires collaboration, and both companies need to complete each other, rather than compete with each other. They have to mutually take advantage of their prototyping expertise to efficiently advance the project.

<u>Expert Built:</u>

By the end of the second phase, the client and the consultants have hopefully reached an optimal solution that the client can further implement for production. In this phase, the design of the concept is refined for manufacturing purposes. The client will start making works-like, looks-like prototypes to test for durability, usability, and to convince the rest of the company to take this product into production, which is a great task in itself. Therefore, expert built prototypes will be indispensable in trying to convince other stakeholders to support the implementation of this new product. **Figure 9b** shows the final design of the product described in **figure 9a.**

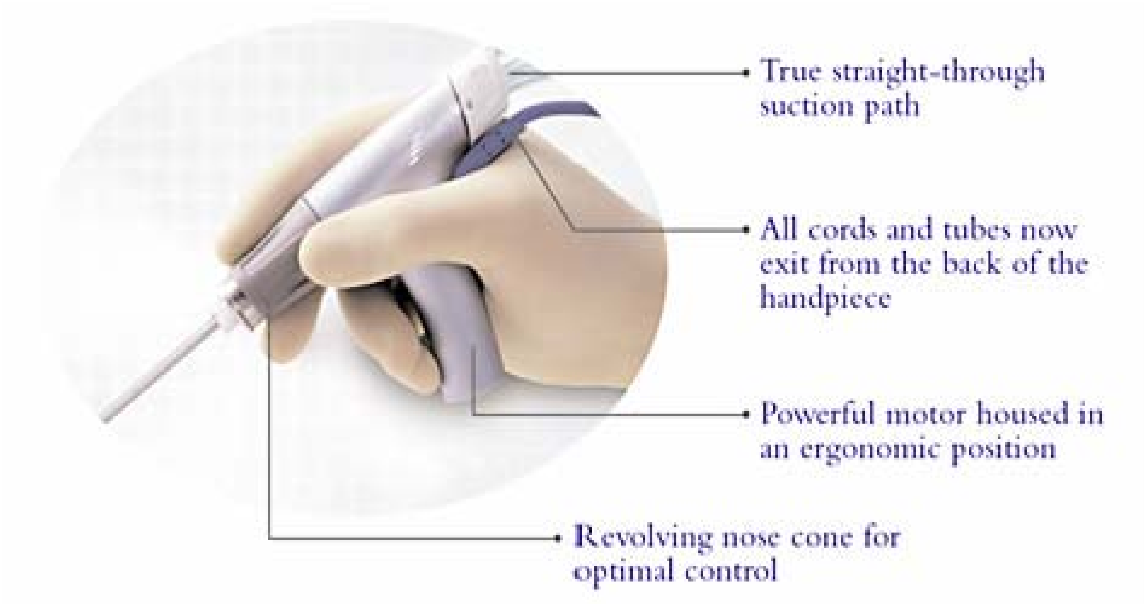
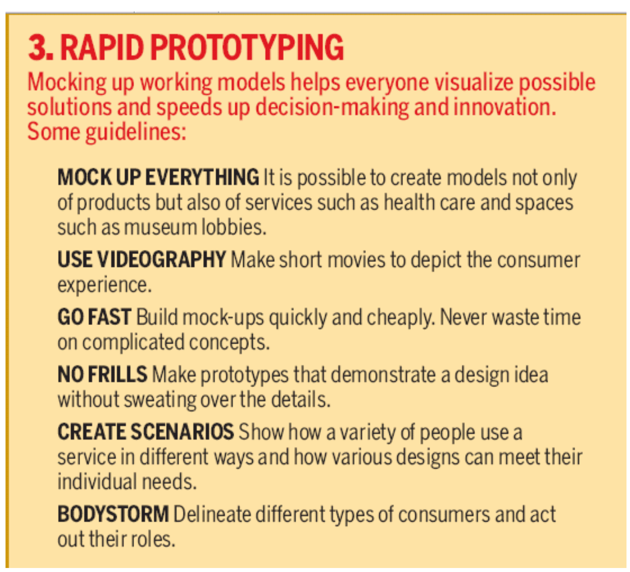


