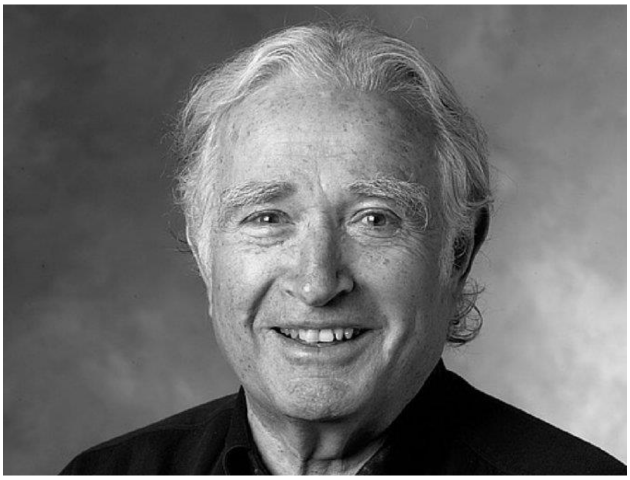

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Roth is one of the founders of the Hasso Plattner Institute of Design at Stanford (the d.school) and is active in its development: currently, he serves as Academic Director. His design interests include organizing and presenting workshops on creativity, group interactions, and the problem solving process. Formerly he researched the kinematics, dynamics, control, and design of computer controlled mechanical devices. In kinematics, he studied the mathematical theory of rigid body motions and its application to the design of machines. All publications – 2016: Books and book Chapters-26; Journal articles-113; Conference Procceding-77.

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Design Process as an Educational Tool

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Abstract

The design thinking methodology is different in basic ways from traditional educational methodologies. It is learning by doing, i.e., problem based learning. The students learn by working on real-world problems. Our philosophy is that a lot of good learning can be obtained by doing something real while you are in still not "fully prepared." We put a lot of emphasis into problem definition. Getting a deep understanding of who the solution is for is a very important part of our process. We call this user a user centered approach. For the past thirteen years, we have been providing design thinking classes to graduate and undergraduate students, and been running workshops for professionals and organizations. This paper will present some examples that reveal the power of our methods to solve difficult problems in the university and in industry and to change people's lives.

Keywords: Design Thinking, Projects, User-centered, Auto-inject, Six-bar.

Introduction

Traditionally education is in the main content centric. Students are expected to learn a specific set of predetermined material using a predetermined curriculum and schedule. Most of this education is done in the framework of logical thinking that deals with predefined objectives that are realized using deductive or inductive thinking. The emphasis is on rationally defined approaches to obtain specific predetermined goals. The path to the goal may be difficult and my even lead to dead ends, yet the desired goal is always in mind and it is clear when the objective is obtained.

In contrast, in a true design thinking approach, the problem gets defined as part of the solution process. In other words, the problem definition is not clear in the beginning. Part of any true design thinking process is to define the design opportunity. In a true design thinking approach both the problem and the solution are not clearly defined in the beginning. Polynesian explorers refer to such a voyage as a cone of possibility, rather than a voyage with a specific predefined destination.

Design Thinking Mindsets

The design thinking methodologies we have developed at the Stanford d.school are different in basic ways from traditional educational methodologies. They fall under the heading of learning by doing, i.e., problem based learning. The students learn by working on real-world problems. Such ideas are not new to education. The modern roots of the learning-by-doing methodology go back to John Dewey, Maria Montessori and hosts of other educational innovators. It is obvious that giving students the opportunity to do something real can be inspirational and often more effective than abstract and seemingly useless learning. Design thinking has the potential to empower students. It can move students from being passive learners to powerful creators.

Many surveys of practicing professionals have shown that skills such as making presentations, cooperating with people from different backgrounds, expressing one's ideas, as well as being able to organize and meet deadlines, are far more widely used than the specific technical content of their expertise. Design thinking projects enhance these needed interpersonal skills. For students, such projects also have the positive effect of fostering creative confidence and empowering people to live more fully committed lives.

