Early-Stage Engineering Design: 
The Designer, the Object of Design, and Design Context

May 9th, 2008

by

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B.S., Mechanical Engineering (2007)
Massachusetts Institute of Technology

Submitted to the Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

at the

Massachusetts Institute of Technology

June, 2008

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Abstract

Much of design research has been focused on developing prescriptive design processes, however, proper description of the designer, the object of design, and the context may be lacking (Dorst, 2007). The present research adds insight concerning these three elements through observation of a creative design course with a diverse student composition. The layout of course was built around six very different early-stage design projects. A technique for characterizing and visualizing design projects and tasks is also introduced and used as a tool for describing the objects of design and project contexts.

Collected data carried several important implications. One profound result was that no measure of designer experience was significantly correlated with general performance across all design projects. However, less experienced designers actually seemed to do better at more atypical projects, while experienced designers had the upper hand in solving more traditional problems. No other design-related skills correlated consistently with performance. Designers who were confident, however, tended to learn more and enjoy the projects, their teammates, and the teaching staff more.

The results raise many important questions for designers, educators, and employers. The possibility that oft used measures of designer competence fail to accurately indicate capacity undermines current employment and matriculation methods. Educational institutions may consider reassessing the value of their curriculum. Budding designers may also question their approach to gaining design experience.

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Acknowledgements

Infinite adoration and appreciation to my stunning wife, Kana, for supporting me during the grueling research process. She single-handedly and masterfully managed every temporal nonacademic aspect of my life while I was virtually incapacitated with scholastic responsibilities. Among countless acts of kindness and tokens of affection, the many thoughtful notes, meals, visits, treats, and hugs were invaluable.

Much love to my sweet daughter, Emily, who was born and lived her first six months during this frantic time. She has been a perfect angel. Her patience, kindness, and character have buoyed me during overwhelming times.

Due gratitude to my advisor, Maria Yang, who has been the ideal mentor – sympathetic, involved, and accommodating. She gave me the freedom to explore and learn, and the encouragement to undertake an ambitious endeavor. Her passion for our shared field of study constantly invigorates our entire research team.
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Chapter 1: Motivation

1.1 Background

There are many important questions about designers and the processes they employ that are relevant to the designers themselves, educators, and employers. “What makes a ‘good’ designer?” “How can design and engineering be taught better?” “Which characteristics of job applicants make them most valuable to a company?” Such questions are nearly endless in number, and the answers can be very difficult to pin down. However, the value in furthering understanding of these issues is enormous as it underscores the basis for many policies and investments made by both educational and professional systems.

For example, knowledge of key indicators of individual performance is crucial to matriculation systems. When deciding which students to extend admission acceptance, universities attempt to determine which students, designers or not, will perform well at their institution. Often, the admission board relies on essays, standardized tests, essays, and other activities and achievements to predict prospective students’ abilities. If these measures are not adequate to gauge whether the students will thrive at the university, then the matriculation system is in dire need of developing an understanding of the factors that contribute to aptitude.

Similarly, educators would like to know how to teach such that both creativity and capacity are expanded among their students. Developing an engineering or design curriculum is a long and costly process that can takes years to establish and even longer to gain accreditation. The reputation and subsequent success of educational institutions is in part based on the quality of their graduates. The graduates themselves may also have invested tens if not hundreds of thousands of dollars in their educations as well. This enormous investment all depends on the quality of education in terms of its ability to increase in the value of its graduates. If an engineering or design curriculum doesn’t help the student perform better, then the investment is wasted. The first question an academic department might ask is, “Does our curriculum help its students perform better?” The next question is, “What could make our curriculum more effective?”
Companies have an equal or greater stake in the quality of their employees. The sum employee output is directly related to the business’s profit and hence, ability to survive. Understanding this relationship, companies invest large sums of money in searching for many appropriate candidates for open positions, often exceeding ten thousand dollars per employee (Davison, 2001). Human resources departments review applicant resumes, cover letters, academic transcripts, recommendations, and interviews to try to assess the degree to which the applicant will profit the company. Ascertaining the value of a potential employee involves not only understanding the individual’s ability to perform well, but also their interpersonal skills, their loyalty to the company, how they fit into the corporate culture, and many other things. A hiring manager might ask, “How can I tell if this applicant will get along with his coworkers?” “What shows how much a prospective designer will enjoy their projects and leadership?” “How can I guess how well this applicant will perform?” With such understanding, companies could make better human resource investments.

These questions apply to every potentially productive individual, including designers and engineers. Much work has been done to understand designers and engineers, of which this research is an extension. It is the hope of this work that answers to these questions can guide educators and businesses to achieve their goals. Similar principles also apply to helping designers know which elements are important in increasing their own happiness and productivity.

1.2 Opportunity

Developing awareness of the factors that contribute creativity, contentment in the workplace, and productivity has enormous potential to benefit society on both an individual and a collective level.

Individually, this understanding will help designers know whether their ability to design is innate, or whether they can hone and improve their ability to design. If the latter is the case (we hope so, because otherwise educators are worthless, and the ungifted are hopeless!), then individuals can realize the possibility of improving their design skills, and with information provided by this and other research, know how to go about achieving progress. This research may also inform the designer regarding which factors
influence their vocational happiness at school and in the workplace. Familiarity with these factors may give the individual important means of making himself more content and fruitful in his career.

On a collective level, the hope is that by characterizing and understanding designers, education and business can be conducted more efficiently and effectively. If, for instance, grade point averages and test scores have little bearing on the abilities of designers, matriculation systems and employers can ignore those statistics and focus on more telling signs of talent. Design students could then avoid wasting efforts attempting to increase their scores. Taken seriously, such knowledge has the potential to overhaul the way our society views qualifications. Perhaps even more importantly, effective evaluation techniques could put those with greater potential to make larger technological and artistic breakthroughs in positions to facilitate their contributions.

The potential of this field of research may be envisioned in the following hypothetical example. Imagine the very capable architect who does poorly on tests and graded projects. Her low marks largely stem from her remarkable ability to come up with creative ideas that are outside of the current architectural understanding. High school architectural instructors emphasizing traditional design penalize her for her outlandish ideas. After getting mediocre grades in high-school from a few closed-minded teachers, she misses the opportunity of going to a top school because of the importance the college acceptance review staff places on grades. Instead of a university with a thriving and recognized architecture program, she ends up going to a small local college without even an architectural program. Further misjudgment at the college by professors unused to disruptive brilliance leaves her with a less than perfect transcript and weak letters of recommendation. Luckily for her, a small unknown firm decides to hire her to help with trivial errands. Over the subsequent decades, if fate smiles on her every step, she works her way up to the point where she can finally put her abilities to good use. She eventually wins large contracts, owns her own firm, and contributes to the progress of her field.

Many years of her productivity, including her would-be-prolific youth, were squandered because she was not in an environment where her skills were appreciated. All the time, she may have been quite capable of making important developments. She
could have been much happier. A university could have been proud to claim her as an alumna. A company could have made a fortune employing her genius appropriately. Her area of research could have been expanded.

There is a magnificent opportunity to reduce the waste of the type of resources that were lost in the example of this architect. Obviously, her case may not be the case all of the time, or probably even most of the time. However, the interactions upon which this hypothetical incident is based can apply to many situations. She could have been an engineer, an artist, or a scientist instead of an architect. “GPA” could be replaced with “standardized test scores,” “recommendations,” “experience,” “personality type,” or anything else that is used to predict performance. Each of these measures may or may not be useful in assessing capabilities. When any method of gauging skill is incorrect, resources are lost. Thus, it benefits both the individual and the community to know which factors contribute to productivity and are accurate indicators of capacity.

1.3 Research Questions

In light of the great opportunity presented to the field design research, this thesis focuses on some of the questions that are integral to understanding measures of creativity and productivity. While the data gathered in this study could potentially be useful in answering many important questions, this paper will concentrates specifically on providing insight on the following issues:

- How does experience affect the quality of a designer’s output?
- Which specific characteristics and skills do “good” designers have?
- Are there indicators of whether a designer will likely enjoy a particular project, their teammates, and their superiors?
- How can educators and employers characterize and visualize the variation in design tasks of their students or employees?
Chapter 2: Literature Review

2.1 Current Understanding

Finger and Dixon give a comprehensive review of the field of research in mechanical design research in their seminal publication, “A Review of Research in Mechanical Engineering Design” (Finger & Dixon, 1989). A proper discussion begins with the question, “What is design?”

Designs problems are divided into three types:

- Original or new designs
- Transitional or adaptive designs
- Extensional or variant designs

The design process is an iterative progression through the following stages:

- recognition of need
- specification of requirements
- concept formulation
- concept selection
- embodiment of design detail
- production, sales, and maintenance

In design there are three stages of thought:

- divergence: In this stage emphasis is on extending the design boundary. The design is unstable, ill-defined, and no evaluation is performed.
- transformation: In this stage, the problem becomes bounded, judgments are made, the problem is decomposed, and subgoals are modified.
- convergence: In this stage, there is a progressive reduction of secondary uncertainties until a single design emerges.

A design is strongly influenced by the lifestyle, training, and experience of the designer.

While this description is very broad and insightful, much of the effort of the design research community has been focused on developing prescriptive design processes. But observed design in practice is almost always different from the prescribed
processes. This prescription-description disjointedness occurs partially because the
designers are not sufficiently systematic, and partially because design theory makes
unrealistic assumptions about the orderliness of actual design (Finger & Dixon, 1989).
Finger and Dixon also state that “no research that we are aware of attempts to verify that
better designs would result if the prescribed process were to be followed.” Thus, there is
a distinct disconnect perpetuated between prescribed or modeled design processes and
observed design processes.

It is also understood within design research community that there is more to
design than that which is physically left behind in design notebooks, documentation, and
the implementations themselves. There is predevelopment of ideas that must occur
before they can be expressed or recorded. Design includes many intangible and
unobserved occurrences perhaps unspoken in team meetings or within a designers mind.
Many developments happen at odd times such as when showering, on the brink for
sleeping, or while doing something totally unrelated to the design project itself. Finger
and Dixon state:

Much of the design process is a mental process; the
sketches and drawings that form the visible record of
designs do not disclose the underlying processes by which
they were created.

One of the major criticisms of design protocols is that a
designer’s words cannot reveal those processes that are
inherently nonverbal, for example, geometric reasoning.
Moreover, the requirement to verbalize may interfere with
the design process itself. Finally, all protocol studies must
address the problem that even though subjects may not
have any reason to withhold information, they may do so
unconsciously. All of these factors must be taken into
account when studying the results of the design protocols.

Finger and Dixon reference a study by Marples that reveals insights about how
designer’s creativity might change with experience (Marples, 1961) (Finger & Dixon,
1989). They claim that “designers reuse familiar solutions and will not explore
alternatives or innovative ideas unless their new design fails badly and cannot be
salvaged.” In other words, designers tend to rely on known solutions. Experienced
designers have access to a larger store of familiar solutions, and thus are less likely to
explore alternatives first, while inexperienced designers with a smaller repertoire of familiar designs will likely jump to innovation earlier. Perhaps this tendency is related to Waldron et al.’s conclusion that experienced designers visualize and process information at a more symbolic level (Waldron, Jelinek, Owen, & Waldron, 1987). Experienced designers can represent the problem more abstractly in terms of elements with which they are familiar. To an inexperienced designer, more aspects of a design challenge are novel, and thus unlikely to be abstracted. Seeing more details and room for change with fewer prior references, inexperienced designers are more likely to try innovation.

Further study on design expertise by Nigel Cross identifies another major difference between expert and novice designers (Cross, 2004).

Novice behaviour is usually associated with a ‘depth-first’ approach to problem solving, i.e. sequentially identifying and exploring sub-solutions in depth, whereas the strategies of experts are usually regarded as being predominantly top-down and breadth-first approaches.

Expert designers are solution-focused, not problem-focused. This appears to be a feature of design cognition which comes with education and experience in designing. In particular, experience in a specific problem domain enables designers to move quickly to identifying a problem frame and proposing a solution conjecture.

Generating a wide range of alternative solution concepts is an aspect of design behaviour which is recommended by theorists and educationists but appears not to be normal practice for expert designers. Most expert designers become readily attached to single, early solution concepts and are reluctant to abandon them in the face of difficulties in developing these concepts into satisfactory solutions.