Figure 9b. Final Surgery Tool Design

PROTOTYPING AS A CONCEPT SELECTION TOOL

Prototyping brings ideas to life and communicate them to teammates, clients, and other stakeholders. If used properly and timely, they can be a great tool to convince or dissuade others of pursuing a certain concept. Oftentimes, concept selection is undergone without having a great understanding of the generated concepts. Prototyping, whether rough or more elaborate, can help designers reinforce their ideas and communicate them ideas in an influential way. It is always difficult choosing between concepts, and usually it is a good idea to select a few of them and prototype them to make a more educated decision. **Figure 10** shows some of the prototyping techniques that IDEO uses early in the process to fully understand the concepts before proceeding to concept selection.



3. RAPID PROTOTYPING

Mocking up working models helps everyone visualize possible solutions and speeds up decision-making and innovation. Some guidelines:

MOCK UP EVERYTHING It is possible to create models not only of products but also of services such as health care and spaces such as museum lobbies.

USE VIDEOGRAPHY Make short movies to depict the consumer experience.

GO FAST Build mock-ups quickly and cheaply. Never waste time on complicated concepts.

NO FRILLS Make prototypes that demonstrate a design idea without sweating over the details.

CREATE SCENARIOS Show how a variety of people use a service in different ways and how various designs can meet their individual needs.

BODYSTORM Delineate different types of consumers and act out their roles.

Figure 10 IDEO's Rapid Prototyping Techniques
Business Week, May 2004

During my internship, I was working on a project where IDEO and a client collaborated on creating an innovative product. The main channel of communication between both organizations during this process was prototyping (whether physical or digital). Oftentimes, both companies did not see eye to eye on different aspects of the concepts. The client usually altered the concept to match their own preferences, but we, consultants, did not always feel this change correctly addressed the problems we had initially set to solve. It was then our responsibility to convince the client to reconsider unnecessary changes. Prototyping turned out to be a powerful convincing tool when used properly and timely.

Although the fidelity of the prototype matters when communicating with clients, simple and rough prototypes can have the same powerful effect if implemented cleverly. For example, the client I was working with was regularly involved in our brainstorming sessions. During one of our sessions where we were brainstorming around fastener-tool systems that would convey simplicity, the client suggested having a fastener that made a ratcheting sound coupled with a ratchet-style wrench to minimize wrist rotation. The client was excited about this idea; whereas, we felt it was not conveying the message of simplicity we were seeking. Because of the two auditory feedbacks, we thought that minimizing the number of wrist rotation was not worth sacrificing the overall simplicity of the product. I made a quick prototype to show the effect of having two auditory feedbacks when tightening the fastener. This prototype was really basic: to simulate the ratcheting sound of the fastener, I took the ratcheting mechanism from a kitchen timer and glued it around a normal screw. We made a video to show the different fastener-tool systems, and when the client watched it, they decided to abandon the double ratchet sound feedback system. Indeed, a prototype is worth a thousand words!

D. TESTING

Testing is an important discipline of the Design Process and designers need to know how and when to use it. Many engineers look at testing in a technical way, where durability is usually the main factor; however, testing should be used to also get user feedback on generated concepts and reassess users' needs. If used properly and timely, testing can be a great concept selection tool.