Traditionally education is about preparing students to do things after they graduate. The d.school philosophy is that a lot of good learning can be obtained by doing something real while you are school and still not "fully prepared." We call this: having a *bias toward action.* The bias toward action manifests itself in many ways. For example, in our Launchpad class students start businesses within a very short time. They need to have launched their business by the fifth week of a ten-week class, or drop the class. The idea is not to worry things to death. Nothing will ever be perfect. Often the best way to learn is from mistakes.

Alongside a bias toward action is the mindset to *learn from failure*. Nobody likes to fail. Our students have generally been very successful, and so failure is hard for them to accept. Yet, failure can be a great gift. If you learn from failure you often can move ahead to better result than is you succeeded. One important way to learn is to test out ideas in their early stages. So, we have a strong bias to *show rather than tell* (that is doing rather than talking about it) and to try out our ideas by making quick prototypes. We call this *embracing experimentation*.

Our methodology is heavily weighted to team based learning and team based teaching. Moreover, we depend heavily on diversity in both the teaching and student teams. We call our form of team teaching and team learning *radical collaboration*.

We put a lot of emphasis into problem definition. Getting a deep understanding of how to embody *human values* is a very important part of our process. We call this user centered approach *empathy*. This is one of the most crucial mindsets. In the past engineers and other professional problem solvers, tended to deal only with other professionals and ignored the end users and the human centered aspects of their work. The idea of co-design, where the users were directly involved in the design process seemed very radical, as was also the idea of being user centered. Fortunately, nowadays there is a trend toward involving users on many levels of the solution process.

Since our methods involve gather a lot of information it is important to have a mindset for creating *clarity from confusion*

Also, it is important for people to know where they are in the design process, what comes next and what specifically they are striving for. We call this being *mindful of process.* Professionals tend to do this subconsciously. For students and other inexperienced design thinkers, it is very useful to have in mind a step by step process that gives a default answer to the question of: what do I do next?

Design Thinking Process

The two most common design thinking processes we use involves involve five or six different steps. The five-step process is usually given as: empathize, define, ideate, prototype and test. The six-step process is usually given as: understand, observe, point-of-view, ideate, prototype and test. These are virtually the same, since understand and observe are part of the process of empathizing, and point-of-view is simply one form of defining a problem. Some people use these two forms interchangeably and others prefer one or the other. In both cases, it is important to realize that nobody is talking about a linear ordered set of steps. In practice, steps may come in any order and be repeated several times during any pert of the process. The process is best taken as a nominal guide, and a fallback position as to what to do when it is not clear what the best next step is.

For beginning students, the idea of a step-by-step process forms a good guide in how to approach a problem and move from problem definition through to a final solution. It is also a good pedagogical device to break the solution process into discrete steps. In that way, each step can be learned and practiced without the need to go through the entire design process. This is very useful in building student's skills. It is also useful for professionals seeking to develop special skills and in depth expertise in specific aspects of the process

We have found that the design thinking learning-by--doing teaching methodology is very appealing to students. It changes the classroom from a low energy, passive, learning environment into a highly charged fully participatory situation.

In traditional education, a professor "teaches" the students. The students "learn" the material. The goal is that after graduation the students will be able to apply their learned knowledge to real-world problems. Whereas in a design thinking educational setting the goal is for students to get engaged and confident in their innovation process at the current time. This goal is accomplished by project based learning, in which the students go through a design thinking process while practice radical collaboration in a culture of prototyping. The faculty's main role is to act as coaches that create situations where the students are the experts. The students get exposed to different faculty points of view due to the diversity of backgrounds within each teaching team.

Our learning by doing culture involves relatively little formal lecturing. We move students quickly to complete immersion in a problem by insisting that they incorporate a human centered viewpoint. After taking as much time as is necessary to make sure we have a good problem statement (we call it point-of-view), we move rapidly into the ideation phase by use of sketches, lists and prototypes.

Human Centered Design-Empathy

One of the strongest aspects of design thinking is that it is human centered. A human centered designer needs to be truly empathetic to the people being designed for. Most professionals are basically not empathic to the people they are supposed to be providing for. This may seem strange, yet it is frequently the case. For example, most professors believe they know better than students what the students need. Doctors feel they know better than patients what the patients' needs are. And so on in virtually every profession. In general professionals talk to their peers, who are other professionals. On those occasions when consumer interest is explicitly considered, it is done on a macro scale by using anonymous surveys or focus groups. In human centered design thinking, the emphasis is on finding implicit human needs by carefully observation and in depth engagement with individual people. Often instead of looking for "average" people, we are looking for the outliers, the so-called extreme users. These are the people that lead to insights that can yield truly new and amazing solutions.