Novices tend to focus on detail more and earlier than experts do. Expert designers tend to focus on a single solution quickly which they avoid discarding even when problematic. On the other hand, Cross also references Ho’s conclusion that both novice and expert designers used similar, backward, or bottom-up problem solving strategies (Ho, 2001). Ho further clarifies another distinction between novice and expert designers.
The results of this study indicate that an obvious difference between experts and novices is the way they approach the problem; this difference might be due to their different problem-decomposing strategies. Experts tend to establish problem structure at the beginning in order to represent the problem in their own way. This kind of strategy results in the tendency that experts usually approach directly the goal state of the problem first, and then adopt working-backward strategies to retrieve the initial state of the problem in order to search for required knowledge. Finally, they would obtain the solution via working-forward strategies. While novice designers tend to eliminate the problem when they fail to handle it. They later on redefine the new situation as a new problem at its initial state, and then approach the goal state of this new problem. After this period, they would continue to search for the solution as experts do.

Sobek and Jain, however shorten the gap between experienced and inexperienced designers (Sobek II & Jain, 2007). They claim that “experienced designers tend to do a ‘preliminary evaluation’ step between generate ideas and implementation that novice designers did not […] Results seem to indicate that this additional step improves design quality, even among inexperienced designers.” It appears that novice designer performance is improved by a similar practice as expert performance. Sobek and Jain report interesting findings regarding the relative importance of tasks within the design process (Sobek II & Jain, 2007).

Specifically, the results support the propositions that problem definition is important to design quality, that earlier design phases have comparatively greater impact, and that intermediate design levels falling between concept and detailed design are important. Results regarding idea generation reflect the mixed results in the literature, suggesting more investigation is required.

But shockingly and somewhat confusingly, Sobek and Jain claim that the early design phases in which brainstorming usually occurs should involve less idea generation and more analysis of current solutions even though these phases were found to have weighty impact as currently practiced (Sobek II & Jain, 2007).
The results pertaining to the idea generation suggest that students should not be encouraged to “try to come up with some ideas,” advice commonly heard from advisors. Rather, they should be encouraged to research existing solutions to similar or analogous problems. In doing so, and in trying to improve them, the novice begins to build that experience base that will enable him/her to become an expert designer.

Research has also been done regarding which other factors affect design quality. Yang conducted a study on a capstone student design project and compared student grades and contest performance with sketching practices and various other design-related skills (Yang, 2003). Surprisingly, the correlations found between sketching and grades were almost opposite that of the correlations between sketching and contest performance. This implies that designers’ grades are not good measures of design ability.

Yang’s results further showed that fabrication skills the only designer characteristics that correlated with design outcome in terms of grade, and there were no designer correlations that correlated significantly to performance (Yang, 2003). In contrast, Song and Agogino did a similar study and found that sketching quantity and variety were important indicators of performance. They state that “the combination of the total number of sketches and the [variety of sketches] positively correlated with design outcome; this combined measure was a stronger predictor than either alone” (Song & Agogino, 2004). Cross, on the other hand, finds that “productive design behaviour seems to be associated with frequent switching of types of cognitive activity” (Cross, 2004). Brockman adds an interesting result that more capable designers spent less time designing and developed a more complete set of solutions, that time spent designing was loosely inversely proportional to design quality (Brockman, 1996).

There have also been studies conducted concerning the effects of team composition on design outcome. Wilde finds tremendous value in terms of design competition performance in matching team members’ Myers-Briggs Type Indicator (MBTI) (Wilde, 1997). Wilde’s study was conducted in conjunction with a graduate design course in which students were split using student preferences, generally linear transformations of student MBTI, into teams of four. Specifically, national contest rankings increased dramatically when members of the designer pool with high Gough
Creativity Indices (GCIs) were distributed across teams and when preference groups were similarly distributed. Well-mixed teams were also found to have high morale.

Mechanical engineering is an excellent area to study creativity and the process of design itself because there isn’t a complete set of formal representations of implemented artifacts like there is for circuit design for example (Finger & Dixon, 1989). This means that instead of rearranging common elements, mechanical designers are likely to think about the components of the design themselves. Because of this, one will notice a tendency to sketch or model actual objects or assemblies (as opposed to just symbols or schematics) and to consider the physical design of the product. These activities all lend themselves to innovation and creative exercises.

2.2 Unexplored Areas

Even recent comprehensive assessments of the study of design claim that much uncharted territory remains. The theme of Kees Dorst’s keynote address at the Congress of the International Association of Design Research on November 14th, 2007 in Hong Kong was the assertion that design research is ready for a revolution (Dorst, 2007). Dorst accompanies the listeners through a thought experiment that explains why design research is ready for massive breakthroughs and describes what some of the current shortcomings are.

*Let us start with a thought experiment. If one would start a new scientific discipline that is aimed at the study of a complex area of human activity like design, how would one go about it? One would probably first observe this complex activity, and then describe it (which already involves a degree of interpretation). Then one would seek to create models that could explain the phenomena as observed and described. That explanatory framework could then be used to prescribe ways in which practice could be improved, developing methods and tools to support the practitioner and the student. There is a certain logic to this progression, yet historians have shown us that in our own field of design research, this is not what happened at all. The field emerged from practitioners developing ways of working to help them cope with the problems they faced. These prescriptive statements were*
If we continue our thought experiment now, let us zoom in on what you would need to do if you want to describe an area of complex creative human endeavour like design. What would be the elements of such a descriptive framework? Well, one would need to describe the object of this activity (in this case, the design problem and the emerging design solution e the ‘content’), the actor (the designer or the design team/designing organisation), the context in which the activity takes place (as far as it impacts upon the activity) and the structure and dynamics of the complex of activities that is being studied (‘the design process’).

Yet when we look at the design methods and tools that are being developed within the design research community, we see that three of these four ‘aspects of design activity’ are often ignored within the descriptive framework that implicitly underlies our thinking on design. The overwhelming majority of descriptive and prescriptive work in design research focuses on the design process, to the exclusion of everything else. Therefore the design methods and tools that are being developed inevitably focus on enhancing the efficiency and effectiveness of design processes. And apparently, this total ignoring of the design content, the designer and the design context allows us to claim that we are constructing models, methods and tools that will be valid for every designer, dealing with every possible kind of design problem, in any situation.

Within design research, the emphasis on the process of design is still overwhelming.

Dorst proposes that there are essentially four elements necessary to understand design –the designer, the object of design, the context, and the process. Most design studies focus on only the last of these four elements, the design process. There is a present need to address the first three components – what is being designed, who is doing the designing, and context of the whole event. Dorst continues to explain here:

However, we still tend to [ignore] the designer and the design context, perhaps because they are so complicated and open-ended. I propose that it is time we tackle them, because we have really reached the point where our
overriding focus on design processes is holding us back from a deeper understanding of the design activity itself. I will argue that we should refocus our attention and enrich academic design research by working on a deep and systematic understanding of the ‘design object’, the ‘designer’ and the ‘design context’.

Dorst also claims that “design researchers seem to be practical people, and rather trigger happy in this respect (‘jumping to prescriptions’ all the time).” Those who study design need to be careful about developing and recommending so many different design strategies. Furthermore, Dorst laments “many professional and experienced designers say that they do not use methods,” yet this notion “has always been shrugged off by the design research community,” and researchers continue to go on prescribing design processes that few ever end up using (Dorst, 2007). The field of design research first needs experiments that develop accurate descriptions of the designer, the object of design, and the design context before more credible prescriptions can be made.
Chapter 3: Methods

3.1 Goals

The objective of the study outlined in this paper is to provide further understanding of the answers to the research questions outlined in Section 1.3. In general, the goal is to examine which factors contribute to the productivity of a designer and how the design object and context relate. In this context, productivity is intended to include design performance, time efficiency, and attitude. Avoiding the chastisement of Dorst and Finger and Dixon for premature prescription (Dorst, 2007)(Finger & Dixon, 1989), the result of the study is not intended to be a recommended model of design, but rather to understand actual design through observation and suggest a few tools for further observation. The experiment is intended to capture information about all four elements of understanding design as suggested by Dorst, the designer, the object of design, the process, and the context (Dorst, 2007). Since prescribed design trajectories are seldom followed among actual professional designers (Dorst, 2007)(Finger & Dixon, 1989), this study is built on a design experiment where there was no prescribed method imposed on designers aside from project constraints such as final deadlines and budgets. Rather the design method chosen by the designers themselves is observed.

3.2 Experiment Design

The study is based upon a month-long design course, which will be explained in more detail in Section 3.3, Implementation. The design course contains several “design challenges” to which the participants are expected to design a solution subject to time and material constraints. The students are told beforehand the manner in which their solutions will be scored. Some challenges are completed individually while others are accomplished in teams of two or three. Mechanisms are built into the course to capture both subjective and objective measures of designers’ backgrounds, methods, and performance. These measures are finally cross-correlated in order to understand any relationships that might emerge.

Objective measures of designer backgrounds include quantifiable characteristics including age, school-year, GPA, standardized test scores, choice of major, etc.
Subjective measures include hobbies, Myers-Briggs Type Indicator scores (MBTI – also referred to as Jung typology), and the participant’s confidence in various skills such as calculation, sketching, building, etc.

Designer methods are captured via direct observation, various surveys, and design notebooks. Observations are made by teaching staff in consultation sessions and as the participants are actively engaged in design. Surveys are given at the beginning and end of each design task and include questions intended to probe the methods used by the participant. For longer projects, there are also daily surveys. Participants are further encouraged to keep a detailed design notebook.

The performance of designs is assessed using objective or subjective scoring rubrics. The scoring for some challenges is based on measurable performance metrics such as weight or strength. Other challenges are judged by a panel on subjective measures such as simplicity, anticipated market, or personal appeal. In each case, design scores are computed numerically to facilitate mathematic comparison with other variables.

After collecting the data, the information is analyzed and processed such that correlated variables are grouped. Exploration of these groupings of variables and their relationships then lends insight on the factors that are related to designer productivity and other important design measures.

3.3 Implementation

Discussion of the actual study implementation is broken into four parts: Scenario Description, Design Tasks, Task Characterization and Visualization, Project Teams, and Data Acquisition.

Scenario Description

The study was implemented as a nine-unit course called “Design-a-palooza” offered by the Department of Mechanical Engineering at Massachusetts Institute of Technology (MIT). Design-a-palooza was offered during the Independent Activities Period (IAP) of January, 2008, which was a month-long period between semesters for optional activities. The core of the class was designed to emphasize creativity rather than
building skills or computational abilities. The course was advertised as a fun, hands-on design experience that was open to all majors and levels of experience. Advertising methods included emails to various lists and fliers posted around campus. Because the research setting was a classroom, participants in the study will also be referred to as “students.”

The formal course meeting times consisted of about six hours of lecture and six hours of lab each week for four weeks. Discussion and exercises included both divergent and convergent elements of the design process. Lectures introduced various design process models and discussed many skills employed by engineers and designers. There were also workshops held during class-time including sketching and foam-core modeling tutorials.

**Design Tasks**

The course was built around six design tasks, which are also referred to in this paper as “design challenges”. There was no outside coursework aside from building solutions to these design challenges. Without external imposition, the students were encouraged to simply focus on the design of their solutions to the challenge. Design challenges were developed and tested in advance by a team of researchers who considered over 50 different potential projects. Most ideas arose independently from previously implemented or studied design projects, although a few were adaptations of projects that the research team members had participated in personally or heard of elsewhere. Several factors guided challenge selection. One of the most important factors was accessibility, meaning having a low barrier to entry for participants of various backgrounds and experience levels. Accessibility was emphasized in order to give each participant similar chance of success and allow comparison of participant performance. Additionally, challenges with obvious or limited numbers of solutions were avoided with the intent of encouraging divergence among design solutions and student design processes.

The crux of each challenge and a few relationships between the challenges are briefly introduced in this section. The actual challenge statements given to the study participants are located in Appendices A1 through A6. Discussion follows in the order
the challenges were completed by the students. Chronological order of the challenges is noteworthy as the possibility of students gaining experience through each challenge may impact the results. Experience gained in one project may affect subsequent challenge performance.