USER TESTING

User testing introduces iteration in the process and allows designers to reassess users' needs. After prototyping a few promising directions, it is recommended to test them with a group of users to get feedback. However, the designers need to grasp what they are testing. On the engineering level, I have learned that it is beneficial to have several different designs prototyped to get more constructive feedback. Many designers show a concept to the user and ask them if they like it. This method leads to ineffective feedback and does not bring anything new to the project. Innovative products are often negatively received when first taken to the users. In the book "Blink", Malcom Gladwell suggests that "it is the new and different that is always most vulnerable to market research" (Blink, p176). Market research has strong shortcomings when it comes to innovative ideas. It is a way of backing decisions with mathematical data without actually having a clear understanding of the users' response to a new concept. For instance, when the Toyota Matrix first came on the market; most people felt it was hideous; this same car is now described as cool and trendy. If Toyota had made the mistake of going to users and asking them if they liked this car, the Matrix would have never made the production line. Therefore, words such as hideous may actually mean that people initially react negatively to different and innovative ideas. This behavior goes back to human nature and how people become judgmental when they feel uncomfortable, out of their safe zone.

Many designers conduct their user testing by putting together a survey. On a personal note, I do not believe surveys serve a positive role in the design process. Surveys are popular because they are time-efficient and result in enough data points for statistical analysis. Unfortunately, they only offer a limited spectrum of feedback and force the user to choose between a few alternatives. Furthermore, designers do not get to observe these users interacting with a concept; thus, making it extremely difficult to comprehend the roots of their feedback. Face-to-face user testing is more time-consuming, but it offers many advantages that surveys do not comprise. Observing the user interaction with the prototypes is an exercise similar to the one conducted during the need finding stage. The same observation and interviewing rules apply. The interviewer asks open-ended questions and tries to dig into the user's responses to better grasp the given feedback. The interviewer should be as objective as possible, and not promote positive feedback for his/her favorite concept. One way of assuring objectivity is documenting the interview with a video camera. Documentation will come in handy when trying to compile the results and present them to the stakeholders.

As part of my job at IDEO, I conducted user testing interviews with a sample size of fifteen users, which is large enough to identify a trend. I learned the importance of user testing because it led to reassessing the initial user needs we had gathered. That does not imply that the users' needs we had initially identified were inaccurate, it means that innovation presents many unknowns and that you will not be able to identify all users' needs unless a certain concept is prototyped. We were trying to design a product that would only have one point of interaction for the user to adjust the product. Competitive products on the market were using several screws and users felt the interaction was too difficult. We were able to design a new configuration where only one fastener was needed. For the user testing, we prototyped two different versions—one with a ¼ turn fastener, and one with a regular screw that required five complete turns—and a competitive product was also given to the users. We asked them to adjust each one of them and comment on their experience. From need finding results, we were expecting users to embrace the ¼ turn fastener since it required the least amount of effort. **Figure 11** illustrates the surprising results we gathered from the testing.

