Unpacking the Digital Zoo: An analysis of the learning processes within an engineering epistemic game

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Mary-Geraldine Navoa Svarovsky

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To My Family

With All My Love and Gratitude

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CHAPTER 1

INTRODUCTION

The Growing Demand for Innovators

In our world today, technology is changing at an unprecedented pace. Computers and other personal electronic devices continue to get smaller in size while increasing in capacity. Advances in energy efficient materials and processes influence the way buildings, neighborhoods, and vehicles are designed and updated. Discoveries in nanotechnology are leading to the development of new products and devices in many sectors, including healthcare and consumer products. And certainly, the maturation of the internet has ushered in a new wave of collaborative and communicative tools that foster and support global networks and interaction (Friedman, 2005).

Seemingly every day, new technologies are introduced to the global marketplace, touting more power, better features, and more efficient design. The wealth of options has made many of today's consumers ever more knowledgeable and selective, allowing them to have increasingly high standards for new technologies. A simple Google search can produce hundreds (if not thousands) of options for a single product, allowing buyers to compare several different options, read through other customer reviews, and be discerning in their choices. Many companies are capitalizing on this emergent power and identity of the individual consumer, allowing shoppers and clients to customize orders and products to their personalized specifications (National Academy of Engineering, 2004). Indeed, today's buyer favors technologies that offer creative, efficient solutions, ease of use, and at least some degree of customizability. Products and companies that understand these conditions and are able to adapt in order to meet them are much more likely to be competitive and successful in the world economy.

Of course, staying on the leading edge of any given industry requires an ongoing commitment to research and development. In order to remain ahead of or gain ground on competitors, companies seek science, technology, engineering, and math (STEM) professionals that are capable of more than simply maintaining production processes and solving routine problems. They want to hire people who can solve novel problems thoughtfully and resourcefully, collaborate successfully with colleagues, listen to and understand what clients and users want, and deliver effective results. In other words, companies are looking for technology professionals who know and understand how to innovate within the constraints and systems of the global and technologically-based economy of the 21st century.

The New Suppliers of Engineering Professionals

As the international marketplace continues to grow and evolve, countries look for different ways to remain, or become, competitive and relevant. Recognizing that the demand for well-trained technology professionals will only continue to rise, many nations – such as India and China – have chosen to invest heavily in science and engineering education over the past two decades. These nations have made education in these fields a top priority, and their efforts have produced significant results. India now awards roughly the same number of bachelor's degrees in engineering, computer science, and information technology on a yearly basis as does the United States, while China now produces *almost three times* as many (Duke University Master of Engineering Management Program, 2005; Friedman, 2005). Moreover, it often costs significantly more to hire an American engineer than it does to hire an international counterpart.

With such a large amount of engineering talent readily available at a lower cost, many companies – including Microsoft, 3M, and IBM – have established research and development sites in these countries, and a great many others have outsourced various types of technical work there. As such, these countries have now become the new suppliers of fresh engineering capital for the world.

This is concerning for our nation in several ways. First, with such an influx of international engineering professionals entering the global job market, American engineers will need to identify specific ways to remain competitive and attractive to employers. Second, when the rise in international engineering professionals is combined with the steady decline of undergraduates earning degrees in engineering in the U.S., our capacity as a nation to compete globally in technology development may quickly diminish. Finally, a decrease in our ability to compete in the world economy may be even more problematic given the nation's current economic conditions, since several experts have said it is only through American innovation and ingenuity that we will be able to recover from the current economic downturn and return to high levels of prosperity. Given these objectionable consequences if we continue to lose ground in engineering, it seems necessary to explore – and potentially refine – how engineers are developed in our nation.

The Role of Engineering Education

In response to the mounting challenges associated with outsourcing and the declining interest in pursuing engineering careers in our country, the National Academy of Engineering (NAE) published a series of reports that have outlined both a vision for engineering in America by the year 2020 (National Academy of Engineering, 2004) as well as several recommendations for how to educate young people in order to realize that vision (National Academy of Engineering, 2005, 2009). The main messages of these reports are that a) we as a nation need to train high-performing engineers who can balance a series of qualities, such as robust analytical and communication skills, ingenuity, creativity, professionalism, and leadership, and b) we need to improve, develop, and implement effective engineering education across all levels of schooling in order to realize these goals. With the first of these two points, the NAE seems to argue that strong technical ability – for so long the most recognizable hallmark of successful engineers – is no longer enough for ongoing success in the global economy of the 21st century. In addition to having the skills and knowledge to develop optimized designs, the engineers of tomorrow must also be able to connect their technical prowess to other concepts, abilities, values, and ways of thinking that allow them to understand and navigate the challenges of an international marketplace.

The second point articulated by the NAE, identifying the need for improved engineering education across all levels of schooling, is further addressed by two separate reports, *Educating the Engineer of 2020* (National Academy of Engineering, 2005) and *Engineering in K-12 Education* (National Academy of Engineering, 2009). The first of these reports presents a series of fourteen recommendations, primarily focused at the undergraduate level, for achieving the vision of engineering outlined above. The subsequent report strongly suggests an increased effort in engineering education at the K-12 level, outlining several potential benefits of engaging young people in engineering activity, such as improving science and math learning, increasing awareness of the profession, introducing young people to engineering design, fostering interest in young people to pursue engineering as a career, and increasing technological literacy. Given the many potential and cascading advantages including those noted above, engaging K-12 students in meaningful engineering activity is the focus of this dissertation.

Engineering at the K-12 Level

Over the past two decades, several studies have explored the use of the design, the fundamental activity of engineering, as a pathway for studying concepts and mechanisms in middle and high school science and math classrooms since the 1990s. Several studies (Middleton & Corbett, 1998; Penner, Giles, Lehrer, & Schauble, 1997; Sadler, Coyle, & Schwartz, 2000) examined how students in middle and elementary school were able to explore concepts in statics, kinematics, and biomechanics by building and testing models in the context of a science class. A comprehensive approach is taken by the Learning By Design (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998; Kolodner, Gray, & Fasse, 2003) curriculum, which consists of several units that explore different scientific concepts including force and motion through the use of design. Within each of these units, students engage in a series of "rituals", or activities, that constitute design and inquiry cycles in order to explore and develop different ideas throughout the project. After participating in a Learning By Design unit, students show significant learning gains in the emphasized science content as well as in collaborative and metacognitive skills (Kolodner et al., 1998; Kolodner et al., 2003).