**Challenge 1**: The first challenge was called the “Egg Structure Challenge”. This challenge was given to the students as soon as they walked into the class the first day. Students were given about 45 minutes to individually build a structure out of given materials including newspaper, straws, paperclips, and eggs. The structure’s purpose was to support a large container of water. The container would be placed on the structure and incrementally filled with water until the structure failed. Scoring was given by the following relation:

\[
Score = \frac{\text{Height-Strength}}{\text{Weight}}
\]  

(Eq.1)

where *Height* was the initial height of the structure in inches, *Weight* was the initial weight of the structure in ounces, and *Strength* was the number of cups of water the structure could support before failure. One imposed stipulation that made design slightly more involved was a parameter that the container could directly contact the eggs only. Otherwise, this challenge could be considered a relatively traditional design task in the sense that engineers are constantly faced with the tradeoffs of material availability, performance (height and strength in this challenge), and other variables like cost, weight, and size. One student’s design is shown as an example in Figure 3.3a.
Figure 3.3a: An example submission for the Egg Structure Challenge.

Challenge 2: “Egg Drop” was the next challenge. In two days, pairs of students designed devices to protect an egg when dropped from approximately 300 feet. Entries were also rewarded for quick descent times. Scoring was as follows:

\[
Score = \frac{Egg\ Preservation}{Descent\ Time}
\]  
(Eq.2)

where Egg Preservation was a subjective rating from one to five of the final state of the egg (five being perfect preservation and one being total annihilation similar to that observed for eggs that were dropped unprotected), and Descent Time was the amount of time the device took to fall from initial release until final impact. A requirement was introduced that only up to one third of the surface area of the egg could be in contact with the device. Once again, this project might be considered a somewhat traditional type of design project that some members of the sample group may have seen before. Many of
the students had done smaller egg drops before, but none where speed was rewarded and
direct egg contact limited. The Egg Drop task was somewhat simple in the sense that it
could be fundamentally decomposed into basic aerodynamics and cushioning. One
team’s submission is shown in Figure 3.3b.

![Figure 3.3b: An example submission for the Egg Drop Challenge.](image)

**Challenge 3:** The goal of the “Lock Box Challenge” was modify a foam core box
to house and protect money. The purpose of the box was to make the money easily
retrievable for the designer, but difficult to access for a thief. The scoring algorithm was
simply

\[
Score = \frac{Thief \ Access \ Time}{Owner \ Access \ Time}
\]

(Eq.3)

where *Thief Access Time* was the average amount of time it took five individuals who had
never seen the box before to extract the money, and *Owner Access Time* was the amount
of time it took the box designer to remove the money from the box. Students worked
alone and were given one hour to complete their submissions. This design challenge
ended up being largely mechanical and students generally incorporated use of basic
mechanisms to achieve their goal. However, there was a large component of this challenge which required the designer to understand the user. The best designs involved thinking of which cues could be given to a thief or distract or confuse him while also considering how an owner might get to the money quickly. Thus, unlike the two previous challenges, user interface concerns were key. The interface for one student’s submission is shown in Figure 3.3c.

![Image](image.png)

**Figure 3.3c: The interface for an example submission for the Lock Box Challenge.**

**Challenge 4:** The next challenge was the “EggNigma Challenge.” The goal of this challenge was to accumulate points by moving an object (a small rubber ducky) from one point to another through a maze. The walls of the maze were made of eggs, and penalties were given for damaging the eggs. There were also extra points that could be gained by tipping over “guards” (plastic toy soldiers) that were placed in and around the maze. The detailed scoring algorithm is shown in along with the challenge description in Appendix A.4. Students worked in small teams over two weeks to design solutions to this challenge. One team’s design is shown in Figure 3.3d.
Figure 3.3d: An example submission for the EggNigma Challenge.

Challenge 5: The “I’m Game Challenge” was different than all other challenges because the output was a proposal rather than a device. Nothing had to be constructed physically. The challenge was to design a sport that would appeal to wide audiences. The sport description was encouraged to include rules, equipment, playing fields, and strategies. After an hour of preparation, students presented their sport to the rest of the class. The other students then ranked the games with regard to four entirely subjective measures – personal spectator appeal, personal participation appeal, general spectator appeal, and general participation appeal. The final score was simply the sum of each of these individual ratings. A sketch of one of the proposed sports is shown in Figure 3.3e.
Challenge 6: The course’s final capstone project, the “Chindogu Challenge,” was also unique. Students were required to develop chindogu. Chindogu is a Japanese design art originally developed by Kenji Kawakami (Kawakami, 1995). Kawakami describes chindogu as is the art of “unuseless” invention. The adjective, “unuseless” is meant to imply that a chindogu is not entirely useless, yet a chindogu cannot be considered useful in an absolute sense either. The art of chindogu lies in building within this paradox. Chindogu are generally simple devices that solve real, everyday problems. However, something about the chindogu prevents its acceptance into mainstream use. There might
be a logistical reason, or maybe a social reason, that would render a chindogu unlikely to be widely adopted. Chindogu are often found humorous. The distinctive art of chindogu has even been the subject of other design research (Patton & Bannerot, 2002).

Perhaps the best explanation of chindogu is firsthand exposure. The ten tenants of chindogu are listed below. Figure 3.3f follows, depicting one of Kawakami’s classic chindogu, the “Hay Fever Hat” (Kawakami, 1995).

1. Chindogu cannot be practical.
2. Chindogu must exist.
3. Chindogu are free from the chains of usefulness.
4. Chindogu are tools for everyday life.
5. Chindogu are not for sale.
6. Chindogu must solve a real problem.
7. Chindogu are not propaganda.
8. Chindogu are never offensive.
9. Chindogu cannot be patented.
10. Chindogu are without prejudice.

Figure 3.3f: Kenji Kawakami’s classic chindogu, the “Hay Fever Hat.”

Chindogu are generally very transparent in the sense that one can immediately discern the use of the chindogu as well as its fallacy simultaneously on first glance. The
essence of a superior chindogu can usually be caught in a single image as in the example above. In this spirit, student submissions for the Chindogu Challenge were limited to a single 8.5” by 11” image containing a picture of the chindogu in use accompanied by a title. These posters were then displayed in a chindogu gallery and scored subjectively by a panel of 11 judges including professors, students, and professional designers.

Chindogu submissions were different from the output of the other projects in that each entry did not have to be entirely functional, but physical implementation of the chindogu was required. The use of an expressive, semi-functional form model to convey an idea was emphasized rather than a robust alpha-prototype-level implementation. Students worked in multiple pairs to submit several submissions for this design challenge. A sample student-generated Chindogu is shown in Figure 3.3g. Judges rewarded submissions up to five points in each of four areas, (1) problem solving, (2) transparency, (3) simplicity, and (4) hilarity. The design’s total score was the sum of these ratings.

Figure 3.3g: An example submission for the Chindogu Challenge.
The Chindogu Challenge was probably the most non-traditional design task performed by the students. While this challenge involved actual implementation of a physical device to solve a real problem, students were asked to make the device fail as a product (in terms of potential for real-world implementation), exactly contrary to typical design procedures. The designs weren’t even scored on measures of functionality. Furthermore, the scoring scheme was entirely subjective, and students were required to cater to an audience who would have no direct interaction with their designs aside from viewing an image. Another difference when compared to the other challenges, the development of Chindogu is considered “comprehensive in scope” (Patton & Bannerot, 2002). This means that making a chindogu includes everything in design from idea generation through presentation to a “customer.” This was also the only challenge where students were required to define the problem that they were to solve. All of these factors differentiated the Chindogu Challenge from the previous design tasks.

**Task Characterization and Visualization**

The six design tasks can be graphically mapped in a way to visually interpret their relationships and differences. The proposed methods of characterizing and grouping the challenges for this study are intended to be versatile enough that the principles can be applied to any set of design tasks as a tool for visualizing the design space that the projects explore.

Any visualization system is inherently subjective in the sense that the variables that are visualized or even considered must be chosen. For visualizing design challenges, one could choose any variable that might be interesting, such as the technical difficulty of the problem, the importance of human factors, or the project timeline. After deciding which variables are important to be able to represent graphically, one must decide how to quantify them. Next one must determine how to illustrate those quantities in a way that makes sense. A simple system for visualization might include choosing three interesting measures relating to a set design challenges, giving the projects numeric ratings for each variable, then plotting markers in a three dimensional space defined be the variables chosen. This visualization can illustrate which regions within the three dimensional design space created by the three chosen variables are well-explored, and which are
relatively untouched. A surface could be made by connecting the points to visualize the region enclosed by design activities. Similarly, each marker could be given some real volume, perhaps even based on a fourth variable, to represent a design space that is occupied by that challenge. The latter method also retains expression of phenomena internal to the outlying data points. This system of characterization is completely versatile because the analyst or designer can choose which axes to use in gauging the design tasks or whatever other objects and space in need of visualization.

In the framework of this research, visualization of the design tasks is important as a way of understanding the types of projects undertaken by the study participants. To a large extent, the challenges themselves define the design object and context.

In order to apply the visualization technique described above, the first step is to make a table of important variables, and ratings for each design project. The example in Table 3.3a uses an arbitrary rating system from one to five for most variables (“Project Length,” however, is in units of days). Variables can be scaled to suit visualization. The first three variables are suggested by Stephanie Houde and Charles Hill as important variables for prototype characterization (Houde & Hill, 1997). However, there may be other interesting aspects of the project set that could be explored, depending on what is considered important to a particular project set characterization. Some other variable options are listed subsequently, but the list could be endless. Variables might also be very closely related to each other or very distinct.
<table>
<thead>
<tr>
<th></th>
<th>Egg Structure</th>
<th>Egg Drop</th>
<th>Lock Box</th>
<th>EggNigma</th>
<th>I’m Game</th>
<th>Chindogu</th>
</tr>
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<td><strong>Working</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>5</td>
<td>5</td>
<td>5</td>
<td>3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consideration of usage scenarios</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>importance of components motions</td>
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<td>4</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
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<td></td>
<td></td>
</tr>
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<td>4</td>
<td>5</td>
<td>5</td>
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<td>2</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>4</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>social implication or humor</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>attention to user</td>
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<td>2</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unlikeliness of having experience</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Number of Objectives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Customariness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>typicality of inherent tasks</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
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<td><strong>Number of Teammates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Team Size</strong></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
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<td>2</td>
<td>1/12</td>
<td>12</td>
<td>1/24</td>
<td>8</td>
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<td><strong>Chronological Order</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 3.3a: Classification of implemented design challenges.
Notice that there are many more interesting variables than could likely be expressed visually in a single image. So, for example, choose three or four variables that might be of particular interest for some reason, say, technicality, audience, typicality, and project length. Figure 3.3a shows where the challenges might lie on a plot using the first three variables as axes, and the fourth as marker size.

Sparse and dense spots within the design space can be seen visualizing the challenges in this way. From this plot, it appears as though challenges were mostly focused in two regimes, those that were technically difficult, although typical and non-audience oriented, and those that were technically easy while atypical and focused on catering to a specific audience. One notably vacant area corresponds to challenges that are technically simple with some degree of typicality or irrelevance to a target audience. This space corresponds to trivial problems that probably couldn’t be considered “challenges” at all and likely wouldn’t have been helpful or interesting to the study participants or researchers. Another large empty area relates to challenges that are highly technical, atypical, and considerate of a target audience. A challenge in this area would
be demanding indeed and might not be appropriate for the limited time-frame of this study. However there is also an unexplored region in the center of challenge groupings that corresponds to projects that would be mildly atypical, technically interesting, and have some consideration of audience or users. A challenge in this region may have been very fitting for this study.

This visualization technique can be helpful in designing a study with multiple challenges, and can be used in retrospect to better understand the study scope. This visualization technique is also useful for project planning, particularly if one wishes to ensure that many different of divergent projects are being undertaken. Yet, perhaps the most valuable aspect of this loose set of visualization guidelines is its versatility. It can be applied to any set of activities on any level and for any reason. Since choice of activity variables to plot, number of axes, and axis scaling are all adjustable, the analyst has total freedom.

**Project Teams**

There were three types of group structures employed among the design challenges in this study, “individual,” “team,” and “multi-team.” The structure for each challenge is shown in table format below in Table 3.3b and explanations of each group structure type are given subsequently.

<table>
<thead>
<tr>
<th>Chronological Order</th>
<th>Egg Structure</th>
<th>Egg Drop</th>
<th>Lock Box</th>
<th>EggNigma</th>
<th>I’m Game</th>
<th>Chindogu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Structure</td>
<td>individual</td>
<td>team</td>
<td>individual</td>
<td>team</td>
<td>individual</td>
<td>multi-team</td>
</tr>
<tr>
<td>Number of Teams</td>
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<td>5</td>
<td>11</td>
<td>5</td>
<td>11</td>
<td>22</td>
</tr>
</tbody>
</table>

**Table 3.3b: Team breakdown for design challenges.**

For “individual” challenges, each participant submitted their own unique solution without the help of teammates. Individual challenges also corresponded to the short challenges which were completed during class-time within about an hour (Egg Structure, Lock Box, I’m Game).
“Team” challenges required subjects to work in pairs (and one threesome). One of the team challenges lasted two days (Egg Drop) and the other lasted two weeks (EggNigma). The teams remained the same for both challenges for consistency.