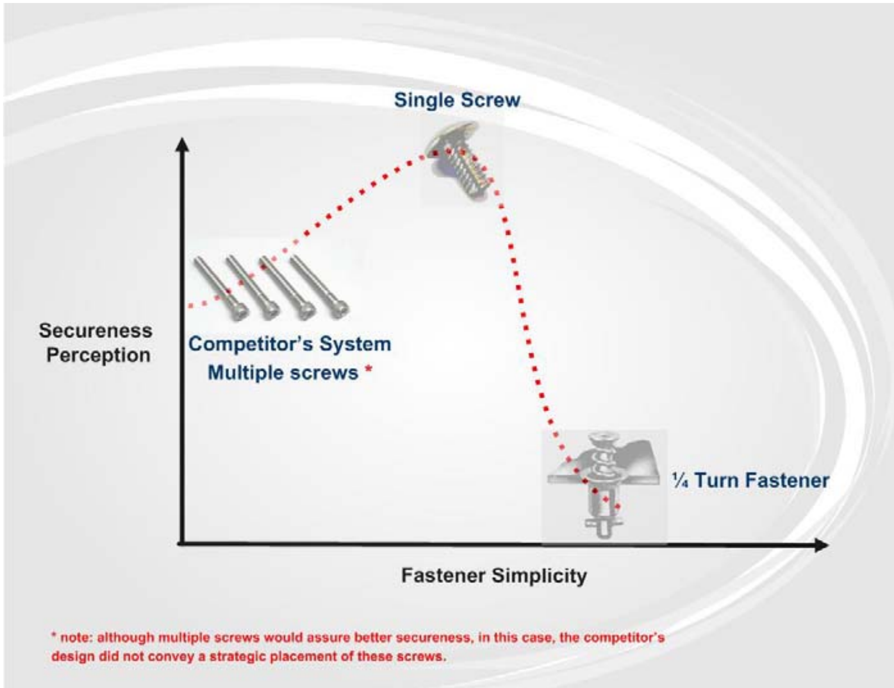


Figure 11. Results of User Testing
Lionel Mohri, October 2005

Figure 11 illustrates how the users' secureness varies with the fastener's ease of use. The competitive product was using several screws and it was considered to exhibit the most difficult user interaction; however, the ¼ turn was considered to be the easiest to use. In between, a single screw system was much easier to use than the competitive product, while being a little bit more time consuming than the ¼ turn solution. The testing results surprisingly revealed that although users liked the ease of use of the ¼ turn, they did not feel confident that the product was secured enough after so little effort. Unexpectedly, although the competitive product comprised several fasteners, many users felt that these were not positioned strategically to withhold normal use of the product and that there was a risk of failure. The single-screw system was extremely popular. Users felt that a single screw was much better than several, but did not mind applying five complete rotations to adjust the product. In fact, they felt that these five turns were justified and that as the user they were doing something positive towards securing the product. This example shows how designers may need to reassess users' needs after prototyping a few concepts. The initial need finding exercise had shown us that users wanted to adjust the product by applying the least amount of effort. Indeed, we designed a system that required minimal effort, and that caused users to realize that they actually wanted and needed to put more effort than they originally thought.

TESTING AS A CONCEPT SELECTION TOOL

User testing is often left to the last minute, making prior concept selections solely based on other factors such as initially gathered users' needs, prototyping, and other concept selection tools. It is difficult to grasp the meaning of all these tools if the concepts in contention are not tested by the users who inspired them. I believe that user testing performed regularly throughout the project injects iteration in the project since it forces designers to reassess users' needs and make improvements to generated concepts. Of course, designers cannot request user testing every time they build new prototypes; however, they should make sure to get customer feedback at important concept selection crossroads that could affect the rest of the project. It is therefore imperative to test users with multiple prototypes to get a benchmark and build on the lessons learned.

As previously stated, user testing interviews and results have to be conducted objectively. Videotaping is a great way of capturing the essence of the results, which can be compiled into a short movie to quickly and efficiently convey the results to stakeholders. In fact, most stakeholders will not have time to examine every single twenty-minute interview designers have conducted during user testing. This movie will be a sort of summary of the main points gathered during interviews. One needs to be greatly careful when compiling such a movie; it is extremely easy to let your subconscious take over and enter bias into the results to reinforce your position on certain concepts. User Testing can be a powerful tool during concept selection, but should be used with the highest level of objectivity.

E. CONCEPT SELECTION

Concept selection is certainly the most difficult exercise in the process assuming the previous stages were properly implemented. As **Figure 4** illustrated, the Design Process is the succession of concept selection stages that require lots of iteration to adequately move the project forward. Academic models attempt to clarify the exercise by introducing a systematic methodology for designers to come to a conclusion. Through experience, a good concept selection is done in a really fuzzy manner that cannot be described academically; it is often the result of experience. As previously discussed, prototyping and user testing are important tools that can facilitate concept selection, but other factors need to be taken into account.

ACADEMIC TOOLS

In academia, Pugh's concept selection matrix is often taught as an important tool for teams to come to a collective decision on which concepts to pursue. **Figure 12** shows a typical design process diagram showing how and when concept selection tools should be used to narrow down the generated ideas. This diagram clearly shows the iterative aspect of the process, but it ignores the importance of early prototyping and user testing to facilitate concept selection.