While these programs use general design practices primarily as a means to fostering science learning, others seek to engage young people in more authentic forms of engineering design to facilitate students' STEM learning as well as generate interest in engineering as a potential career path. Notable examples of these types of programs include Project Lead the Way and the Infinity Project, both of which offer full engineering curriculum packages for middle and high school students. Project Lead the Way is implemented in over 1,300 schools across the nation, while the Infinity project has been used by over 285 schools (Brophy, Klein, Portsmore, & Rogers, 2008). In these programs, students engage in a series of introductory engineering courses, which in some cases can be counted for college credit. Both Project Lead the Way and the Infinity Project have been shown to improve students' math and science understanding, and students have reported increased interest in pursuing engineering careers as a result of participating in the courses (Brophy et al., 2008; Douglas, Iversen, & Kalyandurg, 2004; Klein & Geist, 2006).

Beyond Engineering Skills and Knowledge

Certainly, the results of these design-based programs are quite promising and encouraging, demonstrating the effectiveness of using design as an engaging and effective means to develop understanding in science and math as well as other important skills such as collaboration and metacognition (Kolodner et al., 2003). Moreover, the two programs that provide more authentic engineering experiences also cultivated interest in young people to potentially explore engineering careers. As such, these programs constitute important steps towards addressing the potential shortage of engineering talent in our nation.

However, many of these programs focus heavily on product design and construction, which may present a limited view of the profession to young people. In their report on *Engineering in K-12 Education* (National Academy of Engineering, 2009), the NAE outlines three principles that should be included in pre-college engineering experiences. Specifically, the NAE argues that pre-college engineering experiences should a) emphasize engineering design, b) incorporate the development of appropriate math, science, and technology skills; and c) promote engineering habits of mind. While the programs described above do address the first two NAE principles by including engineering design activity in the classroom and promoting the development of math and science understanding, these interventions do not directly address the third principle, which advocates for the development of engineering ways of thinking in young people. This can lead to the development of an "uneven" perception and understanding of the engineering profession in young people, which not only leaves them unprepared to enter engineering majors in college, but can also disenfranchise particular underrepresented groups such as women and minorities from pursuing engineering careers (Eccles, Barber, & Josefowicz, 1999).

For example, many of the extant engineering programs, activities, and curricula for pre-college students focus heavily on the creation of a specific product, strongly emphasizing the development of basic design skills and scientific knowledge (American Association of University Women Educational Foundation, 2004, National Academy of Engineering, 2009). While these goals may be well aligned with the objectives of a middle or high school science course, the impression of engineering these activities leave with students can often be limited and incomplete because other facets of real-world professional engineering practice are not equally prioritized. This lack of context can make engineering seem quite unappealing to girls, who typically dislike "narrow and technically focused" classes and activities that "lack social relevance" (Denner et al., 2005). Moreover, the limited view of engineering presented in these programs can inadvertently reinforce the unfavorable stereotypes (Ambady, Paik, Steele, Owen-Smith, & Mitchell, 2004, Eccles et al., 1999; Knight & Cunningham, 2004).

Given the persistent underrepresentation of women in engineering (Etzkowitz, Kemelgor, & Uzzi, 2001; Sonnert, Fox, & Adkins, 2007; Hewlitt et al., 2008; Thom, 2001), it seems useful to explore the development of K-12 programs that are interesting to pre-college girls and provide a more accurate and complete view of the profession to young women. Providing positive engineering experiences for K-12 girls can potentially increase the female talent in the engineering pipeline (Berryman, 1983; Eccles et al.,

1999) and ultimately increase the number of women in engineering (Nauta, Epperson, & Mallinckrodt, 2003). Moreover, engaging in meaningful engineering activity that links the skills and knowledge associated with engineering design to other elements of professional practice – as recommended by the three principles of the National Academy of Engineering – can reduce negative stereotypes about the profession and make engineering a more favorable choice as an undergraduate major (Ambady et al., 2004). As such, creating a K-12 engineering program that targets young girls and helps them develop complex, professional ways of thinking is a central focus of the work presented here.

Characterizing Engineering with an Epistemic Frame

Part of the impetus for the NAE to outline the three principles listed above was the realization that to date, an operational definition of engineering as a profession did not exist for the K-12 arena. Indeed, in some programs examined by the Academy, parts of the learning experience identified as being part of "engineering practice" were incongruent with the actual definitions and practices accepted and held by the profession. Like other communities of practice (Lave & Wenger, 1991; Wenger, 1998), the engineering profession has, over time, created and defined a particular culture all to its own. Engineers act like engineers, engage in design like an engineer, understand what is important to an engineer, and know about engineering. These ways of knowing, doing, and acting are made possible by a looking at the world in a particular way – by thinking like an engineer. One way to think about and define this culture is through the three principles outlined by the NAE. However, another way to describe the structure of a particular profession such as engineering is an *epistemic frame* (Shaffer, 2006a): the particular skills, knowledge, identity, values, and epistemology that comprise the grammar of a particular professional culture and organize the ways in which the profession is practiced in the world. As new professionals become more expert in the practices of the profession, these individual frame elements are increasingly connected and bound together into a more coherent epistemic frame.

Connecting the Different Elements of Engineering Practice

Thus, developing an epistemic frame requires not only the development of specific frame elements but, more importantly, the connections between the elements. The principles and recommendations of the NAE echo this connection of skills and knowledge to ways of thinking by suggesting the three principles should be balanced in order for a K-12 engineering environment to be most effective. In engineering and many other design professions, the connections between different elements of professional practice are made in the *practicum* setting, where novices work on authentic real-world problems within a simulated professional environment (Schon, 1987). For engineers, practicum experiences are typically seen (commonly occur) in the senior-level capstone design course, where college students typically work on realistic design problems under the guidance of a professor or mentor. Unlike abstract content courses encountered early on in engineering degree programs, capstone courses immerse undergraduates in an authentic professional setting, where they work on authentic problems from the field and face authentic constraints and challenges such as designing under a budget and meeting project deadlines. Through their realistic design work, students come to know key engineering terms, how to carry out an engineering design process, and what issues engineers need to care about in their work. They also begin to understand what it means to be an engineer, how engineers communicate to colleagues and clients, why engineers act in particular ways, and most importantly, how to think like an engineer. In this way, within the meaningful context of the practicum, new professionals begin to link different elements of practice together and form an epistemic frame (Shaffer, 2005; Shaffer et al., 2009).

Several engineering programs have recognized the pedagogical effectiveness of capstone courses in helping students make key connections between different components of the profession and, as such, have begun to incorporate authentic design activities further "upstream" in the curriculum in order to help first and second year undergraduates develop a more meaningful and accurate foundation for engineering (Cox, Diefes-Dux, & Lee, 2006; Montgomery, Follman, & Diefes-Dux, 2003; Sheppard, Macatangay, Colby, & Sullivan, 2008). In a similar manner, introducing authentic and situated engineering activities like those seen in the practicum at the K-12 level may help young people not only develop engineering skills and knowledge, but also engineering habits, views, and ways of thinking.

