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EMBRACING AMBIGUITY: A PERSPECTIVE ON STUDENT FORESIGHT ENGINEERING

Anna-Katrina Shedletsky[1], Matthew Campbell[1] and David Havskjold[1]
(1) Stanford University, Mechanical Engineering Department

ABSTRACT

We propose that concept creation for foresight engineering design projects requires a modification of current pedagogy, because the scope is expansive and the final deliverable may never be fully realized. In current design curricula, there is little distinction between different types of design problems, yet foresight engineering design teams often struggle with their broad, sometimes under-defined, design problems. Based on a case study from Stanford University's well-documented graduate design course, ME310, we discovered three insights that can be applied to other foresight engineering projects. The first is to use the ambiguity of the design space as an impetus for innovation; the second is to ensure that a chosen project concept complies with tacit limitations within the design field; and the third is to use parallel prototyping.

Keywords: foresight engineering, project-based learning, design education, ambiguity, ME310

1 BACKGROUND

The process of tackling a foresight engineering project is not well-understood. There is little established language addressing even the definition of foresight engineering; we use the term to mean engineering and designing for a problem space that will emerge at least twenty years in the future. There is no prevalent process that addresses the differences between a future engineering problem and one that is readily accessible in the present. The large scope of a foresight engineering project pushes the indeterminacy typical in design projects to a level beyond "wickedness" [1], since current technology and markets are not constraints. When working in a problem space that may not currently exist, how does one make progress towards solving the problem? How do design teams define a problem and create a concept that may never be finished or fully realized within the timeframe of the project? How to design teams create physical prototypes of something that technology might not yet support?

This paper provides a description of the six week concept creation phase of a design project with a foresight engineering problem during the autumn of 2008, from the perspective of the design students six months later reflecting on their process. The project was part of a yearlong graduate sequence, ME310, offered by the Mechanical Engineering Department at Stanford University. Following the Project-Based Learning philosophy [2], globally distributed teams work on industry-sponsored projects with the goal of building a physical prototype deliverable. In the 2008 to 2009 academic year, the class consisted of nine teams with global partners in Europe and South America, covering a broad range of fields from computer vision to toothbrush design. The case study team consists of four Stanford University students and four students at Universidad Nacional Autónoma de México (UNAM) in Mexico City. Its members have a diverse range of specializations including industrial and product design, mechanical engineering, and mechatronics engineering. Each local team was self-selected and assigned to their project based on ranked preferences.

The participants in the case study became the researchers after significant reflection on our process and experiences. Our unique student's perspective allows us to share the story of our design process. From this story we will share several of our key insights into defining and approaching foresight engineering problems.

2 CONCEPT CREATION

Our one-page brief from Autodesk, Inc., a leader in digital prototyping and imaging software for the manufacturing, construction, and entertainment markets, suggested that we investigate the future of buildings and construction. The purpose was to provide a basis for new capabilities that they should develop for future versions of their software through explorations and prototyping. The expectation was to work on something "cool and innovative", and not to focus on how Autodesk, Inc. might directly monetize our work. The product brief was the first divergence from the focused design project path, which typically begins with some statement of "design X that does Y" (where X may refer to a technology, process, or object and Y typically refers to a statement of user need). Here the design team begins without the specificity that assists in directing the initial explorations which are critical to the eventual project outcome.

With the breadth of possibilities in the construction field and few constraints, we found ourselves with an under-defined foresight engineering problem. Initially, the freedom was stimulating and we held many high energy brainstorms, generating a broad range of ideas from the expected to the outlandish. This process was natural for us; we had been trained as designers to embrace ambiguity and accept the impossible during brainstorms. But when the post-it notes were put away and the whiteboards erased, we were still clueless about the direction to choose and lost our comfort with uncertainty. We had been trained to confidently proceed with a design problem, at times retracing steps, but ever towards a final solution – the X that does Y – and that training was failing us now. At this point, the team had neither X nor Y to direct the brainstorming or to use to evaluate the ideas produced. The disadvantage could be interpreted as a lack of clear project direction, but the advantage was a list of concepts that persisted past a judging stage far longer than they otherwise might have, allowing the team to continue working with a broad range of possibilities. We think this forced suspension of judgment is a key factor in allowing us to reach innovative solutions earlier and quicker than other teams.

Unsure how to proceed, we fell back on something that was more concrete: research. The design team had only limited exposure to construction and architecture, so we spent a week making cold calls, emailing friends in the field, and walking onto construction sites. Members of the team visited the production lines at American Modular Systems, California's largest manufacturer of prefabricated modular school buildings, and Tekkne ticonsa, a prefabricated steel firm in Coyoacán, Mexico. We also visited a few construction sites, including one on the Stanford University campus where Hathaway Dinwiddie, a California-based contractor, was in the process of an eight year project to build four adjacent buildings.