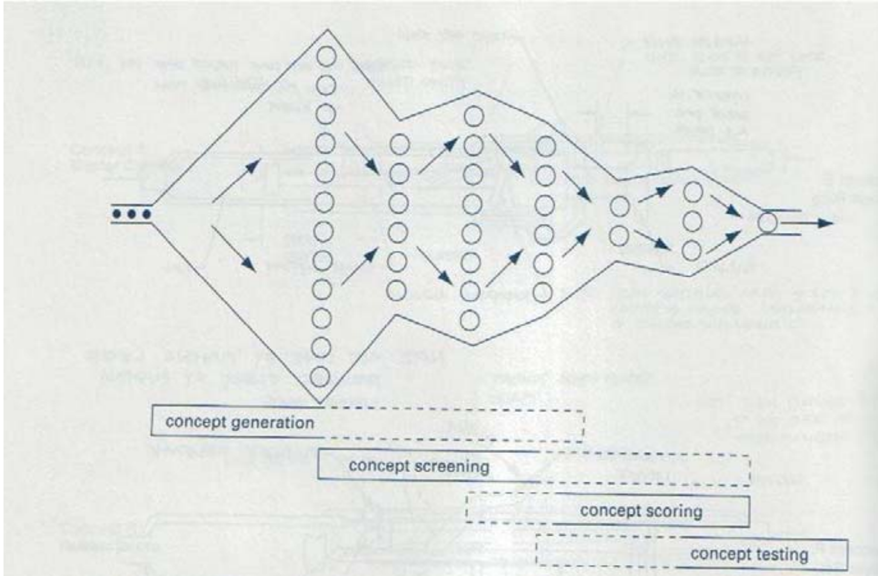


Figure 12. Concept selection tools used to focus design
Product Design and Development, Ulrich and Eppinger, 3rd Edition, page 128

Figure 12 exposes two related concept selection tools—concept screening and concept scoring—that comprise Pugh's concept selection method. Pugh's method takes into account all factors related to the design project and offers metrics to compare multiple concepts. Concept screening and concept scoring matrices are shown in **Figure 13**.

	Concepts						
Selection Criteria	A Master Cylinder	B Rubber Brake	C Ratchet	D (Reference) Plunge Stop	E Swash Ring	F Lever Set	G Dial Screw
Ease of handling	0	0	–	0	0	–	–
Ease of use	0	–	–	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	–	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	–	–	0	0	–	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum –'s	0	2	3	0	1	2	1
Net Score	2	–1	–2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

EXHIBIT 7-5 The concept screening matrix. For the syringe example, the team rated the concepts against the reference concept using a simple code (+ for "better than," 0 for "same as," – for "worse than") in order to identify some concepts for further consideration. Note that the three concepts ranked "3" all received the same net score.

		Concept							
		A (Reference) Master Cylinder		DF Lever Stop		E Swash Ring		G+ Dial Screw+	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of handling	5%	**3**	0.15	3	0.15	4	0.2	4	0.2
Ease of use	15%	**3**	0.45	4	0.6	4	0.6	3	0.45
Readability of settings	10%	2	0.2	**3**	0.3	5	0.5	5	0.5
Dose metering accuracy	25%	**3**	0.75	3	0.75	2	0.5	3	0.75
Durability	15%	2	0.3	5	0.75	4	0.6	**3**	0.45
Ease of manufacture	20%	**3**	0.6	3	0.6	2	0.4	2	0.4
Portability	10%	**3**	0.3	3	0.3	3	0.3	3	0.3
	Total Score	2.75		3.45		3.10		3.05	
	Rank	4		1		2		3	
	Continue?	No		Develop		No		No	

EXHIBIT 7-7 The concept scoring matrix. This method uses a weighted sum of the ratings to determine concept ranking. While concept A serves as the overall reference concept, the separate reference points for each criterion are signified by **bold** rating values.