Because there is much to be gained in exploring authentic, practicum-like engineering experiences for pre-college students that connect different elements of the engineering profession, this dissertation focuses on such a study. Specifically, the work presented here explores whether a group of middle school students engaging in authentic engineering activity within a program called *Digital Zoo* can develop not only engineering skills and knowledge, but also engineering ways of thinking. In addition, this study begins to examine how the learning processes unfolded in Digital Zoo by exploring whether particular activities in the learning environment elicited reflection about engineering values and epistemology – and the linkages between these elements and other frame components – within the participants. By exploring both the learning outcomes and learning processes involved in an authentic pre-college engineering environment, this work examines how the NAE's three principles of K-12 engineering can be addressed in one learning experience, and as such can make a significant contribution to the engineering education community.

Educational Research, Engineering Style

This study follows in the tradition of educational design experiments (Brown, 1992; Collins, 1992), which are used in the field of learning sciences (Kolodner, 2004) as vehicles for iteratively developing, evaluating, and refining theories of learning (Barab, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; diSessa & Cobb, 2004). Borrowing from the practices and procedures of design-based professions like engineering, design researchers build learning environments and test them in the real world, putting their ideas "in harm's way" (Cobb et al., 2003) in order to examine the applicability and resonance of their conjectures. Results from one cycle or stage of a design experiment inform the next, leading to the progressive refinement (Collins, Joseph, & Bielaczyc, 2004) of both pedagogical practices and – more importantly – learning theories. Although most design experiments are cyclical and ongoing, each iteration of a design experiment commonly involves three phases, similar to those in the design-build-test cycle from the profession of engineering (Burghardt, 1999; Dym & Little, 2000): the *design phase,* where a learning environment is crafted to test a particular theory of learning; the *implementation phase,* where learners are carefully observed as they engage in the designed environment; and the *analysis phase,* which examines the learning outcomes and processes of the environment in order to potentially refine both the theory being tested as well as the next instantiation of the learning environment.

One of the most challenging pieces of educational design research is the capture, measurement, and investigation of intricate learning processes and mechanisms within a naturalistic setting. Unlike highly controlled laboratory experiments that remove context in order to isolate specific variables, design experiments seek to understand and uncover the essential role(s) of context within the learning environment (Collins et al., 2004). Moreover, design research typically explores complex and sophisticated forms of learning, and how that learning develops over time. Not only is it more difficult to characterize and assess this type of learning in a "messy", real-world setting, but in order to capture its temporal trajectory, repeated observations and measurements are necessary throughout the duration of the experiment.

Given the many challenges associated with design research, it is not surprising that there has been much discussion about the appropriate methods and techniques to employ when engaging in (and evaluating) a design experiment (Barab, Hay, & Yamagata-Lynch, 2001; Cobb et al., 2003; Collins et al., 2004; diSessa & Cobb, 2004; Hoadley, 2004; Joseph, 2004). On the one hand, the need to understand the role of context in the learning process suggests that qualitative methods – which yield highly descriptive data and results – would be appropriate for use in design research. On the other hand, the need to evaluate and assess complex forms of learning over time suggests that the quantification of data and the use of quantitative analytical techniques – which necessarily remove some layers of context in order to facilitate the identification and characterization of key factors, patterns, and relationships – would also be informative and fruitful. Indeed, design experiments tend to be situated between purely descriptive ethnography work and purely generalizable large scale studies (Collins et al., 2004), thus making them quite well suited to a mixed methods approach (Brown, 1992; Collins et al., 2004; Teddlie & Tashakkori, 2003).

In this work, an example of how qualitative and quantitative techniques (Chi, 1997; Shaffer et al., 2009) can be integrated within a mixed methods approach in order to uncover and analyze the learning mechanisms found within a design experiment is presented. While the learning outcomes for Digital Zoo were measured and explored with traditional pre-, post-, and follow up clinical interviews, the analysis of the learning processes within the program required a more novel approach, and as such is a key feature of this study. In short, the mechanisms of learning throughout Digital Zoo were uncovered through the examination of *in situ* data repeatedly and systematically collected during the intervention. A new technique, *Epistemic Network Analysis* (Shaffer et al., 2009), was used to characterize and explore the emergent patterns of complex learning over specific periods of time during the participants' experiences, ultimately revealing trends within the data that led to the identification of essential activities that specifically elicited player reflection on engineering values and epistemology during Digital Zoo. Finally, these trends were examined with fixed effects logistic regression (Allison, 1996; Cox, 1972) as part of an intra-sample statistical analysis (Shaffer & Serlin, 2004) to generate statistical findings on the repeated measures (*in situ*) data. Thus, by providing an integrated, mixed methods approach for the careful examination of student learning during particular events within a design experiment learning environment, this work also makes a contribution to the learning sciences community.

Dissertation Overview

While the remainder of this dissertation will describe and explain the design, implementation, and analysis phases for Digital Zoo in much greater detail, a brief summary of each of the chapters may provide a helpful overview for the reader. In Chapter 2, the theoretical framework for the study is presented. Digital Zoo is a technology-supported learning environment in which middle school girls role play as engineers and engage in authentic engineering activity under the guidance of a design advisor. It is based on a particular theory of learning, the *Epistemic Frame Hypothesis* (Shaffer, 2004a; Shaffer et al., 2009), which builds on the theoretical constructs of *communities of practice* (Lave & Wenger, 1991), and *the reflective practicum* (Schon, 1987) in order to posit both a definition and a mechanism for the development of professional abilities, understanding, and expertise. During the design phase of the experiment, activities for Digital Zoo were informed by two preliminary studies (Svarovsky & Shaffer, 2006a, 2006b, 2007) and developed in such a way as to allow for the examination of the epistemic frame hypothesis in an actual K-12 learning environment. During the design phase of the experiment, activities for Digital Zoo were developed and orchestrated in such a way as to allow for the examination of the epistemic frame hypothesis in an actual K-12 learning environment. During the implementation phase, which is described in Chapter 3, ten middle school girls participated in the study, and each participant was assessed and observed before, during, and after the experience. These observations – collected in various forms of qualitative data – were the transcribed and organized in preparation for the analysis phase of the study.

The analysis of the learning environment, conducted in the third and final phase of the study, examined both the learning outcomes and learning processes within Digital Zoo. A description of all analysis techniques is presented in Chapter 3. Results from these analyses are presented in Chapter 4 and demonstrate that the students were able to not only develop engineering skills and knowledge but also engineering ways of thinking. Additional results also identify key activities within the environment that elicited reflection within players about specific elements of the epistemic frame. Chapter 5 presents a discussion of the study's findings, limitations and potential implications, and provides closure to the study by outlining a trajectory of future research that builds on the current work. Finally, complete publications from the two preliminary studies that initially informed the design phase of Digital Zoo can be found in Appendix A, and the game guides used during the implementation of the game can be found in Appendix B.