There was also one “multi-team” challenge (Chindogu). For this challenge, each participant worked in four separate teams of two. Each team submitted one solution, meaning that each student participated in four different designs. Among the pairs in which each subject worked were the teammates from the previous team challenges. The purpose of maintaining common teammates throughout all non-individual challenges was to avoid complicating analysis by changing too many variables from challenge to challenge. In the multi-team challenge, original teammates were included as a baseline or control. The remaining pairing was determined using students’ Myers Briggs Type Indicator ratings (MBTI). Each student worked with at least one other student with a very similar MBTI, and another student with very different MBTI with the goal of highlighting the affects of MBTI similarity on team performance.

Data Acquisition

As explained by Finger and Dixon, design is not solely a physical process and involves more than is generally recorded or left behind (Finger & Dixon, 1989). Because of this, objective and subjective data were obtained using surveys, daily logs, and direct observation in addition to design notebooks and the design products themselves. Each method of data acquisition and the objectivity of the data are described in more detail below and examples of these methods are located in the appendices.

Several surveys were used throughout the study, each containing both free answer subjective questions and quantifiable objective questions. Participants in the study completed a characterization survey upon enrolling in the class. The characterization survey was directed at ascertaining the subjects’ self-reported degree and type of past experience (such as project classes and engineering-related hobbies), typical performance measures (such as GPA and standardized test scores), and personality traits (such as Jung typology). Participants also completed an initial “shock” survey upon receiving each design challenge and a final “hindsight” survey upon its completion. These surveys focused the feelings of the designer upon receiving and completing the challenge, but
also captured some of the design process (such as time management practices and amount of concept iteration). An exit survey was also conducted at the conclusion of the study which was intended to capture retrospective feelings about the study as a whole (including comparisons of each challenge in terms of difficulty of each design activity and overall enjoyment). Images of each survey as employed in the study are shown in Appendix B.

Subjects also completed daily logs for challenges that lasted longer than a week. The daily logs were submitted electronically and were tailored towards obtaining an accurate report of daily activities. Fields included the amount of time spent and progress made in each type of design activity as well. Projected performance, relationship with teammates, and number and type resources used were also recorded. Daily logs were focused on objective, numerical data as frequent but quantifiable measures of designer activities. Documentation and images of both daily logs are included in Appendix B.

Direct observation of the participants’ activities was conducted throughout the study. The teaching staff observed each participant throughout much of the design process for each design challenge. Direct observations were entirely subjectively assessed. Some observations were physically recorded and others noted mentally. These observations were used as filters for the interpretation of the analyzed results and as inspiration for the suggestions made in the discussion and conclusions sections of this paper, but did not enter in the numerical analysis or presentation of results.

Paper design notebooks were given to each student on the first day of class and the keeping of accurate, detailed records was encouraged. Students were instructed that the notebooks were for their use, not as a presentation medium and that they should feel comfortable including any sketch despite fidelity or skill. Likewise, calculations, lists, and notes were permitted to be as unsightly or attractive as the student liked. Ultimately, the design notebook was emphasized as a personal tool for the student in their design process. This being emphasized, students were also instructed to label their sketches with different numbers for different concepts and letters for different iterations or sketched for each concept. Labeling by the student was meant to allow easier and more accurate tracking of concept generation and development. Other than perhaps the data contained in the sketch labels, the data extracted from the design notebooks is largely subjectively
interpreted. Design notebooks are valuable data sources because they are minimally intrusive (Sobek II & Jain, 2007). Several typical examples of student design notebook entries are contained in Appendix C.

### 3.4 Limitations

Despite the thought put into the research design, this study has many possible shortcomings which deserve discussion before data is presented. Acknowledgement of the limitations of this study should temper the results and their implications which is presented subsequently.

The first and most obvious feature to note is the sample size. There were eleven participants in this study. For several design projects, participants worked in teams, yielding only five discrete quanta of performance results. However, in one challenge in particular, the Chindogu Challenge, there were more challenge entries than there were participants because students worked in several different groups in parallel, in this case yielding 22 distinct performance data points. Although working in depth with a small number research subjects can yield some very interesting and telling observations, one must be careful about making generalizations and mathematical interpretations from extrapolations of a small data set.

Another characteristic of this study which is related to the sample size is the sample composition. The research subjects were all relatively diverse in many ways including Jung typology, academic year, age, gender, and chosen field of study. A summary of study participant metrics is shown below in Table 3.4a. However, the sample composition may differ from a representative sample of designers, engineers or students in general for many reasons. All participants were MIT students. The participants were also self selected and participated in the study with various motives that might not apply to design in general such as availability, the need for awarded academic credit units, and interest in design and creativity. There were also a disproportionately large number of mechanical engineering students. Participant self-selection was also affected by other elements of the study implementation such as means of advertising, location, and scheduling.
<table>
<thead>
<tr>
<th>Gender</th>
<th>Jung Typology</th>
<th>Major Course of Study</th>
<th>Academic Year</th>
<th>Age</th>
<th>GPA (5.0 scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (7)</td>
<td>E / I (5 / 6)</td>
<td>Aeronautics and Astronautics (1)</td>
<td>Freshman (1)</td>
<td>18 (1)</td>
<td>3.0 – 3.4 (3)</td>
</tr>
<tr>
<td></td>
<td>S / N (5 / 5)</td>
<td>Biology (1)</td>
<td>Sophomore (2)</td>
<td>19 (2)</td>
<td>3.5 – 3.9 (2)</td>
</tr>
<tr>
<td></td>
<td>T / F (7 / 3)</td>
<td>Management (1)</td>
<td>Junior (2)</td>
<td>20 (2)</td>
<td>4.0 – 4.4 (2)</td>
</tr>
<tr>
<td></td>
<td>J / P (4 / 4)</td>
<td>Mechanical Engineering (6)</td>
<td>Senior (5)</td>
<td>21 (2)</td>
<td>4.5 – 5.0 (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban Studies and Planning (1)</td>
<td>5th Year (1)</td>
<td>22 (3)</td>
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</tr>
<tr>
<td>Female (4)</td>
<td></td>
<td>Undeclared (1)</td>
<td></td>
<td>23 (1)</td>
<td>N / A (1)</td>
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</table>

Table 3.4a: Study participant characterization.

The design tasks were also very short compared to most project time spans typical in academic or professional settings which can last for months or years. In this study, three of the challenges lasted between one and two hours, one challenge two days, and two challenges lasted about a week and a half. Therefore, one may argue that the results discussed here are likely more applicable to projects with quick turnaround times. However, the projects implemented in this study focus on the early conceptual stages of design, rather than the later phases of detailed engineering and construction of alpha-prototype levels of products. The critical initial phases of design in which concepts are generated and selected determine the development direction, but may be of similar length in academic or industry settings, even for longer projects. These early stages include activities that are often associated with creativity, the understanding of which underscores the impetus of this research.

All of these limitations being considered, the results presented in this paper have been analyzed as statistically significant, generally with at least a 95% confidence level. Thus, the findings of this study are meaningful and can be used to expand the current understanding of the questions posed in the Motivation Chapter (Chapter 1) and the Goals Section (Section 3.1).
Chapter 4: Results

4.1 Measurements

Measurements were all transcribed from surveys, logs, and notebooks electronically, or by hand and compiled in a Microsoft Excel spreadsheet. All of the numerical data combined consisted of approximately 1,400 values for each participant, totaling at around 15,000 data points total. Presentation of all of this data is beyond the scope of this paper, but Figure 4.1a is a graphical example of the some of the types of data gathered for any particular challenge. This figure shows the amount of time in hours that one participant spent on each of several design activities each day throughout one the EggNigma challenge. The participants expectation of final design performance is also rated (on a scale from 1 to 5, 5 being the best) in the last row.

Figure 4.1a: An example of collected data.
Due to the sheer magnitude of information collected, most of the data presented included within this paper is limited to correlations found among some of the more interesting of the 1,400 tracked variables. These correlations are presented in the next section, Analysis.

4.2 Analysis

Data analysis was performed using several methods. Major variables were correlated using three measures of statistical significance, Pearson’s correlation, Kendall’s correlation, and Spearman’s correlation. Interestingly, statistical significance implied by Pearson’s correlation and Kendall’s tau were almost identical while Spearman’s correlation only differed slightly. The high level of agreement across correlation methods substantiates the results.

In order to use a very conservative approach, graphical analysis is based on only the variables that were correlated with more than a 95% confidence level using all three correlation methods, Pearson, Kendall, and Spearman. This level of confidence is quite high and the 95% cutoff, while somewhat arbitrary, is necessary for clear and accessible visual analysis. Later discussion of the results will include some borderline correlations not shown graphically to enhance understanding of the graphical results. Figure 4.2a shows a matrix map of these correlations among some of the data collected throughout the study. Green dots (which appear lighter in grayscale copies) correspond to positive correlations, while red dots (which appear darker in grayscale copies) correspond to negative correlations. For the MBTI variables listed, the “positive” value for the variable is a higher ranking for the first letter listed. For example, a positive value for “Jung E/I” signifies a higher tendency towards “extroversion” rather than “introversion.”

Subsequently, data correlations were grouped into clusters of interacting variables using a design structure matrix technique (Honda, 2008)(Thebeau, 2000). Clustering the correlated variables into groups facilitates visualization and analysis. The resulting clustering is shown in Figure 4.2b. Clustering was accomplished by minimizing a cost function, the minimization profile of which is shown in Figure 4.2c. Table 4.2d lists the cluster group members; however, recall that there are other interactions between different clusters shown Figure 4.2b that will prove interesting in the ensuing discussion.
Figure 4.2a: Data correlation matrix.
Figure 4.2b: Clustered design structure matrix
Table 4.2a: Correlation cluster member list.

| Cluster #1 | Liked Class, Liked Staff, Liked Team, Confidence Improvement, Overall Enjoyment, Self-Confidence, Visual Skills, Calculation Skills, Skill with Ambiguity, Jung S/N |
| Cluster #2 | Average Skill Rating, CAD Skills, Mechanical Skills, Hand Skills, Team Skills, Engineering Work Experience, Engineering Class Experience |
| Cluster #3 | Jung E/I, Egg Drop Performance, Overall Performance |
| Cluster #4 | Leadership Skills, Jung E/I, Lock Box Performance |
| Cluster #5 | Age, School-year, Humanities Class Experience |
| Cluster #6 | Overall Difficulty, Chindogu Performance |
| Cluster #7 | Decision-making Skills, Time Management Skills |
| Cluster #8 | Skill Improvement, Math Class Experience |
| Cluster #9 | I'm Game Performance |
| Cluster #10 | EggNigma Performance |
| Cluster #11 | Egg Structure Performance |
| Cluster #12 | Jung P/J |
| Cluster #13 | Jung T/F |
| Cluster #14 | Science Class Experience |
| Cluster #15 | Project Experience |
| Cluster #16 | Design Class Experience |
| Cluster #17 | Estimation Skills |
| Cluster #18 | Art Skills |
| Cluster #19 | GPA |
| Cluster #20 | Gender |

Figure 4.2c: Correlation clustering cost history
4.3 Observations and Implications

Although many implications may be drawn from observations of the variable clustering shown in the Analysis Section (Section 4.2), this paper will focus on some of the possible implications for designers as individuals, specifically explanations of the relationships regarding the designer experience level, other design-related skills, and designer confidence. Following, characterization of the object of the design challenges including the design object and challenge context is discussed.

Designer Experience Level

In this study, all of the study participants were students, and as such, there is no intention of the term “more experienced designer” being construed to mean “experts.” Designer experience in this section simply refers to a designer’s school-year, amount of past independent project experience, and age. All of these factors were strongly positively correlated, so they will be used almost interchangeably as “design experience” to streamline the flow of the discussion.

Surprisingly, there was not a clear-cut relationship showing indicating that more experienced designers perform better in general, i.e. in terms of total normalized results across all of the projects. There was only a 0.03 cosine correlation for general results versus designer age. Similarly, there was only 42.4% probability that there was any significant relationship at all (P) with a weak relationship of about 0.19 (rho). Perhaps the lack of correlation is due to the fact that the design projects presented in this study didn’t necessarily focus on traditional engineering skills or even building ability and were a relatively accessible mix of challenges to pose to designers of different experience levels and backgrounds.