Figure 13a Pugh's Concept Screening Matrix **Figure 13b** Pugh's Concept Scoring Matrix

Product Design and Development, Ulrich and Eppinger, 3rd Edition, page 128, p134

Although notable, Pugh's methodology does not address the right issues as far as concept selection is concerned. Obviously, it is a great academic model that students can learn to trust, but in reality, designers rarely take the time to follow Pugh's method during concept selection. Designers go through the same process before making a decision, but in a fuzzier way that leaves more room for innovative ideas. The concept selection matrix is often promoted in academia to make the task easier on teams to compromise on a final concept. Each team member individually fills out the concept selection matrix and compares scores with the rest of the team. There is an incredible amount of bias introduced into the data since many of the elements in the matrices are vulnerable to subjectivity (choosing a reference, associating weights with different needs, and comparing scores). In **Figure 13b** for instance, four concepts are compared and only one is chosen for further development. In this example, the chosen concept has a net score of 3.45, whereas the second ranked concept has 3.10. These numbers are difficult to interpret and do not have the same convincing impact as a prototype would. If designers were to justify their concept selection to stakeholders and colleagues by basing it on a 0.35 net score differential, it would be extremely difficult to draw any sort of interest. Pugh’s method is often promoted over prototyping because of time constraints, completing the scoring matrix is difficult and time-consuming, and not always conclusive.

Concept selection models provide students a neutral and safe ground where they can express themselves in a collective effort to compromise. Unfortunately, concept selection should not be about compromising, but rather about making sure that the right concepts are chosen to fulfill users’ needs and industry realities. Design requires dealing with all sorts of factors to make the right innovative concepts. In an ideal world, these factors would not have any sort of influence on each other. Alas, designers have to deal with the realities of physics, economics, time constraints and others, which become hurdles on the way of innovation. Good designers keep their eyes on innovation while understanding that there are trade-offs to consider. Of course, innovative ideas can minimize the effects of trading-off, but there are just some realities that cannot be avoided.

The iPod is a great example. The primary need Apple was trying to solve was portability, and therefore they had to make the iPod as small as possible. Consequently, they had to sacrifice battery life over portability. Because of battery technology and cost, Apple had to trade-off in favor of size over battery life since it was the iPod’s primary appeal. Although the company now faces some difficulties from consumer groups, it was able to revolutionize the market by bringing this innovative idea early and in a way that positively changed their brand. Sometimes innovation cannot wait, and it is better to bring an innovative idea on the market and subsequently make subtle improvements, rather than expecting a perfectly designed product to enter the market at a time where the product will not seem as innovative. In the Apple case, designers had to deal with trade-offs such as, cost, technology, size, time, and usability. Technology and cost are often trade-offs that cannot be ignored, but innovative design can reduces their effect as much as possible, while realizing that there are some absolute constraints that cannot be eliminated.

The case of the iPod is a typical case of how engineers need to find the most creative solutions to minimize trading-off. Design, and especially concept selection, is about trade-offs, not compromises. Returning to Pugh’s methodology used in academia, students often use it as a compromising tool, where all team members contribute to the final project by combining their respective favorite ideas, i.e. a few concepts will score somewhat equally in the scoring matrix, and the group will decide to combine these concepts for their final deliverable. Unless done for good reasons, it is extremely dangerous to combine numerous concepts into one in order to compromise with the rest of the team. In some cases, a student will have a favorite concept and the rest of the team does not want to address the shortcomings of the concept. It is in human nature to try to protect the feelings of others when they feel strongly about a certain idea. Concept selection is a brutal and non-compromising process that is only driven by users' needs and reality. I personally do not feel comfortable in these situations where people expect a compromise, and unfortunately I usually do compromise. I am, however, learning to challenge the person by trying to explore their ideas in more details, which helps better understand the concept and leads to reassessment of the concept value; or, it will help the person realize the shortcomings of his/her favorite idea(s). Prototypes are also an excellent way of dealing with such situations. The person who is "married" to a certain idea must be willing to build a prototype to communicate to the rest of the team the concept value. Conversely, the prototype may illustrate the shortcomings of the concept and this person will realize the issues with pursuing it.