Without criteria to judge which information mattered most, during our visits to these three locations, almost everything we observed was an opportunity worth considering. In our tours and interviews, we observed construction site tradition, hierarchy, and process, took copious notes on the problems of integrating HVAC and fire sprinkler systems into modular units, and learned how architects and constructors interact with each other and consider the users of the future space. On the Hathaway Dinwiddie side, we learned that changes to the plans are made hourly and noted in red pen on paper plans. A project engineer we interviewed said he spent a large amount of time communicating these changes to his sub-contractors via email, a method of communication which could be archived in the event there was a reason to legally defer blame [3]. While we observed these behaviors on sites, it took additional interviews with other players in the process – clients, who pay for the project, and users, who use the space after it is built – to fully understand the ramifications of the traditional construction process. We found that these quick hourly changes caused by budget or timeline constraints are made without the users in mind, and as a result user-centric features of the architect's original design can be lost during the construction phase [4]. When the building is complete, the design phase is finished with or without the user in mind, and the user is then forced to adapt to the space.

Our observations also suggested that traditional construction, including architects, contractors, and builders, is mostly concerned with finishing a job quickly and under budget. This field is not interested in risking either of these two priorities to change their methods, partially evidenced by the continued use of manual correction on paper and resistance to technologies specifically designed for them. The effects of this aversion to change were elegantly summarized in a conversation with Nancy Brown, who develops new software for architects: "Over the course of time, the construction industry has gotten less productive, even as nearly every other industry has become more productive." [5] The design team's initial explorations went back to the literal request of the prompt – to look at design and construction – but remained very broad. This breadth led us to insights we might have otherwise missed or overlooked.

After only a week of explorations, the class was assigned to build one physical prototype that answered a critical question about a key function of the final deliverable. None of the design teams felt ready to "get physical" on a final deliverable so quickly, but the point of the assignment was to start the cycle of testing and assessing as soon as possible. The team proposed over twenty possible ideas for prototypes, focusing on needs we had observed and some of the project directions of the initial brainstorming. While the task was to make one prototype during the week, our team felt uncomfortable making only one selection. We decided to break into four pairs and to make multiple prototypes: two addressing information management and two investigating new applications for modular buildings.

In selecting the functions to prototype, we made the mistake of gravitating towards ideas that we could easily imagine and as a result, they were more like demonstrations than a "metaphor" for "what [the product] is like, not what it is" [7]. An example was a proposed portable computer-aided design (CAD) device, which would allow the various people on a construction site to see and track design changes in real-time. A pair of teammates built several mock-ups of various sizes and an engineer working on a site in Mexico City carried the simulated device around for several hours, illuminating interesting concerns about ruggedness and site hierarchy. The process of building and testing the device resurrected initial concerns that if the device was useful, it would already be in use as rugged laptops have been available for years [8][9]. Upon reflection, we determined that we had not been very imaginative in selecting this as a prototype and as a result we did not advance our understanding about what would be a good project.

Another prototype got closer to the "metaphor" and led us to many interesting findings that could be applied to potential project concepts. During the same week, another pair of teammates spent most of their time narrowing down myriad ideas to the single concept which they believed was most compelling. They decided to investigate how to store a building's physical information, like wiring and plumbing maps, behind its walls so that it could be retrieved years in the future. To avoid technology that could become obsolete, they represented information with metal strips hidden behind drywall and decoded it with a stud finder. While we learned about the specific materials used, we also understood from user testing that the process of manual information recovery was tedious and impractical, and that any such device would need to be automated. This inspired us to consider ways in which information about a building was maintained throughout its use.

After two weeks of divergent prototyping, the next class assignment was to converge on the concept we would pursue for the next six months. When we began to brainstorm project concepts, the pressure of choosing the "right" idea made it difficult for us to embrace projects outside the comfort zones of our prototypes. We were not yet ready to converge: we needed more information about other fields within construction and most importantly, more time to accept crazier ideas.

During a week in November, we set the goal of each developing several unexpected ideas to share with the rest of the team while also individually documenting our activities from the previous weeks for the first quarter report. With time to reflect on the previous explorations and prototyping through documentation, and the opportunity to do some additional web research, we each reinforced our impressions of the construction field. When we were ideating, each of us championed needs that we had previously observed but which had been unaddressed, and collaborating on the team website allowed those ideas to grow organically without a formal brainstorm. At the end of the week, even our more unrealistic ideas had begun to sound feasible.