However, among certain design projects, there were clear relationships between designer experience and performance. For example, more experienced, older designers tended to better on the Egg Structure Challenge. Recall that the Egg Structure Challenge was a short, individual challenge that employed relatively traditional design skills, probably more so than any other challenge. Similar definitive positive or negative
correlations between experience level and performance were not evident for any other individual or short projects. On the other hand, younger designers with less formal engineering and design training statistically did better at the Chindogu Challenge, which was probably perhaps the design challenge to which traditional design process skills applied the least. No comparable correlations were evident in other team projects or long projects.

This result suggests that while formal design training helps with more traditional design projects (at least in the short term), that it may hinder more non-traditional projects. Perhaps as students learn the “correct” ways to approach and solve routine engineering problems, their ability to think creatively and solve problems that do not conform to traditional design methods atrophies. It might also be the case that engineering education succeeds at teaching students to be able to deliver products that achieve a measurable function while education might lack preparation for appealing to human emotion such as humor or swaying a subjective judge (such as a potential consumer looking at a packaged product, for example). Another possible explanation is that maybe younger, less experienced designers retain the ability to develop more unexpected designs, which was rewarded in the Chindogu Challenge.

The implications of these results are complimented by the findings of Marples, that designers tend to reuse ideas (Marples, 1961). Interestingly enough, one student even claimed the tendency to turn to already known solutions in her written self-assessment. She states, “I’m reluctant to adopt new ideas unless I see proof that it works.” An experienced designer would have more ideas to rely on and be more inclined to turn back to her quiver of known solutions to address a new problem. This method of addressing challenges could clearly be labeled as less creative. While this would work nicely for the Egg Structure Challenge, a common structural problem, the same tendency would fail for the Chindogu Challenge. Since the study participants had little exposure to existing chindogu, and certainly no training in the art, experienced designers could not rely on known solutions. Even if a solution was discovered, it would be useless since the designer would be expected to create a unique solution. An inexperienced designer, however, would more readily move towards innovation which was difficult to avoid for the Chindogu Challenge. This mirrors Ho’s finding that “the less experienced designer
seems to show more creativity than the more experienced designer” (Ho, 2001). In light of Waldron et al.’s conclusions (Waldron, Jelinek, Owen, & Waldron, 1987), chindogu is also much more difficult to represent abstractly or symbolically, whereas a structural problem would lend itself to analysis and representation with more traditional engineering tools. Even Cross’s claim that “expert designers are solution-focused, not problem-focused” is echoed here. These studies combined with this experiment seem to agree in suggesting that experienced engineers would excel at traditional design problems, while novel problems might be the forte of novices.

It was also noted that there was a negative correlation between designer experience and rated difficulty of challenges. This result is expected. As designers gain experience and skills, they should become better equipped to overcome challenges. A related finding is that there was also a negative correlation between the amount learned in the design projects and amount of time that a designer had spent on design projects previously. This also makes sense in terms of the law of diminishing returns. As a designer participates in more projects, her knowledge base will grow, and in general less new information will be learned in subsequent design experiences. The combination of these results, however, carries interesting implications. The next level of inference is that less is learned from less challenging design projects. This observation supports the idea that in order to continue learning, one must continue tackling difficult problems. It was interesting that there was no significant relationship between how difficult a challenge was and how much the designer enjoyed working on the project. These findings would suggest that it is there isn’t a trade-off between challenge difficulty and challenge enjoyment. Therefore, difficult challenges are valuable as a learning tool, and the desire to avoid difficult challenges for fear of the project becoming miserable is perhaps unfounded.

Another intriguing finding was that those who had taken more design classes previously enjoyed both the class and the challenges less. Contrarily, those who were less experienced found that their skills improved more, and they enjoyed the challenges more. This implies that learning and developing are part of the enjoyment of design. One student echoed this fact in his self-assessment, “I like learning new skills/techniques, even if I’ll only use them once … Learn[ing is] my favorite.” Perhaps the reason why
experienced designers enjoyed the class less was exactly because they were learning less, or maybe the more experienced designers had lost an appreciation for more creative, open-ended, or recreational design. This result would suggest that if a manager or professor intends for their subordinates or students to enjoy their design work more, they might try to address how to make their projects more challenging and edifying. Enjoyment of the project seems to accompany growth.

**Other Design-Related Skills**

A few interesting results emerged regarding the degree of skill or preferences that a designer claimed they possess and their design performance. The most surprising result was that the only factor that related to overall performance in all of the challenges was the MBTI extroversion score. The more extroverted the student’s MBTI rating, the better they tended to perform. There were no other measured factors that ended up have a significant relationship with overall performance. Perhaps this phenomenon is unique to creative design or early-stage design tasks. Extroversion might be important in creative design work as those that generate ideas must be willing to share their ideas at some point in order to contribute. Sharing one’s original ideas would likely be easier for extroverts than introverts. Assessment of this characteristic may already be reflected somewhat in interview settings to the advantage of employers. More extroverted individuals tend to be more comfortable speaking with new people in new settings and first impressions of them, such as those retained from interviews, are often more favorable.

Those who claimed higher leadership abilities also found that concept generation was easier. Understandably, these designers also received higher MBTI extroversion scores. Perhaps those who are more comfortable coming up with and sharing ideas feel more at home in leadership positions. Sharing one’s opinions and ideas is also a natural companion to an extroverted typology. Those who find they have difficulty thinking of ideas, either because of self-criticism or lack of inspiration may have more difficulty placing themselves in high-profile or leadership roles.

Other unexpected results also emerged. For example, mathematical skill was inversely related with performance on the Chindogu Challenge. Specifically, estimation skill hindered chindogu score with a -0.36 cosine value and a 95% confidence level, and
calculation skill impeded performance even more acutely with a cosine value of -0.40 and a 97% confidence level. This relationship may be due to the nature of the way much of mathematics is practiced, as an analysis exercise, rather than a synthesis exercise. A possible explanation might refer to left-brain, right brain dominance among students. Mathematics is considered a left-brain activity, while chindogu would be more appropriately described as a right-brain exercise. Developing several different chindogu is inherently a synthesis intensive task requiring thorough idea generation. Although the brainstorming element of the Chindogu Challenge was not rated as particularly difficult by students, their design notebooks showed that fluency in developing a large number of ideas was most central to this challenge. In other words, even though brainstorming was one of the most time and effort intensive tasks, it was not considered difficult.

The ability to work with one’s hands also played a role in the results of a couple challenges. The Lock Box Challenge had a very strong positive correlation with a rho value of 0.654 and a confidence level of 97.1%. This result seems intuitive because building skill and fluency was probably most important for the Lock Box Challenge. The challenge focused on mechanisms, allotted time was short, materials were limited, and students couldn’t rely on a more dexterous teammate to construct mechanisms. This implies that participants with the ability to quickly build functional devices out of simple materials had an advantage. The existence of this correlation is not particularly startling, but there is value in noting the characteristics of the specific challenge in which it played the strongest role.

**Designer Confidence**

Correlations with designer confidence and productivity related variables yielded many interesting results. Among positive correlations that existed regarding confidence, there arose a stark dichotomy between those that rated themselves as highly self-confident, and those that did not. Self confident individuals liked the class more, enjoyed the challenges more, appreciated the teaching staff more, and liked their teammates better. Those whose confidence improved more also enjoyed the class more. Those who were less confident or who didn’t feel like their confidence improved enjoyed everything less. Confidence didn’t affect the numerical performance results as scored per se, but
definitely influenced several very important factors in any workplace or educational setting. Namely the work atmosphere, morale and designer satisfaction. These are important byproducts of designers that aren’t equal to the direct output of their work, but do affect the company dynamic in a very real way. The relationships found in this study seem to suggest that either people are confident, happy, and appreciative of their superiors and peers, or they are the opposite and that experience doesn’t help. This result is important to consider for those who work with or employ designers and reinforces the importance of meeting potential hires in face-to-face in interviews and requesting letters of recommendation.

Another interesting finding is that those who were more skilled at solving ambiguous problems liked the class more. This relationship was strongly statistically significant with a 97.2% confidence interval and a positive rho correlation of 0.658. (This skill was self-assessed directly in the initial questionnaire by a simple question asking students their skill level at solving ambiguous problems.) Designers who are involved in the early divergent stages of design will likely enjoy their work more if they feel that they are more comfortable with ambiguity. Thus, hiring managers for early stage research and development or high-level design positions might contemplate developing measures of prospective employees’ levels of comfort with ambiguity in order to find designers who will enjoy their occupation more and be more productive.

Designer confidence wasn’t linked strongly to experience. The relationship was only -0.26 for rho with a 42% confidence level. If anything, experience may slightly suppress confidence. This suggests that designer confidence might be a more inherent trait with little relation to age, school year, training, or experience. Perhaps the significance of this result is that as designers get more experience they gain the perspective to put their abilities in context. For example, as a design student’s skills improve, they might find more areas in which they’d like to grow or feel unqualified. As more is learned, the more designers may realize they don’t know. Thus confidence might remain relatively constant or may even decrease over time.
Characterization of Design Challenges

Measurements of student’s opinions about the design challenges also reveal something about the nature of each challenge. Table 4.3a shows the difficulty level of each challenge as rated by the students in terms of overall difficulty and difficulty of individual design activities within each challenge. Standard deviation of the ratings is also listed. Heavy, green entries are the highest rated challenges in each category, and heavy, italicized, red entries are the lowest rated. The difficulty scale was imposed such that one signified “very easy,” three meant “okay,” and five denoted “very hard.” Enjoyment of the design challenges is also listed, with one being “hated it,” three being “okay,” and five being “loved it.”

<table>
<thead>
<tr>
<th></th>
<th>Egg Structure</th>
<th>Egg Drop</th>
<th>Lock Box</th>
<th>EggNigma</th>
<th>I’m Game</th>
<th>Chindogu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological Order</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Brainstorming Difficulty</td>
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<td>3.91</td>
<td>3.36</td>
<td>2.50</td>
<td>3.00</td>
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<td></td>
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<tr>
<td>Concept Selection</td>
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<td>2.45</td>
<td>2.45</td>
<td>3.55</td>
<td>2.40</td>
<td>3.27</td>
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<tr>
<td>Difficulty (st. dev. = 1.4)</td>
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</tr>
<tr>
<td>Detailed Design</td>
<td>3.55</td>
<td>2.86</td>
<td>3.09</td>
<td>4.00</td>
<td>2.00</td>
<td>2.27</td>
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<tr>
<td>Difficulty (st. dev. = 1.4)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Implementation</td>
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<td>2.36</td>
<td>3.73</td>
<td>4.18</td>
<td>1.89</td>
<td>2.18</td>
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<tr>
<td>Difficulty (st. dev. = 1.4)</td>
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<tr>
<td>Overall</td>
<td>3.50</td>
<td>3.10</td>
<td>3.77</td>
<td>4.00</td>
<td>2.00</td>
<td>2.86</td>
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<tr>
<td>Difficulty (st. dev. = 1.2)</td>
<td></td>
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<tr>
<td>Overall</td>
<td>3.00</td>
<td>3.82</td>
<td>3.09</td>
<td>3.91</td>
<td>3.60</td>
<td>4.64</td>
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<tr>
<td>Enjoyment (st. dev. = 1.3)</td>
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</table>

Table 4.3a: Classification of implemented design challenges.
The challenge ratings have interesting significance. Note that the EggNigma challenge was rated the most difficult, but it was also one of the most enjoyable projects. On the other hand, the second-most difficult project, the Lock Box Challenge, was ranked as one of the least enjoyable projects. Therefore, it seems that designers don’t like or dislike projects based on project difficulty. It is interesting that the two longest challenges ended up being the most enjoyable, and the two projects that were the least liked required the students to actually build a physical device and were done in during class within an hour time-frame. Perhaps designers appreciate enough time to think through a project and develop solutions rather than more frantic scrambles to throw solutions together.

The ratings for the challenges can also be visualized using the challenge visualization technique discussed in Section 3.3 to gain more insight on the challenge set as a whole. A visualization of the challenges plotted on the axes of brainstorming difficulty, concept selection difficulty, and implementation difficulty with marker size being overall difficulty is shown in Figure 4.3a.