Design is about trade-offs, not compromises

CONCEPT SELECTION IN INDUSTRY

In industry, concept selection is a quick and iterative process. Tools, such as prototyping and user testing are used to facilitate decision making. **Figure 14** lists some of the rules IDEO follows when narrowing down generated concepts.

4. REFINING

At this stage, IDEO narrows down the choices to a few possibilities. Here's how it's done:

BRAINSTORM in rapid fashion to weed out ideas and focus on the remaining best options.

FOCUS PROTOTYPING on a few key ideas to arrive at an optimal solution to a problem.

ENGAGE THE CLIENT actively in the process of narrowing the choices.

BE DISCIPLINED and ruthless in making selections.

FOCUS on the outcome of the process—reaching the best possible solution.

GET AGREEMENT from all stakeholders. The more top-level executives who sign off on the solution, the better the chances of success.

Figure 14. IDEO's Concept Selection Rules

Innovation is about dealing with trade-offs, and ideally eliminating them. Nonetheless, realistically, designers need to make tough decisions based on trade-offs. Many factors other than users' needs, prototyping, and user testing should be used for concept selection:

- **Manufacturing & cost:**

Manufacturing is a field that undergraduate and graduate students do not get enough exposure to, and consequently cannot use it in concept selection. Manufacturing plays an important role in concept selection since it is the link between ideas and marketable products. That said, manufacturing should not be seen as a barrier to innovation, but designers should be aware of it and remember to accordingly design for it. Sometimes design for manufacturing dramatically increases cost, so much so that the concept needs to be altered or abandoned no matter its value to users. The trade-off is then to what extent you are willing to change the concept to bring manufacturing cost down to a reasonable level.

- **Market Size**

If designers have a good understanding of their target market, they should be able to estimate the market size they are designing for. The question then becomes determining the long-term impact of the product. In some cases, a certain project can generate relatively small earnings because of market size, while positively influencing the company's brand. For my design course for instance, we designed a stove for people in wheelchairs. The target market was relatively small and not financially appealing to big corporations. We were able to argue that developing such a concept would revive stove manufacturers' brands because of the social responsibility they would be undertaking. In a world where corporations are becoming more dominant, consumers are losing trust in them. Most big corporations are seen as unethical and money-driven; therefore, social responsibility increasingly becomes a decisive factor for consumers when purchasing products.

- **Competitive products, timing, and implementation time**

Companies often need to innovate in response to a successful product in the market, and they run the risk of imitating the product rather than considerably improving it. To become or remain the industry leader it is crucial to take advantage of trends by entering the market promptly with a product that addresses users' needs without validating the competitors' product(s). Most industry leaders cannot commercialize a "me too" product since it may be detrimental to their reputation, but at the same time they cannot waste too much time before they enter the market.

- **Durability**

Many advanced engineering products need to pass severe durability testing before being commercialized. Therefore, durability is frequently a major driver behind concept selection, but it should not be the only one. It is important to understand when to run durability tests during the process. If not used timely, testing can work against innovation. If done too early, it might bury a good idea, but if done too late, the developed idea may turn out to be a waste of time and resources. Durability testing should be done in a way that reproduces reality; otherwise, the results will be misleading and will affect the concept selection process.

- **Regulations**

Oftentimes, industries are regulated by a governing body that certifies all products to meet their requirements. These governing bodies, whether governmental or private, strictly enforce theses regulations. Designers need to find clever and innovative designs to challenge these rules. Here again, designers need to realize that they will have to deal with trade-offs. **Figure 15** shows an example of how governing bodies can play an important role in concept selection. In this example, several concepts were prototyped and were sent to the governing body for feedback. The preferred concept was rejected because of regulations that limited a certain sort of mechanism to be used on the product.