When we gathered to decide on our future course of action, we used the list of ideas as a way to discuss our Y's, or needs. Fresh from synthesizing our findings in documentation, we recalled the disconnects caused by the traditional nature of construction, where the same methods have been in use for decades with little interest in adopting even readily available new technologies to become more efficient [5]. We wanted to prevent user needs from being lost during building construction; however, we knew that we could not change how these buildings and design change decisions are made. Over the week we had looked for examples of innovative products that had made it in the construction field, such as green materials and the new breed of glamorous modular construction. We realized these products change what traditional construction built, not how they built it. We followed this example – we wanted to ensure that user needs were not lost during construction – so we decided to design a space that empowers the user to make design decisions about the space during its use phase. We called this a dynamic space, and our original concept included the possibility to configure furniture, walls, doors and windows, lighting, and acoustics.

At the conclusion of the concept creation phase after what seemed like six weeks of blind stumbling, the design team settled on a very specific, yet innovative design concept and vision to drive the next six months of work. While the "design X that does Y" teams had also arrived at visions or concepts, these remained very close to restatements of the original prompt – with the addition of a discovered requirement or two (ie. our toothbrush must encourage flossing). These statements were also relatively specific on implementation – the X (ie. incorporate floss into toothbrush). The design visions for the two foresight engineering projects had gone through significant narrowing from their original broad prompts, but had also resulted in statements that were unexpectedly specific, although still vague on implementation. The Autodesk team had a very good idea of what was or was not a dynamic space, but none of us knew what it looked like and how it would work.

3 DISCUSSION

Six months after the concept creation phase was completed, all nine projects were developed to the point of a proposed solution and several iterations of high resolution, functional prototypes. From this hindsight perspective, the design team revisited the list of insights and transferable knowledge we compiled immediately following the concept creation phase of the project. We carefully reviewed these insights with new eyes and found that our most compelling ideas for concept creation success fell into three key areas – addressing and embracing ambiguity, understanding the limitations of the design space, and team resource management through cycles of divergence and convergence.

Ambiguity

The standard design process includes a judging phase, where prototypes or ideas are evaluated against criteria formulated from the problem statement or initial requirements. In needfinding, there is a common belief that the users do not really know what they need, even though they will tell you things that they want [6]. The same idea applies to the sponsor company or individual who writes the project prompt – he or she might have ideas for what people "need" and write "design X that does Y" statements that are unfounded. A common misstep for the student design teams in this class was to take these statements as fact, because clinging to some statement that allows a student to visualize the final product is more comfortable than starting from scratch. Without initial criteria, the design team had the freedom of complete ambiguity in project direction – which forced the team to go back to the start and really find a problem and a need, before working on a solution.

As the six weeks progressed, the design team moved from being uncomfortable with the uncertainty of a broad problem statement to being excited about the undefined possibilities offered by the concept of dynamic spaces. In the beginning, we sought familiarity in both design process and solutions; the portable CAD device is an example of an "expected" solution which gained a lot of early attention. This tendency to focus on what is less ambitious and easy to envision is aligned with Cockayne's observations of students tackling foresight engineering problems [7]. Progressing through the project, we received honest input from the teaching team pointing out ideas that were "ordinary" and prototypes that were only models. Internalizing the experiences of making and using the prototypes, and comparing the outcomes based on those that provided us with the most information, we began to view our own work with a critical eye. We became more self-aware, and when our ideas became flat and uninspiring, we revisited old brainstorm proceedings and exploration observations. We found that the process of forgetting and returning to the ideas of our first brainstorm, with the perspective of several weeks of research, reinvigorated the team's ability to ideate on final concepts. By the end of the concept creation phase, we had become somewhat comfortable with the idea of being uncomfortable, and it was easier to embrace the freedoms of our problem space. While each member of the design team struggled with uncertainty at one point or another, in the end, the team felt that the ambiguity inspired imaginative ideas and induced creativity. Learning to let go of the security offered by an idea one could visualize, allowed the team to access the potential of many more possibilities.

Limitations of the Design Space

In choosing a foresight engineering concept that will not be fully realized for a long time, design teams must understand the limitations and opportunities offered in their project domain. Engineers and designers are taught to focus on the needs of users, not only to intimately understand what they think they want, but to dig into what they really need and what cultural sensitivities may exist [10][11][12]. We found that a building's users' needs were only considered during the design phase of a building, and not at all during the construction phase where changes are made hourly on projects which might take years to build. We saw the source of the problem as a lack of connection with a building's users once construction began. Through our research in understanding the construction field, we understood that traditional construction was stubbornly resistant to change – even in the future, any product we designed to solve the problem at this source had a higher chance of not being adopted and therefore ineffectual. We looked for where innovation was occurring in the construction field and aligned our strategy to what was successful; we decided to change what was built, instead of how, and proposed that we could solve the need by postponing certain decisions about the design to the building's use phase. An understanding of the inherent, and probably unspoken, constraints of the project space allowed us to find a more promising, alternative way of solving our initial problem.