![Figure 4.3a: Visualization of difficulty space of design challenges.](image-url)
The value in this visualization comes in noting the populated and unpopulated areas in the difficulty space of the design challenges. There appears to be a few clusters among the challenges that emerge in three-dimensional design difficulty space. There is a group of challenges for which idea generation, concept selection, and implement are equally easy. There is another cluster for challenges that are difficult in terms of implementation and brainstorming, but for which concept selection is difficult. There is also a challenge for which idea generation was difficult although implementation and selection were difficult, and there is another challenge that is difficult in all of these areas.

It is interesting that students rated all challenges as difficult to brainstorm and difficult to implement or easy to brainstorm and easy to implement. This result implies that difficulty in brainstorming may be due to the fact that either any solution to the challenge would be difficult to implement, or contrarily, that a when one has difficulty generating ideas, they are more likely to have difficulty implementing the one that they end up developing. There also weren’t any challenges that were rated as difficult in terms of concept selection except those of medium difficulty in terms of implementation. Perhaps this phenomenon is a result of the difficulty in choosing which concept to pursue comes when the implementation of the concept difficulty is unclear. The fact that there were challenges located well within all four quadrants of the brainstorming difficulty and concept selection difficulty axes is noteworthy. This means that concept selection can be easy or difficult independent of whether or not brainstorming was challenging.

It was observed that each subsequent design challenge increased in novelty for an average student. One student commented on how the increasing degree of atypicality of challenges opened his mind and helped him be more creative. He said,

*If Chindogu had been our first challenge, I wouldn't have known how to start it. The [Egg Structure] challenge was a perfect first challenge because it was accessible – most everybody has seen a version of the paper tower challenge at some point, and we all had an idea about how to tackle it. The challenges that followed were progressively more complex and harder to start, so we were able to build up a sort of mental momentum which let us think outside the box to take them on. By the time Chindogu came along, you had torn our minds open and we knew how to approach it.*
When planning design tasks, making sure that the task domain (especially in terms of atypicality) continues increasing in variance enhances the ability to meet a new, more atypical challenge. Thus, facing creative design tasks that demand increasing creativity can foster the ability to be creative and confront non-traditional challenges.
Chapter 5: Conclusion

5.1 Summary

The various data collected throughout several short, early-stage design projects from diverse sample of students had several interesting implications. Discussion each of the research questions individually is an effective summary.

How does experience affect the quality of a designer’s output?

Analysis showed that upperclassmen excelled in traditional design problems while less experienced student doing well in more atypical types of projects which require more creativity. More experienced students also found the challenges less demanding, but surprisingly, they didn’t perform any better overall. These results suggest there is room for improvement in our methods for training designers in terms of retaining creativity and mental agility. Perhaps curriculum may not be achieving its goals of increasing designer productivity, or maybe design ability is more closely tied to innate talent than experience.

Which specific characteristics and skills do “good” designers have?

Designers with a higher extroversion MBTI rating tended to perform better overall. Extroversion was the only variable found to be significantly related to score across all challenges.

Correlation between specific skills and designer performance in the challenges individually also yielded interesting implications. It appears that mathematical is not a major factor in determining design ability. For some mechanism intensive or fabricationally nontrivial challenges, the ability to work with one’s hands, tinker, take things apart or build things seems to benefit output. Other skills seemed to play less important roles. Unexpectedly, there was little visible correlation between conventional means of determining student aptitude and their actual design skill as measured by design output. Conventional measures include GPA, standardized test scores, and past experience.
Results from the Chindogu Challenge also offered information on understanding the characteristics of “good” design teams as well. In the Chindogu Challenge, special attention was given to pairing students by MBTI ratings. The results indicate that the degree of similarity and dissimilarity within partnerships had little relation to performance in this non-traditional design task.

Are there indicators of whether a designer will likely enjoy a particular project, their teammates, and their superiors?

Confident designers tended to be happy all around with respect to their workplace. The data insinuated that confident designers enjoyed their work and those with whom they worked. The same set of designers also appreciated the teaching staff more. In the workplace, the amount that designers liked the teaching staff may be an appropriate analog to superiors. Learning was also closely tied to designer confidence and happiness. Cause and effect is difficult to determine, but either happy designers learned more, or designers who learned more were happier. The idea that these important morale factors, confidence, contentedness, and learning, are closely related is valuable to understand when assessing or stimulating the potential trajectory or productivity of a designer.

How can educators and employers characterize and visualize the variation in design tasks of their students or employees?

A useful tool for visualization of the relationship between design projects was presented. An analyst can simply choose the factors of interest as design space axes, and plot all of the projects in the space defined by those axes. Assigning each project marker a size based on effort, emphasis, or timescale is also appropriate. Then relatively sparse or dense areas in the design space can be assessed. Planning increasingly divergent projects using this visualization technique was found to be helpful in increasing design ability and creativity.

5.2 Recommendations

Situations differ greatly across a variety of applications regarding design, engineering, creativity, and productivity. Recommendations made here aim to help
increase designer satisfaction, creativity, and productivity. Suggestions are based on the phenomena observed within this study; however, none of the recommendations have specifically been implemented as the basis for a long-term study, but are rather the opinions of the author based on student feedback and personal observation. Thus, the efficacy of these suggestions remains unproven. Rather, the thoughts presented are intended as a starting point for consideration of possible responses to some of the conclusions of this research. The proposals presented in this section would be appropriate as the basis for future studies that build from the results discussed earlier. Specific recommendations are directed at academic and industrial audiences, although application of the principles discussed is certainly possible elsewhere.

**Academic Recommendations**

As traditional engineering and design skills become increasingly computerized or outsourced, educational institutions gain value in being able to cultivate skills that are indispensable and not easily programmable. Increasing the ability to perform synthesis tasks proficiently is particularly valuable for these reasons. Encouraging creativity and flexibility is a vital component of such an education.

Keeping the designer’s mind limber allows them to confront a wider variety and larger number of challenges. This flexibility may likely be promoted by varying assignment types, especially synthesis-intensive activities. Most classes offer one or two types of activities for practicing and learning the course material. Weekly homework assignments generally require the students to use information from the class and arrive at a very small subset (often the case is one) of “correct” answers. Tests are similar, but even more convergent, with less access to resources and in a shorter time frame. Some courses incorporate tasks that involve synthesis, often in the form of projects. Projects allow practice of fundamentally creative tasks like generating ideas, strategies for implementing them, and hands-on experience applying the principles learned in the course. However, most courses with a project have only one project. With only one project, students don’t get to practice the design process in a real sense.

A larger number of projects may help stimulate design creativity and productivity. When a pitcher practices pitching, he throws hundreds of balls with slight variations as he
improves. When ballroom dancers practices a routine, they run through the steps over and over again – hopefully changing and getting better each time. Similarly, design students may be able to extend creative abilities by experiencing the design process more than once, maybe even trying out more than one method, leaving room for mistakes and refinement. Several participants in this study seemed to gain a better understanding of their tendencies, strengths, and weaknesses as a designer by being able to participate in several projects within a short amount of time. As a useful and unexpected byproduct of this research, many students also claimed that they developed confidence in their idea generation skills and the ability “come up with crazy ideas” and “put out a lot more concrete ideas” because of the diverse multi-project experience inherent to the study activities.

When multiple projects or assignments are implemented, it may be useful to gauge the diversity of the exercises on various spectra. Curriculum planners may use the visualization technique introduced in Section 3.3 to graphically understand the proximity of proposed exercises in a space defined by axes of their choosing. For example, if a particular course’s goals are to allow students to practice creativity, traditional engineering skills, and user interface design, a course planner might plot all of the assignments, activities, and instruction on these axes. Each point might be assigned a color based on the type of activity and size based on intensity of the activity. This method allows the course planner to assess whether or not the current plan explores the desired areas and their combinations with similar intensity. If a particularly desired region in the space is unacceptably sparse, then appropriate activities corresponding to that region could replace other activities in corresponding to denser regions. Giving students the chance to attempt diverging exercises in multiple combinations may keep their minds nimble.

Incorporating design situations for students that are very unusual may also help retain creativity and the ability to succeed at non-traditional tasks. For example, assign students to develop a transportation system for another planet, like mars or the moon, were the planet populated. Or another activity might be to design a new language. One might ask for a possible computer interface for dogs were they intellectually highly developed and capable of using a computer. Any exercise to bring students totally away
from prescription and current existing design methodology could be given to help practice and retain creativity. Such exercises are practice working in areas in which the student has little or no experience. Allowing students to address occasional problems like these expose them to climates where they are totally free to let their concept generation soar. This freedom comes because current design solutions are non-existent; so, there are neither direct analogs to rely on or stifle creativity nor current experts to tell them that their concepts are “wrong.” The designs may be difficult to test, but the beginning stages of the design process remain valuable and interesting. The ability to think things through problems that were totally foreign until a minute ago will assist students in their ability to adapt to new situations, understand the ever-expanding knowledge base of the global technical community, and contribute to forefront development.

Combining the last four recommendations by having students participate in a large number of diverse, non-traditional, and creative projects, may help students avoid developing the habitual design styles of experts, expand design ability (especially for non-traditional design tasks), and retain or even magnify their creativity. This sentiment is echoed in a New York Times article by Janet Rae-Dupree dated May 4th, 2008 who cites research to support the claim (Rae-Dupree, 2008).

\textbf{[T]he more new things we try — the more we step outside our comfort zone — the more inherently creative we become […] Researchers] have found what they call three zones of existence: comfort, stretch and stress. Comfort is the realm of existing habit. Stress occurs when a challenge is so far beyond current experience as to be overwhelming. It’s that stretch zone in the middle — activities that feel a bit awkward and unfamiliar — where true change occurs.}

\textit{AFTER the churn of confusion, […] the brain begins organizing the new input, ultimately creating new synaptic connections if the process is repeated enough.}

Occasional self-reflection is also invaluable to students and educators. The process of listing and evaluating personal weaknesses and strengths helps students to assess and manage their own performance. Written reflection also allows instructors to see what is actually happening within the student. What is important to them? What are they worried about? Is it the same thing that you’re worried about? As observed in this
study, both well-developed and weak elements of a student’s abilities and skill set as perceived by a professor or educator may be totally different from the actuality or from what the student sees him or herself. Self-assessments recorded in the students’ design journals were indispensable in understanding the student situation in this research. Students also seemed to value this exercise as an opportunity to understand themselves as well as make goals for personal progress.

Educators need to be wary of the way that design processes are presented. Design guidelines, suggested processes, and rules of thumb can be oppressive for students. For example, does the KISS (“Keep It Simple Stupid”) principle (Slocum, 2007) keep designers from coming up with far-fetched ideas which can later be tamed into feasible solutions? Do project timelines and milestones penalize some perfectly appropriate designs which may necessitate a different design trajectory? In the author’s experience, the answer is often “yes.” In this experiment, researchers found that some students felt guilty when not using even non-emphasized elements of suggested design approaches. For instance, one student noticed from a specific class presentation that we listed “concept selection” one of a handful of important design activities. The graphical size of the “concept selection” box was as large as other boxes containing other design activities. When the concept selection step never seemed to take as much time as other steps for this student, he felt guilty and expressed his embarrassment in one of the “hindsight” surveys. Partially due to self assessments and timekeeping, some students either tried to force themselves to do activities that didn’t make sense, or expressed guilt at not having followed the prescribed process more closely.

Focusing on encouraging students to understand design by equating it to what they would do naturally to solve a problem may be more appropriate. A design method that has become innate would allow students to have the freedom to eliminate or emphasize design tasks as appropriate for their application and design more productively and free from guilt.

**Industry Recommendations**

Since the goals of different companies and at various levels may differ greatly, useful industry recommendations are difficult to make. For example, on company whose
strategy includes constant innovation and development to keep on the front-side of the technology development curve might have much greater need for creativity in its engineers and designers, while other companies in a much more traditional field with a more static product and lower-risk development plan may need engineers with very strong basic engineering skills and not need creative employees. The wide spectrum of businesses considered, the suggestions outlined here are geared towards segments of companies who hope to keep their designers’ minds flexible and adaptable to new problems and new solutions.