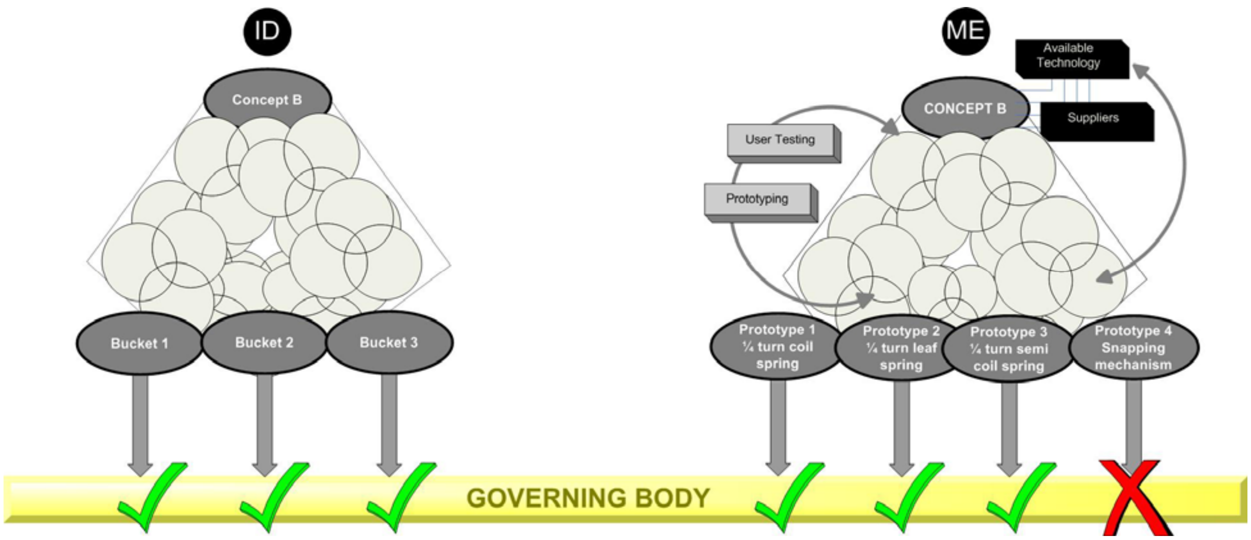


Figure 15. How Regulations Influence Concept Selection

This section shows the complexity behind concept selection. Many factors come into play when making such a decision and the way designers deal with trade-offs is in my mind what makes the difference between a good and a mediocre design.

IV RECOMMENDATIONS

SUGGESTIONS FOR CURRICULUM MODIFICATIONS

Combine ME 102 and ME 110 into a two-semester course

- The 1st semester would cover need finding, brainstorming, and early rough prototyping techniques
- The 2nd semester would cover electronics, programming, more advanced prototyping, and testing

Combine ME 107A and ME 107B into a one-semester course

- Avoids redundancy
- Enhances flexibility of curriculum

Make Manufacturing a mandatory course for the undergraduate program

- Prepares students for design
- Exposes real world operation

Promote joint projects between graduate and undergraduate programs

- Builds practical skills from an early stage
- Promotes a Berkeley engineering culture through peer collaboration

CAL-IDEO FUTURE COLLABORATION

Form an advisory board consisting of industry representatives

- Creates a strong correlation between academia and industry
- Keeps academia in constant contact with industry and vice-versa

V CONCLUSION

Any change necessitates a good understanding of the current situation. Although UC Berkeley students are well-prepared under the current curriculum, there is still room for improvement in the area of design. A number of positive steps have been taken by some faculty members in the past few years; however, modifying the curriculum to foster design coupled with collaborations with industry leaders would reinforce UC Berkeley's position as a highly innovative institution.

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