A good example of human centered design is given by the development of an automatic injection mechanical system for people that take periodic injections of a given dose size. Such regular dose size treatments are often used by Rheumatoid Arthritis and Multiple Sclerosis patients. By doing extensive interviews and watching people's actual behaviors designers deduced several valuable guidelines for the mechanism synthesis phases of their designs. For example, they learned that people have lengthy routines as they target an injection and work up the resolve to insert the needle. A person with Rheumatoid Arthritis used the needle tip to probe around and identify an injection target. After she chose the spot, she took a couple practice swings for courage, then missed and inserted the needle close by. She would like to be able to aim better and to be able to compose herself before starting the injection, confident that the needle will go where she expects it to go.

A person with Multiple Sclerosis made a paper "clock" to help rotate through injection sites on her thigh. She lined the clock up with a freckle and then worked her way around the clock, targeting a different "hour" for each day's injection. She tried to build up her courage (sometimes with wine), took practice swings, closed her eyes, and then inserted the needle knowing that she would inevitably miss her target. She had built up a ritual around control and targeting, even though it was not achievable with the tools she was using.

The design team built prototypes to test the hypothesis that a stable base with site visibility and a needle that is retracted prior to injection would help people feel more confident. The prototypes began as syringe accessories, with the first being a two-part tool: literally a puck-like "site" or guide piece that interfaced with a separate "inject" piece.

The team observed the benefits of being able to move the prototype around freely, to then hold it stably in place while still having the option of changing your mind, and to then start the injection without disturbing the device from its targeted position. For people with compromised or unsteady hands, this design offers ergonomic advantages. For everyone, the anxiety that comes with inserting the needle can be deferred, as the stakes feel low while the injection part is being positioned and repositioned.

This approach works best when the act of placing the device on the skin is not what either unlocks or triggers the injector. From this the concept arose that auto injectors have clear bases to help target the injection. This allows for the auto injector to be repositioned on the skin and then held stably on an injection site while a user gets ready to trigger the injection.

The designers chose to work on populations that require injections on a weekly up to a monthly basis of fixed drug volumes from 0.2mL to 3mL delivered subcutaneously about 6mm deep. Furthermore, given the drug's refrigeration requirements, they restricted themselves to full dose injections.

The actual mechanism for automatic injection and needle retraction is quite complicated, as seen in the patent application figure bellow It turned out that only engineers are interested in seeing it. So, the final design had the mechanism covered by labels with product information.

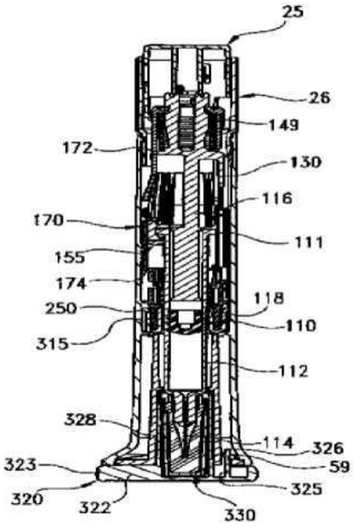

Fig. 1. Patent drawing of automatic injection device The patients are mainly interested in seeing the drug flow out and being assured it has all been injected. In the photo below, the auto-injector on the left shows the mechanism. It is purposely covered first as shown in the center and ultimately as shown on the right. So, that only the bottom part of the auto-injector is left transparent and the patient can see the piston pushing the drug out of the syringe

Learnings from watching patients deal with prototypes led to making it so the patient does not see the needle and does not need to apply force to actuate. The injections activate automatically after a short delay once the patient has rotated the top form the lock to the unlocked position. Since patients were concerned about wasting very expensive drugs, the bottom is left transparent so the patient can visual confirm that the actuation entirely empties all the medicine.