The overall goals of this work are to investigate the learning gains and mechanisms – particularly for engineering ways of thinking – that occur for particular group of middle school girls engaging in authentic engineering activity within a particular learning environment. It is important to note that this study *does not* intend to position Digital Zoo as the most appropriate or effective method for engaging young people in authentic engineering activity; indeed, it is but one among many potentially fruitful approaches to meaningful and engaging engineering experiences at the pre-college level. However, the specific value of this work can be found in the contributions it makes to the learning sciences and engineering education communities. In presenting how an integrated methodological approach can be applied to assess complex thinking and learning in context, this study provides an example of qualitative and quantitative techniques can be combined in order to uncover and analyze the learning mechanisms found within a design experiment. Furthermore, in identifying potentially powerful activities that elicit reflection about engineering values and epistemology – and linkages between these frame elements and others in the engineering epistemic frame – in young people, this work provides key insights on how to improve other K-12 engineering experiences and thus better prepare the next generation of innovative and globally competitive engineering professionals.

CHAPTER 2

THEORETICAL FRAMEWORK

The Looming Shortage of American Engineers

Given the rapid technological growth abroad, it becomes increasingly important for our nation to cultivate talented science and engineering professionals in order to remain technologically competitive in the global economy. Nations such as India and China are not only increasing their production of engineers, but a much higher percentage of their undergraduate populations are choosing to enter engineering disciplines (Friedman, 2005). While a recent study (Duke University Master of Engineering Management Program, 2005) suggests that qualitative differences exist in the training of American versus international engineers that help the United States maintain a specific advantage in the international engineering job market, other resourceful nations are likely to adapt and implement current American pedagogical approaches in technical fields (Friedman, 2005). Once this occurs, the qualitative differences that currently separate American engineers from the rest of the international engineering talent pool will become greatly diminished, and our capacity to compete in the technology sector will as well.

Unfortunately, in contrast to the international trend of increasing engineering professionals, our nation is currently undergoing a period of negative growth in the production of talented engineering candidates. After reaching a peak in 2002, the number of first year college students choosing to enter engineering programs has steadily declined in recent years (National Science Foundation, 2009). Women and minorities continue to be underrepresented in these programs, representing approximately 18% and 30% of the students enrolled in engineering majors, respectively (National Science Foundation, 2009). Of particular concern is the decreased interest of young women in pursuing engineering careers after completing high school. While there has been an influx of women entering the biological and social sciences over the past decade, the number of first year undergraduate women entering engineering programs is at its lowest point in fifteen years (National Science Foundation, 2009). With fewer young people embarking on engineering career trajectories, the potential depletion of our nation's technological capacity will only more quickly become a stark reality.

Given the many unfavorable consequences of falling behind international peers in engineering and technological prowess, several agencies and organizations are have issued an urgent challenge to the engineering community, advocating for intensified efforts in the recruitment, retention, and training of innovative engineering and technology professionals in our nation. At the center of this call to action lies the need to refine current practices in engineering education, as well as to develop and implement new and effective engineering programs across the entire K-20+ educational spectrum. Indeed, the future of our country's economic prosperity and national security is, to a non-trivial degree, tied to the ability of the engineering education community to address – and if at all possible, avoid – the impending shortage of highly qualified engineering and technology professionals in near future.

The Potential of K-12 Engineering

While many efforts are being undertaken to improve engineering education at the undergraduate level (National Academy of Engineering, 2004; Sheppard et al., 2008), there is a growing focus on developing effective K-12 engineering programs. Providing pre-college students with meaningful and engaging engineering programs can contribute in several ways to our nation's efforts to build technological capacity. Specifically, these experiences have been shown to help young people become more interested in engineering as a career path (Eccles et al., 1999) and develop a stronger foundation in both math and science courses (Douglas et al., 2004).

Several studies have suggested that engaging K-12 students in engineering programs may be the most effective way to expose and educate young people about the profession (Blickenstaff, 2005; Denner, Werner, Bean, & Campe, 2005; Margolis & Fisher, 2002). By providing opportunities for K-12 students to explore engineering through activity, young people come to have a better understanding of both the scope of the engineering profession as well as what engineers actually do (Hutchinson, 2002; Ogle, 2004). Evaluations of engineering programs at the high school level reinforce these theories, showing significant increases in student interest towards entering engineering and technology careers after participating in an extended engineering experience (Brophy et al., 2008; Douglas et al., 2004).

Designing for Math and Science Understanding

Beyond reducing the effects of negative stereotypes and cultivating interest in engineering as a profession, several studies (Eccles et al., 1999; Nauta et al., 2003) suggest that engaging young people in engineering activity can provide a motivating and engaging context for them to develop math and science understanding. Indeed, children tend to have an inherent curiosity about the physical world, (Petroski, 2003) and it can be quite powerful to use the design and construction of objects to capitalize on this interest and promote meaningful science learning. Activities such as building a bridge that can hold the most weight, building a catapult that can launch the furthest projectile, or building a car that can go the fastest have been shown to stimulate both learning and excitement for K-12 students, and in many cases these design challenges can lead to a richer understanding of concepts in math and science (Bernsten, 1995; Borja, 2001; Hurley, 1996; Ogle, 2004; Tucker, 1998) For example, one study (Middleton & Corbett, 1998) found that students were motivated and curious when exploring different aspects related to the concept of stability by building toothpick and gumdrop structures within a geometry unit. In another study (Penner et al., 1997), elementary students investigated the biomechanics of an elbow joint by building various models out of clay, straw, and cardboard. When compared to students who studied the structure and function of an elbow without designing models, the students who engaged in design demonstrated a more robust understanding of the scientific concepts.

Building on the demonstrated effectiveness of design challenges in fostering scientific understanding, comprehensive design-oriented science curricula have been developed in recent years. For example, the Design-Based Science curriculum was developed by a team of researchers at the University of Michigan and included a series of multi-week units that engaged high school students in iterative design for the purposes of inquiry-based scientific learning (Fortus, Reddy, & Dershimer, 2003; Mamlok, Dershimer, Fortus, Krajcik, & Marx, 2001). In the Safer Cell Phones unit, students are asked to design a cell phone that minimizes various potential hazards such as radiation, battery leakage, and damaging sound levels without sacrificing usability. Students are introduced to the problem, conduct background research, develop ideas, design and build models, express ideas through drawings and essays, and obtain feedback through pin-up critique sessions and tests (if possible). Students discuss feedback with peers and teachers and then engage in another cycle of design. Results of the study suggest that students were able to learn about scientific principles such as battery chemistry, electromagnetic waves, and energy (Mamlok et al., 2001).