Divergence and Convergence

In a foresight engineering project, covering as much ground as possible in early explorations and prototyping is critical to understanding what and how to innovate. Design teams, especially large ones, should split into smaller groups for diverging exercises and reconvene as a team to converge again. Since our team is composed of four SU and four UNAM students in two different locations, dividing into sub-teams based on location was natural for physical activities such as prototyping. In order to promote an equality of ideas in both locations, we chose to divide the team such that some SU and some UNAM students were working on similar ideas, but with different prototypes. This splitting offered many advantages. We were able to build more prototypes in the same amount of time, covering more ground and addressing more questions. While each prototype was lower resolution, sub-teams increased a team member's ability to make a direct contribution and feel personal ownership of the work. The sub-teams at each global location motivated each other to work harder to deliver a worthy prototype through the sharing of ideas and progress. When it came time to converge, each global team had more access to the experiences of the various prototypes, which made it easier to converge as a unified team.

4 INSIGHTS

With a focus on transferable knowledge for future design teams who must face prolonged periods of uncertainty, we drew the following insights from our discussion of the case study.

Insight 1: Embrace ambiguity.

During the concept creation phase of a foresight engineering project, ambiguity is unavoidable, and yet it can be used to a designer's advantage by extending the playful imagination of a brainstorm to prototyping and beyond. Recognizing when a group is tending towards comfortable ideas versus daring ideas is the first step to applying this insight. Once identified, the team can take action to become more innovative before making critical design decisions. We found that photographs of the playful ideas from an initial concept brainstorm that took place when we did not know of any limitations became increasingly valuable after we gained perspective on the project space. Often, we found that different ideas came to the forefront than the ones we had first chosen as "most promising".

Insight 2: Understand the limitations of the current design space, but with the future in mind.

Understanding the topography of the design space starts with user needfinding, but must go beyond it to understand which user needs result from systematic, relatively unalterable factors. By identifying and projecting those factors into the future, a design team can devise some design limitations to take them into account. While these limitations should not necessarily supersede other explorations and evidence gathered in terms of importance, identifying them encourages the design team to look for alternatives which may result in a more innovative, yet pragmatic, solution.

Insight 3: A design team should subdivide to diverge and unite to converge.

The design process is a repeating cycle of divergence and convergence [2]. Especially for a foresight engineering project, where there is so much ground to cover, the organization of a design team should mirror this cycle. During divergence activities such as brainstorming and prototyping, design teams should subdivide to increase the number of "best ideas" and the individual's utility. Particularly early in the design process when there is a lot of learning to do, low-resolution prototypes are often sufficient and can be built faster by two people than by four or eight. More of these low-resolution prototypes can then be made in the same amount of time, increasing the overall team's rate of learning. When converging on an idea or critical design decision, design teams must reform to ensure dialogue and coherence so that everyone is engaged and the cycle can repeat itself.

5 CONCLUSIONS

This case study of a globally-distributed team of students in a foresight engineering ME310 project demonstrates the importance of using ambiguity to assist in innovation, covering as much ground as possible through research and prototypes, and understanding the limitations of a design space. The insights from this study led to specific suggestions and advice for application to future foresight engineering projects. While focusing specifically on foresight engineering provided a perspective from which to determine what experiences were most relevant, we found that these insights may also provide value for design projects in general. In future design projects as students and professionals, we want to understand how ambiguity about the direction of a project or a specific prototype can be channeled as an innovative force for the design team. Additional case studies and research on foresight engineering projects will be essential to understanding how these special types of design projects can be nurtured, both in teaching and industry settings.

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Contact: A. Shedletsky
Stanford University
Care of Bernice Marshall and Denise Curti

Mechanical Engineering Department
Center for Design Research
424 Panama Mall
Stanford, CA 94305
650.353.1140
anna.shedletsky@gmail.com (preferred)

Anna-Katrina Shedletsky was a mechanical engineering coterminal student at Stanford University during the time of writing. She now works as a product design engineer at Apple Inc. in Cupertino, CA.

Matthew Campbell is a mechanical engineering masters student at Stanford University planning to pursue a Ph. D. in Thermoscience. He is interested in exploring how design techniques can be used to make efficient and clean energy solutions available and desirable for society.

David Havskjold was a mechanical engineering coterminal student at Stanford University during the time of writing. He now works as a design engineer at Palm Inc. in Sunnyvale, CA.