Creative technical professionals can lose effectiveness in addressing non-traditional problems over time. It is the opinion of the author that this ability that once existed in the younger students had been suppressed in older students, conceivably due to the strong emphasis on left-brained analysis tasks that prevail in science and engineering curriculum. Frequent practice of right-brained, creative, synthesis activities may not only keep these abilities alive, but even strengthen them (Rae-Dupree, 2008). Likely, engineers in most industries specialize, coming across similar problems day in and day out. If the challenges they solve were plotted using the design task visualization technique discussed in Section 3.3, their design tasks would probably be very closely huddled together when plotted against most any set of axes. Using the visualization tool to determine which important design skills aren’t being practiced enough has the potential to help guide supplemental activities or further assignments that could expand the variety of tasks to which the designer is exposed. Picking an activity or two a week that really diverge on one or more axes in the design space may contribute to maintaining a creative workforce with lithe enough minds to confront unexpected and novel challenges.

Designers and engineers hoping to continue to develop should consider making regular written self-assessments in their design journals. Aside from the numerical data presented in the results section, observations supporting this recommendation were found almost universally in students’ paper design notebooks. All students were required to submit self-assessments towards the end of the course. In this evaluation, students reviewed their own strengths and weaknesses and gave their opinion of how they could improve. More than one student said that this exercise was useful in determining where
to focus effort in order to become more productive. In each case it seemed as though by
the end of the review, the students had resolved to improve in some area. Neither
acknowledgement of personal design habits nor the resolve to improve them was
observed to this degree otherwise in any other part of the course. Also, the students’
views of themselves were much more telling than were the almost daily interactions with
course staff. This information becomes valuable from a personal and professional
progress awareness standpoint, especially to managers or team leaders. It’s also useful to
know if an employee is worried about the same things concerning his performance as his
superiors and coworkers are. In general, companies conduct yearly reviews for a similar
purpose. A regular non-threatening self-assessment would improve the fidelity of these
reviews.

A final suggestion to industry deals with assessing potential hires or team
members. It appears that a designer’s outlook, including optimism, extroversion, and
confidence, are big factors in evaluating the total productive potential of an individual.
This doesn’t necessarily mean that happy people make better designs. Productivity
includes more than merely what the designer can make. The designer’s affect on team
dynamic and morale, the value the designer gains by learning, and the way the designer
represents the company all contribute to the overall success of the company. These
details are related to productivity. Designers who like what they do enjoy those with and
under whom they work. These content designers also learn more (learning could be a
cause or an effect, but either case is important). Companies and design teams would do
well to recruit confident designers who enjoy what they do, are constantly learning, and
have good interpersonal skills.
Chapter 6: Future Work

The present research gives many insightful hints towards describing the designer, the object of design, and the design context. These elements of design are each so complex that they each merit in-depth study independently. Such studies will have larger, and more controlled sample sizes so that more definitive and convincing correlations can be generated.

Future studies characterizing the designer require a wider breadth of experience (i.e. including professional and expert designers as well as true novices) to capture more of the spectrum necessary to make the results generalizable and broadly applicable. Greater breadth and more representative samples of backgrounds and skill-sets will also be included. More reliable assessments of design-related skills and experience will be developed and incorporated. Such measures will provide much-needed insight on different stages or types of designers if they exist, and possible designer development trajectories. These upcoming studies will examine team and individual designers through separate dedicated experiments in order to assist in characterizing and comparing these two distinct types of “designer.” Combined team-individual studies testing both one-person and multi-person teams and individual designers will follow as a step in developing comparisons between individual and group designer types.

Context and object characterization studies will also be conducted using the proposed visualization technique along with several existing and new design project measures. Characterization of several levels of design and engineering curricula as well as samples of designer job descriptions will be included and compared. Designer characterization studies carried out in parallel will help explain what the design context means in terms of designer development.

It is the opinion of the author that the field of design research would do well to heed Dorst’s council and emphasize study of the three underemphasized elements of design research, namely the designer, the object of design, and the design context in addition to descriptive studies of actual design processes(Dorst, 2007). Considering the complexity and intricacy of that emerged in the present attempt to characterize these ingredients of design, these elements themselves are certainly worthwhile to study, even
occupying several dedicated research attempts. Not only are these facets interesting and fulfilling to explore, but they are also requisite to develop a true understanding of the design endeavor and for the field of design research to progress. Indeed, it is hard to justify the plentiful production design process prescriptions without first developing a more extensive model of the “who,” “what,” and “where” of design.
Appendix A: Design Challenges

The following are the actual design challenges as issued to study participants including all rules, guidelines and scoring methods. As the design and purpose of each challenge is discussed in Section 3.3, Implementation, the challenges are not discussed in this section. Rather, the actual challenges themselves as issued are given for reference.

A.1 Egg Structure Challenge

Objective:
The goal is to make the lightest, tallest and strongest structure possible.

The height and weight of your structure will be measured before testing its strength. To test the strength, we will place a clear container (you can check it out at the front of the room) on top of your structure and fill it with water until an egg cracks, the container touches the ground, or water spills from the container. The amount of water your structure can support will be its strength. One stipulation – the only thing that can be in contact with the water container is egg!

Scoring:
\[ \text{Score} = \frac{\text{Strength} \cdot \text{Height}}{\text{Weight}} \]

Materials:
- 5 Eggs
- 2 Newspapers
- 10 Straws
- 10 Paper clips

Time Limit:
30 Minutes

Some Inspiration →

Figure A.1a: Egg Structure Challenge.
A.2 Egg Drop Challenge

Objective:
Protect an egg dropped from the Green Building!

Constraints:
- 2/3 of the surface of the egg must not be in contact with anything
- Your device must fit inside an 18in. x 18in. x 18in. cube
- Device must include a release tab from which it will be dropped
- Devices must land in the designated target area (within a 30 foot radius of the point directly beneath which it is dropped), or it will be disqualified.

Materials:
Anything you can get your hands on, but no hard-boiled eggs. We have a bunch of stuff in 3-446 that you can use.

Scoring:
\[ \text{Score} = \frac{\text{EggSurvival}}{\text{DropTime}} \]

The degree of egg survival is rated from 1 to 5.
(1 = Obliterated, 2 = Cracked, but not leaking heavily, 3 = Pristine)

A prize will also be given for the most creative idea.

Time Limit:
You will have two days to complete this task.
The devices will be tested Saturday at noon. You can bring your devices to the trials at the Groen building just before noon on Saturday, or you can drop them off in 3-446 before 5pm on Friday.

Figure A.2a: Egg Drop Challenge.
A.3 Lock Box Challenge

THE LOCK BOX
SOCIAL SECURITY MUST BE PROTECTED!

Build a box that only you can get into from the outside!

Materials:
1 Premade Box
1/6 Sheet Foamcore
10 Skewers
10 Paperclips
10 Brass Fasteners
5 Rubber Bands

5 Feet of Duct Tape
10 Feet of String
Glue

Time Limit:
1 HOUR!

Scoring:
Your score will be the amount of time it takes the judges to open your box without breaking it, divided by the time it takes you to open the box (also without breaking it).

\[
\text{SCORE} = \frac{\text{Time}_\text{Me}}{\text{Time}_\text{You}}
\]

As the new election approaches, let us not forget what we have learned from the past, namely, the need for a LOCKBOX.

Image\(^1\) and text\(^2\) courtesy of Saturday Night Live

SNL Al Gore (Darrell Hammond): [speaking slowly and in broken syllables] Well, Jim.., Governor Bush and I have two very different plans to cover seniors tied to American families. In his plan, the wealthiest 1% of Americans would receive nearly fifty percent of the ben-efits. My plan, Jim, is different. Rather than spend or the sur-plus on a risky tax cut for the wealthy, I would put it in what I call a... "lock box." ... May I just say that in my plan, the "lock box" would be used only for Social Security and Medicare. It would have two different locks. Now, one of the keys to the "lock box" would be kept by the President, the other key would be sealed in a small, metal container and placed under the bumper of the Senate Majority Leader's car... There are some of you who would like to spend our money on some made-up war. To you I say, what part of lockbox don't you understand?

Same design ideas courtesy of Mr. Gore himself\(^3\) from the 2000 Al Smith Dinner:
"My plan to put Social Security in an inviolable lockbox has gotten a lot of attention recently, and I'm glad about that. But I'm afraid that it's overshadowing some vitally important proposals. For instance, I'll put Medicaid in a walk-in closet. I'll put the Community Reinvestment Act in a secured gun locker. I'll put NASA funding in a hermetically sealed Ziploc bag."

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2 Located at: http://saltranscripts.jtv.com/00/00/debate.php
3 Located at: http://politicalhumor.about.com/od/algore/a/al gore quotes.htm

---

Figure A.3a: Lock Box Challenge.
The eggs are restless now too. Eggstra-Terrestrials! After putting Rob off to celebrate. Rob overheard his weapon, the Eggs Ray, on their newest captive. Sounds Eggsciting!

Rob scrambled around frantically until he managed to eggstract himself from the cell. But, outside the cell, he found himself in a maze made entirely of EGGS! Rob sees that every egg is booby trapped, so if one cracks, it will set off the alarm and Rob is, well, done for! Luckily, Rob’s an engineer, but even so, he doesn’t Eggspect this challenge won’t be over-easy!

Your Mission, should you choose to Eggcept it, is to help Rob get through the Egg Nigma and eggscape the horrifying Eggstra-Terrestrial Eggs Ray!

**OBJECTIVE:**
- Make a device to help Rob get through the Egg Nigma!

**RULES:**
- The Egg Nigma contains an approximately 8 in. wide path enclosed with walls of eggs.
- Entries must start within a 1 ft. length by 1ft. width by 2 ft. height volume, and only contact the Egg Nigma within the 8 in. square starting cell.
- You may not interact with the entry after activation.
- Entries must not damage the permanent parts of the Egg-Nigma (basically anything besides eggs and guards) or students. If it looks / is dangerous, it won’t be allowed to compete.
  - Explosions, fire, acid, nuclear power, sharp projectiles, poison clouds, napalm, firearms, and chainsaws are all examples of features that would not be allowed to compete.
- All materials in the “OPEN MATERIALS” section of the lab are fair game. You can also use anything else that you want, as long as:
  - The object is not digitally programmable.
  - The object wasn’t stolen or purchased (Eggcept maybe really cheap stuff like paper, etc.)
  - The object can be thrown away after the competition. In other words, you can use common disposable items, things you find in dumpsters or for free on craigslist, but you can’t buy anything just for this project or use anything valuable like your friend’s Segway. If you have questions, ask.
- There must be 10 guards on the table at the beginning of each trial. The guards may be placed standing on any of the 20 guard positions (marked by stickers) in or around the Egg Nigma, as the you like.
- The Egg Nigma is currently on display for eggzamination and practicing in the lab.
The Egg Nigma

SCORING:
- 100 points are possible.
- 3 points are awarded for each guard compromised (knocked over).
- 5 points is awarded for each colored region Rob enters.
- Up to 40 points are awarded depending on Rob’s final position.
  - 2 points for the PURPLE region.
  - 5 points for the BLUE region.
  - 10 points for the GREEN region.
  - 15 points for the YELLOW region.
  - 25 points for the ORANGE region.
  - 40 points for a successful EGGSCAPE!
  - 0 points for any other region.
- If Rob ends in more than one region, points are awarded for the most valuable region.
- 5 points are deducted for each egg dislodged.
- 10 points are deducted for any egg that is cracked.
- 15 points are deducted for any egg that is brutalized to the point that it leaks.

Figure A.4b: EggNigma Challenge, page 2.
Important players in the Egg Nigma

Rob R. Daqui

The Guards

The Egg Stands
(which line the Egg Nigma walls)

Figure A.4c: EggNigma Challenge, page 3.
A.5 I’m Game Challenge

OBJECTIVE:

Simply stated, this challenge is to develop a new sport or game.

DEVELOPMENT:

Development of the sport should include all necessary pieces of information needed to understand and play the game. This might include consideration of rules, equipment, number of players, positions, scoring, sketches of the playing field, game-play storyboard drawings, objectives, strategies, etc.

It might help to think of some of the crazy sports that already exist. There are pictures on the back of this page to help inspire you.

SCORING:

You will present your sport to the MIT Sporting Council who is in search of a new game to promote on campus. Your sport will be rated by the council on each of the following factors:

- **Individual Participatory Appeal**
  - How much would your classmates like to participate in your sport?
- **Individual Spectator Appeal**
  - How much would your classmates like to watch your sport?
- **Broad Participatory Appeal**
  - How much do your classmates think that the populous in general would like to participate in your sport?
  - This might take the form of high-school teams, city leagues, pick-up games in the park, etc...
- **Broad Spectator Appeal**
  - How much do your classmates think that the populous in general would like to watch your sport?

Figure A.5a: I’m Game Challenge, front page.
A.6 Chindogu Challenge

CHINDOGU
ULTRA CHALLENGE!