Another example of a design-oriented science curriculum for middle school classrooms is Learning By Design, developed by a team of researchers at Georgia Tech, which consists of five different multi-week units where students also engage in product design in order to explore and cultivate science learning. For example, in the Vehicles in Motion unit, students learn about the concepts of force and motion by iteratively designing vehicles and exploring different methods of propulsion (Kolodner et al., 1998). Students work through three mini-challenges before attempting the grand challenge of designing a vehicle that can travel a certain distance and over a hill at the end of the unit. Within each of the units, students engage in a set of ritualized practices, or activities, that iteratively oscillate between one cycle of investigation and exploration and another cycle of design and redesign (Kolodner et al., 1998). Learning By Design rituals include both small-group and full-class activities. Small group rituals include activities such as "messing about", where students playfully explore exemplars or scenarios in order to uncover key characteristics and qualities that can impact design later, and running experiments to test different elements of a designed object. Large group rituals include activities such as "whiteboarding," where students list ideas, questions, and answers in a communal space to share with others, and pin-up sessions and gallery walks where students share work with peers and teachers in order to get feedback. Students who engage in Learning By Design units demonstrate significant gains in science understanding, collaborative skills, and metacognitive skills (Kolodner et al., 1998).

Programs Focused on Specifically on Engineering in the K-12 Arena

The design activities and curricular programs described above, though certainly not an exhaustive list, illustrate the considerable pedagogical effectiveness of using design-based activities to foster learning within K-12 classrooms. By providing students with an exciting learning environment that incorporated elements of real world design, students engaged in meaningful and purposeful activity, which led to significant learning gains in science. However, the primary goals of programs such as these are to foster content learning in math and science, not necessarily to generate interest in engineering or expose students to authentic engineering practices. As such, curriculum designers were free to include elements of design from other professions, such as the pin up sessions from the architecture design studio.

Other curriculum packages for pre-college students, such as the Infinity Project (Douglas et al., 2004) and the Project Lead the Way (Brophy et al., 2008), are more specifically focused on exposing young people to engineering practices and cultivating engineering interest. The Infinity Project, which has been implemented in 230 high schools in 34 states, engages students in exploring how engineers design and optimize relevant real-world technologies such as the Internet, cell phones, and digital music. In addition to a course textbook, the Infinity Project curriculum includes over 350 integrated laboratory exercises that use real-time signal processing hardware, developed in collaboration with Texas Instruments. Students who participate in the program have demonstrated learning gains in math and science understanding, as well as an increased interested in pursuing engineering careers.

The Project Lead the Way curriculum has been implemented in over 1,300 schools in over 45 states, with over 175,000 students enrolled in the program (Brophy et al., 2008). High school students take part in the Pathway to Engineering sequence, which consists of eight courses that focus on the development of problem-solving skills while designing solutions to real-world engineering problems. The sequence exposes students to different disciplines of engineering and culminates in a capstone Engineering Design and Development course, in which student design teams work with a community mentor on open-ended design problems. Students who participate in the high school component of Project Lead the Way demonstrate significant gains in both math and science understanding and also report an increased interest in pursuing engineering as a career path. Project Lead the Way also has a middle school component, Gateway to Technology, which consists of five multi-week units that can be implemented within math, science, or technology courses in a similar manner to the Learning By Design curriculum.

The Tip of the Iceberg

Many of the programs described in the previous two sections have proven to be quite successful in advancing students' understanding of various scientific and mathematical concepts, which is certainly important and essential to the development of a talented and globally competitive group of engineering professionals in our nation. Moreover, those programs specifically authentic to engineering such as Project Lead the Way and the Infinity Project provide K-12 students with a basic introduction to engineering practice and generate interest in young people to pursue engineering careers. However, as promising as these programs are, the heavy concentration on developing a product for the sake of learning about math and science found within each of these interventions can result in a limited view of the engineering profession. While math and science learning goals are well aligned with the objectives of a middle or high school STEM classrooms, the impression of engineering these activities leave with students can often be incomplete because other facets of real-world professional engineering practice are not equally prioritized (American Association of University Women Educational Foundation, 2004).

Recognizing the growing interest in K-12 engineering education over the past 15 years, the National Academy of Engineering recently released a report (National

Academy of Engineering, 2009) which presented findings and recommendations based on a comprehensive survey of pre-college engineering experiences. One of the major findings of the study echoes the point above regarding the potential overemphasis of design, suggesting that in many of the programs surveyed, there was an "uneven" treatment of ideas from the engineering profession, with perhaps too intense a focus placed on the iterative design cycle. More serious, however, was the way in which other concepts from engineering practice, such as optimization, modeling, and analysis, were absent, incomplete, or not representative of their actual roles in real-world engineering within many of the surveyed programs. The NAE suggested that the inconsistency and unevenness demonstrated by the programs included in the study were due in large part "to the lack of specificity and the lack of consensus on learning outcomes and progressions". As an initial response to this finding, the Academy posited three specific principles for K-12 engineering education programs, suggesting that these learning environments should a) emphasize engineering design, b) incorporate the development of appropriate math, science, and technology skills; and c) promote engineering habits of mind. In light of the overemphasis of the first two principles and the lack of attention on the third principle, the NAE goes on to strongly recommended continued and ongoing research into the learning goals and learning processes of pre-college engineering environments.

K-12 Engineering and the Leaky Pipeline of Women Engineers

Developing effective K-12 engineering programs that address all three of the NAE's principles is not only important to the preparation of the next generation of globally competitive engineering professionals in our country, but also to the ways in which young people perceive engineering as a profession and potential career path. Programs that overemphasize engineering design and content learning in math and science present a limited view of the profession and make engineering seem quite unappealing to girls, who typically dislike "narrow and technically focused" classes and activities that "lack social relevance" (Denner et al., 2005). These product-centric engineering experiences can, in turn, lead to the reification of negative engineering stereotypes already held by young people – and in particular, girls – about engineering being a profession much more focused on machines instead of helping and working with people (Knight & Cunningham, 2004).

While the decision to major in engineering can be heavily influenced for young women by inaccurate perceptions about the profession (Eccles et al., 1999; Nauta et al., 2003), gender stereotypes and socialization also contribute the underrepresentation of women in engineering. Girls as young as third grade have been shown rate their math competency lower than boys do, despite showing no differences in achievement (Herbert & Stipek, 2005; Lloyd, Walsh, & Yailagh, 2005). Girls also tend to attribute task failure in STEM classrooms to a lack of ability, where as boys are more likely to attribute failure to the difficulty of the task (Voyles & Williams, 2004). These ability beliefs and attributions persist into the college years, when some young women who leave engineering majors have been shown to be self-defeating and attribute their failures to their own lack of ability (Nauta et al., 2003).