A classic example of both how a lack of empathy can lead to troublesome results, and how incorporating empathy can lead to amazing results comes from Doug Dietz, a senior designer at GE Medical. Doug's group designed an MRI machine to be used to examine children. The group worked in the usual professional way. They talked to other design engineers and scientists. They talked to customer engineers, and to doctors and hospital administrators. They talked to everyone but the patients!

They completed a very professional looking machine, and it was successfully marketed to hospitals and clinics. After some time, Doug decided to visit a local clinic and see the machine in operation. When he identified himself to the nurses they heaped praise on him about how well the machine worked. He felt elated. Then a child was dragged in screaming by his mother, and the nurse asked Doug to leave since they had to sedate the child to get him into the MRI machine. Doug soon learned that to use his machine approximately 85% of the children had to be sedated. It made him feel terrible.

Fig. 2. The injection mechanism fully visible, and partially and fully covered

Ultimately Doug realized he had not been practicing human centered design. Acting on his realization he formed an advisory group of children that were chronic patients. He also consulted children's museums, child psychologists and parents. The result was a reframing of the experience. Instead of a medical procedure he made the MRI machine the center of an adventure. He made comic books showing the idea of seeing inside your skin and sent them to the children in a knapsack two days before their examination. Mainly though he had the room and MRI machine repainted. One adventure had the room painted so that the machine was part of a pirate ship, and the child had to hold still lying on her back so the prates would not find her. Another adventure involved holding still looking up at the stars.

With the adventure series, the sedation rate dropped to less than 2%. Some children were heard saying: "mommy, can we come back tomorrow?" When you look at the original MRI machines with the eyes of a child, it becomes clear how getting into the machine could seem like crawling into the mouth of a metallic monster. Empathy for his users allowed Doug to see his design with the eyes of a child.

Culture of Prototyping

A useful way to check if you have a good POV is make small tests. Think of these tests as prototypes. People often use the term "mock-up" to indicate a quick prototype. I prefer the term "crap-up" to indicate an even simpler and quicker form of prototype. The noun "prototype" implies a formal model of some complete object. So, for our purposes, it is best to think in terms of the verb "to prototype."

Useful simple prototypes quickly give you some important information. A classic example is the surgical tool configuration put together for doctors by IDEO. It is made from a clothes pin, a film container, a marker and some scotch tape.

Fig. 3. Prototype of surgical tool

Two less traditional prototype that were created by Stanford students are a simulated bicycle accident, used to get information about bike safety design, and the game of *musical chairs*, used to test ideas for the design of the airline *Jet Blue's* customer callback system. These are shown here:

Fig. 4. Prototype of bicycle accident

Courses and Workshops

The scale of our activity has grown each year. This year at the Hasso Plattner Institute of Design at Stanford we offered over 70 interdisciplinary courses of which half were regular 10 week long classes and half were shorter length "popup" courses. Over 1,000 Stanford students attended these classes, and over 900 Executives and Educators participated in special short term workshops and trainings.

Fig. 5. Prototype of call-waiting experience

Our classes are all project based. A few courses have been offered regularly. While many others tend to only be offered for several years. All our courses tend to change each time they are offered. Our longest standing class is the two-quarter sequence now called *Design for Extreme Affordability*. The class generally has forty students that are divided into 10 teams of four. As of 2017, the class has been offered for 13 years. There have been 120 projects for 21 Countries, of these 33 are still in the market. Two of the early projects have received a lot of publicity due to the social good they have bought. They the *d.light* and *Embrace* projects, described below.

d.light is a for profit company that makes affordable solar powered LED task lights. Since kerosene and candle lighting are dangerous, toxic and relatively expensive, the students felt there was a strong need to replace them with solar powered lighting in areas that do not have electricity. The success of their concept can be seen by the following cumulative results, as of May 31, 2017: 75 million lives empowered; 5.8 billion dollars US saved in consumer energy costs; 19 million school aged children serviced; 26 million tons of CO2 offset; 40 billion productive hours created from darkness.