CHINDOGU is a traditional Japanese art with a long history dating back to the late 80's. Literally, CHINDOGU [珍道具] means “priceless tool.” Without a translation, one might assume the meaning to be “worthless tool”.

According to Wikipedia, “Chindogu are sometimes described as 'useless' – that is, they cannot be 'useless' in an absolute sense, since they do actually solve a problem; however, in practical terms, they cannot positively be called 'useful'.

You must become one with the Japanese art of CHINDOGU!

The guidelines for this challenge are as follows:

- Make at least one perfectly functional device with each partner that completely solves a single problem of your choosing.
- The use of the device should be obvious by looking at the device and/or hearing its title.
- The device must be ridiculous and unusable, not for lack of functionality, but rather for social or logistical reasons.
- Each student has a $20 budget for all their devices.
- The funnier, the better!

Your CHINDOGU will be judged by a panel of experts, rated from 1 to 5 on each of the following criteria:

- Functionality – Does it solve a real problem?
- Simplicity – Are there a minimal number of components?
- Integration – Are components well integrated?
- Transparency – Can one determine how the device functions from merely looking at it?
- Hilarity – How funny is the device?

Figure A.6a: Chindogu Challenge, front page.
The **teammate organization** for this challenge is much different from the organization of the other challenges thus far. Unlike the other challenges, each student will work separately with four partners and develop at least one CHINDOGU with **each partner.** For example, Alex will develop one CHINDOGU with Andi, one with Josh, one with Matt, and one with Petek. The chart below shows the partners with which each student will work.

![Chart showing partners](chart_image)

The **DAILY LOGS** will also change to a more streamlined form where you will list the amount of time that you spent with each partner doing different design activities. Please remember to log on securely by using this link for the **DAILY LOG:**


Each CHINDOGU will be presented in a single 8.5” x 11” photograph with title. Judges will view the gallery of CHINDOGU and rate each entry on **functionality, simplicity, transparency, and hilarity.** Presentation examples are shown below.

- **Butter Stick!**
- **Green Lighter**
- **Shirt Protector**

*Figure A.6b: Chindogu Challenge, rear page.*
Appendix B: Actual Surveys

Surveys were used throughout the study for numeric data collection and some subjective retrospective self-assessment. Each of the surveys is discussed here in order of first use chronologically and is accompanied by images of the actual survey.

B.1 Entrance Survey

The entrance survey was given on the first day of class. The purpose of the entrance survey was to assess some element of the subjects’ backgrounds including past performance, experience level, and MBTI characterization. The format was an electronic survey submitted online via a secure server reading the students’ certificate. The entrance survey as implemented is shown in Figure B.1a.
2.97 Introductory Survey

Tell us a little bit about yourself...

Your answers to the following survey will have NO effect on your grade in the class. Please be honest. An important part of the class is learning together which factors participate in making a good design. This survey will help us learn which factors are important for designers and which are not. This should only take about 15 minutes.

Thank you! We’re excited to have you in the class!

Please answer with numbers as appropriate. Decimal numbers are fine. If not applicable, please enter "N/A"

How old are you? ______

What is your gender? ______

What year are you in school? ______

What is your department number? ______

What is your current GPA? ______

What are your hobbies? ______

What were your scores on the ACT? ______

SAT ______

GRE ______

In general, how self-confident would you consider yourself?

1 = Very Insecure

2

3 = Average

4

5 = Very Confident

How would you rate your abilities in the following areas? (1 = No skill, 3 = Average, 5 = Expert)

Technical Skills

Art (Sketching, Painting, Sculpture) 1 2 3 4 5

Computer Aided Design (any modeling package) 1 2 3 4 5

Mechanical Design (mechanisms, for example) 1 2 3 4 5

Visual Thinking (solving problems using mental imagery or sketches) 1 2 3 4 5

Working with your Hands (construction, tinkering, woodworking, crafts, etc.) 1 2 3 4 5

Calculations (for example, setting up and solving detailed equations) 1 2 3 4 5

Estimation (ability guess at a solution with minimal calculation) 1 2 3 4 5

People Skills

Leadership (guiding a group of people towards a goal) 1 2 3 4 5

Teamwork (working as a member of a group towards a goal) 1 2 3 4 5

Project Skills

Decision Making (making trade-offs between choices) 1 2 3 4 5

Solving Ambiguous Problems (problems that don’t have a clear cut answer) 1 2 3 4 5

Time Estimation (approximating how long a task will take) 1 2 3 4 5

How many years of experience do you have in the following? (use decimal points as needed)

Engineering-related work

Engineering classes after high school

Specifically design classes after high school

Other design projects outside of work or classes

Math classes after high school

Science classes after high school

HSS classes after high school

Please do the Myers-Briggs personality test at http://www.ibi.org/personality/ and enter the results below. These will be kept in the class in the aggregate, but will otherwise remain anonymous.

Extraverted (E) ______%

Introverted (I) ______%

Sensing (S) ______%

Intuitive (N) ______%

Thinking (T) ______%

Feeling (F) ______%

Judging (J) ______%

Perceiving (P) ______%

Figure B.1a: Entrance Survey.
B.2 “Shock” Survey

The “shock” survey was intended to capture the initial state of shock (thus, the name) of a designer immediately upon first receiving a design challenge. Predictions of how they will go about solving the problem, how much time will the problem take, and how good will the solution be are key. The actual survey is shown in Figure B.2a.

**SHOCK SURVEY**

**NAME:** ___________________  **TEammate:** ___________________

Your answers to the following survey will have NO effect on your grade in the class. Please be honest. This survey will help you individually and us as a class to understand the design process better.

- How long do you think this challenge will take?
- Try to outline how you would go about solving the problem? What steps might you take? Also write a copy of this outline in your design notebook.

- What do you think will be your biggest challenge in solving this problem?

- How well do you think you will do compared to other students?

<table>
<thead>
<tr>
<th>Horribly</th>
<th>Average</th>
<th>Awesomely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

- As you’re doing the project, try to keep track of the time spent in each design phase. We’ll ask you about it later:
  - Generating Ideas
  - Selecting a Concept
  - Developing and Refining your Concept
  - Building
  - Testing

Figure B.2a: Shock Survey.
B.3 “Hindsight” Survey

The “hindsight” survey was generally given after each challenge had been completed, but before the designs’ performance had been tested. The front page of the hindsight survey is shown in Figure B.3a and the rear is shown in Figure B.3b.

![Hindsight Survey Front Page](image-url)

Figure B.3a: Hindsight Survey, front page.
B.4 Daily Logs

Daily logs were online surveys that each student was required to do for both the EggNigma and Chindogu challenges. The logs were slightly different for each challenge. The daily log for the EggNigma challenge is shown below in Figure B.4a. The daily log for the Chindogu challenge is shown subsequently in Figure B.4b.
Welcome to your DAILY LOG!
Egg Nigma Challenge Only!

My first name is ___________________. This Log Entry is for January ____________, 2008.

Your actual responses have NOTHING to do with your grade! Just be honest!

Please comment on the following design activities:
(Please insert numbers with decimal points as needed - for example, .25 or .50)
(Progress is measured as percentage of total work anticipated in the phase for this project)

<table>
<thead>
<tr>
<th>DESIGN ACTIVITY</th>
<th>How much TIME did you spend in this area TODAY?</th>
<th>How much PROGRESS do you think that you made in this area TODAY?</th>
<th>How much TIME do you expect to spend in this area TOMORROW?</th>
<th>How much PROGRESS do you expect to make in this area TOMORROW?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONCEPT GENERATION: Brainstorming or thinking of new ideas or strategies</td>
<td>hours minutes</td>
<td>% of total progress</td>
<td>hours minutes</td>
<td>% of total progress</td>
</tr>
<tr>
<td>CONCEPT SELECTION: Deciding between ideas or strategies to pursue</td>
<td>hours minutes</td>
<td>% of total progress</td>
<td>hours minutes</td>
<td>% of total progress</td>
</tr>
<tr>
<td>CONCEPT DEVELOPMENT: Deciding how to implement a concept (materials, dimensions, mechanisms, etc.)</td>
<td>hours minutes</td>
<td>% of total progress</td>
<td>hours minutes</td>
<td>% of total progress</td>
</tr>
<tr>
<td>IMPLEMENTATION: Actually building</td>
<td>hours minutes</td>
<td>% of total progress</td>
<td>hours minutes</td>
<td>% of total progress</td>
</tr>
<tr>
<td>TESTING: Trying things out, doing experiments, or verifying functionality</td>
<td>hours minutes</td>
<td>% of total progress</td>
<td>hours minutes</td>
<td>% of total progress</td>
</tr>
</tbody>
</table>

2.97 Teaching Staff
Other Faculty or Grad Students
2.97 Teammates

How many of the following resources did you use for help, feedback, information, or research? (0, 1, 2, etc.)

Internet Sources
Books
Other

How do you feel your team is doing compared to other teams in the class?
1 = Horribly
2 = Terribly
3 = Average
4 = Greatly
5 = Awesomely

How are you getting along with your teammates(s)?
1 = Horribly
2 = Terribly
3 = Average
4 = Greatly
5 = Awesomely

Figure B.4a: EggNigma daily log.
Welcome to your DAILY CHINDOGU LOG!

This Log Entry is for January ____, 2008.

If you don't see your name here: [Bob],
then you need to log on with a browser that has your certificates, or try this link.

Please answer the following questions INDIVIDUALLY and regarding each of your PARTNERS.
Your actual responses have NOTHING to do with your grade. Just be honest!

<table>
<thead>
<tr>
<th>CONCEPT GENERATION: How much time did you spend with this person brainstorming or thinking of new ideas today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] hours [ ] minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How many different ideas did you come up with today with this person?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] ideas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONCEPT SELECTION: How much time did you spend with this person deciding which ideas to pursue today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] hours [ ] minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CONCEPT DEVELOPMENT: How much time did you spend with this person deciding how to implement a concept (materials, dimensions, instructions, etc.) today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] hours [ ] minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IMPLEMENTATION: How much time did you spend with this person actually building a CHINDOGU today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] hours [ ] minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TESTING: How much time did you spend with this person trying things out, doing experiments, verifying functionality, or interacting with potential users today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ] hours [ ] minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RESOURCES: How many and what kind of resources did you use with this person today?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>RELATIONSHIP: How well are you getting along with this person today?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = Horribly</td>
</tr>
</tbody>
</table>

Figure B.4b: Chindogu daily log.
In general, students completed the logs each day, although there were many cases in which participants forgot and later went back to fill in missing logs. In general, the EggNigma daily logs were done more punctually than the Chindogu daily logs.

**B.5 Exit Survey**

The Exit Survey shown in Figure B.5a was given on the last day of the course after the final project had been completed. This survey was intended to catch retrospective thought and comparisons among the challenges.

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**Exit Survey**

Your answers to the following survey will have NO effect on your grade in the class. Please be honest. This survey will help you individually and us as a class to understand the design process better. As we have throughout the class, we will also email the class with interesting correlations that we think you may find enlightening.

How did you like the class?

1. Hated it
2. Meh
3. OK
4. Liked it
5. Loved it

How did you like the teaching staff?

1. Hated them
2. Meh
3. OK
4. Liked them
5. Loved them

How did you like your teammates?

1. Hated them
2. Meh
3. OK
4. Liked them
5. Loved them

What was the correlation between challenge difficulty and how well your team got along?

- Positive (Easier challenge = Team worked better together)
- Negative (Harder challenge = Team worked better together)
- No correlation

How much have your design skills improved over the course of this class?

1. None
2. Little
3. Some
4. Plenty
5. Tons

How much (if any) has your confidence as a designer increased over the course of this class?

1. None
2. Little
3. Some
4. Plenty
5. Tons

In general, in which design phase do you think you most underestimated your time commitment?

---

Figure B.5a: Exit Survey.
Appendix C: Example Design Notebook Entries

Design notebooks were relatively well-kept by all students. Sketches, lists, notes, anything was encouraged to be recorded in the design notebooks. Students labeled sketches with numbers and letters to represent separate concepts and also the different iterations of each concept. Students also signed and dated each page. The notebooks were useful in the study as the source of self-reflection entries and also seeing how many concepts students came up with and how their ideas evolved. Example notebook pages are shown below in Figures D.1a and D.1b.

![Example notebook pages](#)

Figure D.1a: Examples of student design notebooks.
Figure D.1b: More examples of student design notebooks.
Bibliography