Obviously, girls do not develop these self-perceptions about their abilities in a vacuum, and several studies have examined different ways girls can be socialized into these patterns and beliefs. For example, parents have been shown to rate the math competency of elementary aged girls lower than for boys, despite no actual difference in ability (Herbert & Stipek, 2005). By the time girls reach middle school, parents have been shown to rate their math competency as equivalent to that of boys, despite girls' higher performance on math assessments (Frome, Eccles, & Barber, 2006). Teachers, while not explicitly discouraging girls, have also been shown to encourage boys more in STEM areas and allow them more access to classroom resources (Blickenstaff, 2005). Peers and social networks also play a role, with girls showing less interest in STEM activities when other friends seem uninterested (Lee, 2005). Negative interactions with male peers can be discouraging for girls as well, such as when they purposefully exclude girls from participating in STEM contexts and at times belittle girls' abilities and skills (Margolis & Fisher, 2004).

Influenced by these social and cultural norms, girls tend to value different subject areas and show interest in different career options than boys from an early age. Studies have shown that girls tend to enjoy language-related courses more than math-related courses (Eccles et al., 1999) and that unlike girls' math abilities, girls' literacy skills are more accurately rated by both parents and the girls themselves (Herbert & Stipek, 2005). Specifically in the STEM areas, girls are significantly more interested in the biological and social sciences, due in part to their concern for helping people and their interest in understanding human social interaction (Eccles et al., 1999). Established and reinforced throughout the pre-college years, these preferences strongly influence young women's choice of degree program, with most women who enter STEM fields migrating towards the biological, medical, and social science majors because of the belief that these professions can help people more directly (Eccles et al., 1999).

However, while engineering programs with a narrow focus can negatively impact girls' interest in engineering, several studies have suggested that positive and meaningful engineering experiences at the K-12 level may help girls remain interested in engineering as a potential career path (Catsambis, 1995; Eccles et al., 1999; Lee, 2002; Nauta et al., 2003). Programs that meet the NAE's three principles may be able to help girls refute negative stereotypes by "individualizing" the profession for young people, helping them focus on the specific and accurate features of engineers and thus helping them develop a more favorable and accurate understanding of the profession (Ambady et al., 2004). By situating engineering activity within a broader context and linking the skills and knowledge associated with engineering design to other aspects of the profession, well-rounded K-12 engineering programs can not only help prepare the next generation of engineers, but also potentially attract additional talented candidates from underrepresented groups into the engineering pipeline.

Engineering as a Community of Practice

By articulating the three principles essential for pre-college engineering programs, the National Academy of Engineering was working to provide K-12 educators with an operational set of ideas that defined and characterized engineering in a way that was aligned with the discipline and practice of engineering (National Academy of Engineering, 2009). The *Engineering in K-12 Education* report provides additional explanation around each principle, clarifying what engineering-specific skills, knowledge, and habits are associated with each. In stating and describing these ideas, the NAE provided an articulation of the *shared repertoire* (Wenger, 1998) of engineering, which includes the "routines, worlds, tools, ways of doing things, stories, gestures, symbols, genres, actions, or concepts" commonly employed in professional engineering practice.

Like other *communities of practice* (Lave & Wenger, 1991; Wenger, 1998), engineers constitute a group of people who have defined a vast set of collective knowledge while – and as a result of – working together over time. The shared repertoire of knowledge is continuously developed and refined through the engagement of multiple community members in a *joint enterprise,* such as working together to solve complex societal problem or to find answers a difficult and intricate cultural question. The shared repertoire of one community of practice may extensively overlap with that of another, but given the way in which the collective understanding of the group is built through shared experience, no two repertoires would be completely identical. However, individuals can, and naturally do, belong to many different communities of practice at once, such as those associated with families, special interest clubs, and neighborhoods in addition to those constructed in the workplace.

Given its definition, learning within a community of practice is, not surprisingly, a social and cultural process (Lave & Wenger, 1991; Wenger, 1998). New members to the practice, possessing (and creating) little of the shared repertoire, begin at the outskirts of the community, participating at the margins. In order for them to move into a "fuller" sense of participation, where full participation is associated with being both an expert and contributor in the shared repertoire of the community, new members must be allowed to engage in *legitimate peripheral participation,* such as in a trade apprenticeship. Participation is *legitimate* because it is meaningful and purposeful, and yet *peripheral* because the new member is only tasked with a manageable portion of the larger practice. As new members develop in their learning, their participation becomes more legitimate, and less peripheral, as they assume more responsibility during practice and move closer towards full participation in the community.

The construct of a community of practice further suggests that no single aspect of the shared repertoire can fully encompass the community. Rather, it is the collection of the different components that create the shared understanding of the group. For example, while scientific knowledge and design skills are essential to engineering practice, they do not fully characterize the entire engineering profession. Engineers need to know about much more than physics and mathematics to be proficient at their jobs, and they need to be able to do much more than generate design ideas in order to be successful. They need to know the ways in which engineers gather information, why it is important to develop to multiple design alternatives, and how to do so. They also need to know what a client is talking about, how to communicate with a client, and why understanding what the client really needs is essential. Engineers also need to know when to evaluate a given solution, how to interpret the results of that evaluation, and what determines whether or not a solution is "good enough" in order to make decisions about how to move forward with the design process. Certainly, this list is not an exhaustive catalog of everything an engineer needs to know and be able to do in order to do her job; rather, this list simply begins to demonstrate how an engineering activity solely focused on product design leaves out many other key facets of the engineering profession.

Epistemic Frames

Conceptualizing engineering as a community of practice has certain advantages, such as being able to talk about different features of the shared and collective understanding of engineers that have been developed throughout the history of the profession. However, in educational contexts where the identification of specific learning outcomes is necessary in order to measure progress and understanding, the notion of a shared repertoire of knowledge is not especially helpful. Instead, a purposeful description or grouping of the different characteristics of the shared repertoire would be more functional for educators who are attempting to create effective learning environments. By more clearly defining and outlining the shared repertoire of the engineering community of practice for K-12 engineering education, the NAE provides one example of how to translate the structure of a particular community of practice into a more practical format.

In the same vein, the *epistemic frame* hypothesis (Shaffer, 2004a, 2006a) builds on Lave and Wenger's work (1991), arguing that the structure and grammar of a particular community of practice – such as a profession – is organized by a particular epistemic frame, which includes the following elements:

- Skills: the abilities and competencies that community members are able to perform and demonstrate
- Knowledge: the facts and information shared by community members
- Identity: the social and cultural roles that community members view themselves as having
- Values: the opinions and beliefs held by community members that define what is important (and conversely, not important)
- Epistemology: the justifications and methods of proof that legitimize actions and claims within the community

In specifying and defining the frame elements for a given professional culture, an epistemic frame cohesively articulates the ways of doing, knowing, being, caring, and warranting of a particular profession. Different professions have different cultures, and as a result, have different epistemic frames. For example, journalists act like journalists, ask questions like a journalist, understand what is important to a journalist, and know about journalism. These ways of knowing, doing, and acting are made possible by a looking at the world particular way – by thinking like a journalist. In an analogous manner, engineers have a set of practices, understandings, roles, opinions, and warrants all bound together by the engineering epistemic frame.