Embrace is a not for profit company that manufactures and markets a lifesaving baby warmer. Premature and other low body weight babies need to be kept warm or they will die. The students realized that in rural areas the traditional hospital incubators are basically ineffective. Firstly, they are too expensive and require a dependable supply of electricity. Secondly, the incubators that do exist in poor countries are in cities and are too far for mother in rural areas to get their babies to the lifesaving incubators in time. The students invented an inexpensive sleeping-bag like device that relies on a removable bladder containing a wax like substances that melts under heat and maintains body temperature for at least 4 hours. The heat can be supplied from boiling water and does not rely on electricity. At this writing, over 250,000 babies in 22 countries have been kept warm by *Embrace*.

One Stanford student was so inspired by *Embrace*, that when he learned that babies die or have lifelong disabilities due the lack of a blue-light therapy for jaundice, he stopped out of school for a year to develop a blue-light LED based inexpensive device, he named Brilliance, which has now been sold to over 20 countries and been used to treat over 250, 000 babies.

This year there was a project that led to the development of a linkage for use in manually tamping dirt floors in Rwanda. The students found that homeowners who aspire for a more dignified, healthier living space need an accessible, affordable way to build a floor. Currently, the skilled labor required for the compacting process makes the installation price unaffordable and serves as a deterrent do-it-yourself construction. The floors are built by adding a top layer of sand and sealant to a gravel base that is compacted into a rigid subsurface by a hand-held ram that needs to be repeatedly smashed into each small section until the subsurface is rigid enough to support a thin layer of cement. This preparatory work is very labor intensive, and the most expensive part of the entire floor building process.

To accommodate the need to reduce the cost of the tamping process, the students developed a planar 6-bar linkage composed of a slightly offset slider-crank 4-bar and a dyad that drives the slider crank's coupler. The device is meant to be powered by the operator's foot, although hand operation is also possible. and Fig. 6. shows a skeleton diagram of the kinematic structure, and Fig. 7. shows a Solid Works sketch of the device. The crank for the slider crank is link EC. It is connected to the device's base with a turning joint at E. The slider-crank's coupler link is BC, which is extended to include point D. The slider is link BA. A is the impact part of the slider which drives an 8 inch by 8-inch square base (0.2m x 0.2m) into the dirt to create the compacting.

It has been shown that the resulting compacted floors are of high quality and can be produced by reasonable expenditures of time and effort. This device a viable alternative to hand compacting in the Rwandan environment. It is currently undergoing final development in the local area where it will be fabricated and brought to market as a $50, bicycle transportable, do-it-yourself compactor. It is estimated that over a million floors will be installed in the next few using the principles embodied in this device.

Creative Confidence

Looking at such results it is easy to understand how this type of experience can deeply affect students. For many their introduction to design thinking project based learning has been life changing.

With design thinking, there is a big addition to the universe of problem solving: Now people are center stage. So, in addition to artifacts we have experiences, in addition to physical prototypes we have stories.

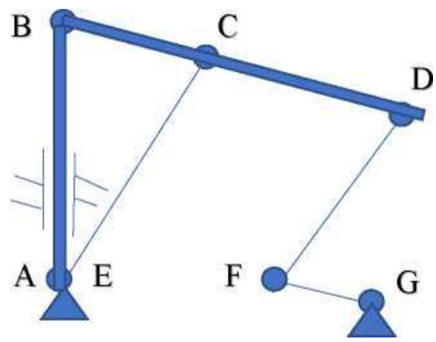

Fig. 6. Skeleton diagram of the kinematic structure action. The linkage could be hand driven by pushing on the coupler at point D. However, since foot power is more powerful than hand-cranking, the dyad composed of links DF and FG is attached to the coupler through a turning joint at D. The input torque is them obtained from stepping on a foot peddle rigidly attached to link FG next

Fig. 7. Solid Works sketch of tamping device

We say that students empowered by design thinking mindsets have increased their personal efficacy, to the point where they have creative confidence. They are imbued with a feeling of confidence that they can problem solve in a meaningful way that will improve the world around them. Traditional education, with its reliance on teachers and other experts, tends to give students a sense of inadequacy, regardless of how well they do academically. Whereas design thinking's project based experiences, with its reliance on coaches that assist students to find their own way, tend to empower students both in their outlook and their own estimation of their abilities. In this sense design thinking is a transformational educational reform.