Part of a larger theory of learning known as the *epistemic frame hypothesis* (Shaffer, 2004a, 2006a; Shaffer et al., 2009), the epistemic frame also defines a metric for professional expertise within a particular profession. Similar to the way the entire shared repertoire of a community of practice cannot be fully represented by one or two components, a profession's epistemic frame cannot be fully characterized by one or two frame elements. Rather, it is the collection of frame elements, and more importantly, the connections between those elements, that more fully illustrate the grammar and structure of a given profession. Put another way, professional expertise is not fully characterized by *procedural knowledge*, which involves knowing how to do particular tasks, or by *declarative knowledge*, which involves understanding a body of information. Instead, professional expertise involves the connection of procedural and declarative knowledge to other components of a professional culture, where actions and understandings have a particular meaning and importance within a particular context as determined by the professional community (Broudy, 1977; Shaffer, 2006a).

By forging linkages between the individual frame elements over time, professionals develop more expertise in their field and become more efficient and effective in their overall practice. When new members enter a profession, it is unlikely that they have a full grasp of each of the different frame elements or, for that matter, the connections between the frame elements. However, as the new members grow and learn in the ways of the profession, their understanding of the individual frame elements – and the relationships between them – will increase, resulting in an increasingly more sophisticated epistemic frame. To connect this to Lave and Wenger's work (1991), new members who are at the periphery of a community of practice would have undeveloped and loosely-linked frame elements in their epistemic frame, while expert members of the community in full participation would have well-defined epistemic frames with dense connections between and among the different frame elements.

The Professional Practicum

In addition to defining the construct of an epistemic frame, the *epistemic frame hypothesis* goes on to suggest a reflective practicum setting, where novice members of a professional community engage in authentic activity in the presence of a mentor, as a mechanism for the development of epistemic frames (Shaffer, 2005) Examples of common practicum experiences include moot court for lawyers, clinical rotations for nurses, or supervised practice for psychologists. The practicum is generally an "off-line" learning environment that recreates and approximates the "real world" professional context (Waks, 2001). Particularly relevant to the domain of design education is the work of Schon (1987), which examines a particular type of practicum – a *reflective* practicum, where novice professionals engage in authentic, messy, and ill-structured problems under the supervision of more experienced mentors, or as Schon calls them, "coaches." As a result of undergoing the reflective practicum experience, novice professionals generally mature in their ways of thinking, doing, and acting, making significant progress towards becoming reflective practitioners who exhibit artistry within their field. Schon identifies this type of expertise as reflection-in-action: the ability to shift from standard, skilled performance to a more analytical and experimental mode when an unexpected complication arises during practice. As the expert designer reflects-in-action, she engages in on-the-spot thought and action experiments, positing a potential action and considering its consequences on her design, and how those repercussions might affect future moves.

As in other learning environments, the different facets and aspects of a practicum can contribute in different ways to the learning processes of new professionals. Some contextual components of the practicum can help build and sustain the authenticity of the virtual "practice world" (Schon, 1987) contributing to the "staged learning opportunities" (Macy, Squires, & Barton, 2009) that allow novices to experience a range of real-world scenarios. For example, students in a design-based practicum might be given fictitious documents from an employer that outlines the authentic problem they will address(Todd, 1993), while pre-service teachers in enrolled in a practicum course might be asked to role play as middle school students as a peer engages in a micro-teaching lesson (Gurvitch & Metzler, 2009). These aspects of the practicum help legitimize the experience for novice professionals, facilitating their immersion in the norms, rituals, discourse, and culture of practice (Schon, 1987).

In addition to the role of context, certain activities will undoubtedly be essential to professional learning within the practicum setting. Amongst the various pedagogical pieces of a practicum, *reflective participant structures* (Shaffer, 2005) have been shown to specifically focus on helping novice professionals learn how to reflect-in-action. A common reflective participant structure is a meeting between novice and mentor where the novice's progress on an authentic problem from the field is discussed. Called a *desk crit* in the field of design (Shaffer, 2005), this reflective participant structure provides an opportunity for a coach to consult with a student on her progress, often reflecting on her actions and helping her reframe the situation to point out misalignments with the norms of the profession. This consultation is an example of the coach's reflection-on-action, where the mentor examines the student's past actions and helps her understand why they might not have been the best choices, thus providing the student with insights into artistic professional practice. After reviewing the student's progress and providing advice, the coach can also reflect-in-action and discuss with the student different ways of moving forward with the problem: positing a set of potential moves, playing them out by considering their repercussions, and perhaps presenting different ways to reframe the problem so that the student approaches it in a new way. This ongoing dialogue that occurs during the desk crit between coach and student is essential in making the ways of thinking and knowing of a profession visible, understandable, and accessible to the novice professional. Over time, engaging in reflective participant structures such as the desk crit can not only help new members of a professional community learn how to reflect-in-action (Schon, 1987), but as epistemic frame hypothesis (Shaffer 2005, 2006) suggests, these activities can also help them develop the epistemic frame of a particular profession.

Island Culture: Tying the Hypothesis All Together

Thus far, the epistemic frame hypothesis extends the work on communities of practice in two ways. First, it provides a way to characterize the shared repertoire of a profession using the construct of the epistemic frame. Second, by arguing that the development of an epistemic frame occurs in a particular context and through particular activities with the practicum and the reflective participant structures, the epistemic frame hypothesis describes a type of environment in which a new member of a community could move from legitimate peripheral practice to a fuller sense of participation. The final component of the epistemic frame hypothesis draws on a theory of learning developed in informal learning environments such as museums, known as *Islands of Expertise* (Crowley & Jacobs, 2002).

Crowley and Jacobs (2002) suggest that young children develop scientific understanding by creating *islands of expertise*: topics "in which children happen to become interested and in which they develop relatively deep and rich knowledge". For example, many young children that visit museums find themselves quite attracted and interested in the dinosaur exhibits. While examining a particular fossil, they may engage in conversation with a parent about the dinosaur, and through the explanations of the parent, the child begins to understand more about the particular specimen. This new understanding can lead to additional questions and interest in other dinosaurs, which can lead to further conversations with a parent, checking out books on dinosaurs from the library, talking about dinosaurs with friends, having a dinosaur discussion with a teacher, and perhaps even hosting a dinosaur-themed birthday party. This cumulative effect of all these interactions around dinosaurs help the child develop a diverse interest and understanding about dinosaurs, resulting in an island of expertise on the subject.

Thus, islands of expertise develop through small, seemingly insignificant — yet collectively transformative — conversations between parent and child: short fragments of explanatory talk where the parent provides information to the child on a topic of interest which Crowley and Jacobs refer to as *explanatoids*. As the child comes to understand more about the topic from each interaction, she becomes more interested it. This can lead to a series of subsequent events in which the child interacts with others around the topic. Each of these explanatoids contributes to the cumulative understanding of the child on the topic, and over time, these explanatoids develop an island of expertise.

In a similar way, instances of reflection in the practicum can help a new professional understand specific pieces of knowledge, develop competency in a particular skill, cultivate a professional image, embrace what is important to her work, and reason through problems and scenarios in increasingly sophisticated ways. Over time, these instances of reflection accumulate, and ultimately help the novice transition to a more expert practitioner by developing a robust and densely connected epistemic frame.

Epistemic Frame Elements: Cognitive "Facebook Friends"

The epistemic frame hypothesis (Shaffer, 2005; Shaffer et al., 2009), is a theory of learning that defines an outcome, the epistemic frame, and a mechanism for learning, which consists of a process by which frame elements are progressively linked together over time as a professional develops expertise. New members to a professional community will be likely to have loosely connected epistemic frames, because they have not yet forged key connections between frame elements that occur in the practicum experience. As new members become more expert, more linkages are made, and the frame elements become more tightly bound together.

Comparing a professional's epistemic frame at different points in time could be a useful way to assess the development of expertise over a trajectory of experience. For example, at a given moment in time, a professional's epistemic frame will exist in a particular state, with a discrete amount of connections between the different frame elements. In this instance, some elements will be more connected to others, some will be less, and perhaps some will not be connected at all. After several months of training, the same professional's frame may exist in a different state, having been further developed as a result of additional experience, mentoring, and practice. One way to measure this type of development would be to measure the "connectedness" of a frame before and after the training period and then examine the differences.

A novel assessment technique, Epistemic Network Analysis provides a method for conducting this type of exploration, employing techniques analogous to those frequently used in Social Network Analysis (SNA) that look at complex relationships within dynamic systems. The methods of Social Network Analysis allow sociologists (and other researchers) to examine, characterize, and often quantify the relationships between groups of people within an interactive space, such as a cocktail party, multinational corporation, or social networking site such as Facebook (Newman, 2003). Instead of examining the connections and relationships between people, Epistemic Network Analysis (Shaffer et al., 2009) examines the connections and relationships between different elements of the epistemic frame. Of course, frame elements are not independent actors like guests at a social event, but using SNA techniques to model the development of the relationships between them can still be a helpful way to understand how different frame elements are connected over time. Thus, by positioning the five major epistemic frame elements of skill, knowledge, identity, values, and epistemology as the "guests" at the epistemic "social event" (or the "friends" within a "Facebook network"), epistemic network analysis provides a theoretically grounded method for assessing epistemic frames and their development over time.

Connecting the Epistemic Frame Hypothesis and K-12 Engineering Education

At the beginning of this chapter, a set of K-12 engineering programs were described which all included some form of engineering design (Brophy et al., 2008; Douglas et al., 2004; Fortus et al., 2003; Kolodner et al., 2003). While these learning environments demonstrated the ability to foster design-based science and math learning in pre-college students, they tended to overemphasize the first two principles that the NAE believes should be addressed in effective K-12 engineering programs. The third principle, related to engineering "habits of mind" or engineering ways of thinking, is often addressed in an incomplete manner in these programs and leads to an uneven understanding of engineering as a profession. This can have unintended negative consequences, such as reinforcing negative stereotypes already held by young people – and especially girls – about engineering.

The epistemic frame hypothesis provides both a different way to characterize the engineering profession as well as a mechanism for how it might be developed. The structure of a particular profession can be articulated in its epistemic frame, which consists of the skills, knowledge, identity, values, and epistemology that comprise the grammar of a particular culture. Moreover, the epistemic frame can be developed incrementally through repeated moments and instances of reflection within a practicum setting. As a result of developing an epistemic frame, new members of a profession develop professional competencies, expertise, and ways of thinking, and this development can be measured through Epistemic Network Analysis.

Given the call of the NAE to help young people develop engineering habits of mind in K-12 engineering programs and the professional ways of thinking fostered by the epistemic frame hypothesis, it seems worthwhile to investigate a learning environment designed for pre-college students that is based on an engineering practicum setting in order to facilitate the development of an engineering epistemic frame. Thus, the overarching focus of this dissertation is the development, implementation, and exploration of such an environment.

Design, Build, Test: Not Just For Engineers Anymore

As mentioned in the previous chapter, this work follows in the tradition of educational design experiments (Brown, 1992; Collins, 1992), which involve the iterative development, evaluation, and refinement of learning theories (Barab, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; diSessa & Cobb, 2004). Learning environments that are specifically developed to test variations or components of the epistemic frame hypothesis are called *epistemic games* (Shaffer, 2006a, 2006b). These learning environments allow researchers to explore whether, and *how,* young people might be able to develop an epistemic frame by role-playing as novice professionals. Using both social and computational simulation, epistemic games recreate a particular practicum experience for players, engaging them in cycles of *action* and *reflection-on-*

action in an effort to facilitate the development of a particular epistemic frame. Results from one iteration of a game inform the *design phase* of the next, leading to the progressive refinement (Collins, Joseph, & Bielaczyc, 2004) of different aspects of the game environment and, if appropriate, specific parts of the epistemic frame hypothesis. Similar to the design-build-test cycle in engineering (Burghardt, 1999), after a game is fully designed, it moves into the *implementation phase* to be tested with players, and then finally transitions to the *analysis phase*, which examines both the learning outcomes and processes of the game.

In order to instantiate the epistemic frame hypothesis within a particular game, epistemic game designers begin by conducting preliminary studies that serve as foundation upon which a game will be built and shaped. A common formative study performed by game designers, known as an *epistemography*, involves the close examination of reflective participant structures within a particular practicum setting in an effort to uncover the learning processes that help novice professionals develop a particular epistemic frame (Shaffer, 2005). Using the results of the epistemography (and other appropriate, formative studies given a game designer's specific research questions), epistemic game designers can initiate the *design phase* of a particular game iteration and begin to recreate the practicum setting for players, weaving together elements of social and computational simulation in a coherent way. Once an epistemic game is designed and the structure and order of activities is set, logistical details are addressed, a research team is trained, and the game is implemented. Data is collected before, during, and after gameplay, allowing for the analysis of both learning outcomes and processes. Results from epistemic game design experiments (see, for example, (Bagley & Shaffer, 2009; Hatfield & Shaffer, 2006; Nash & Shaffer, 2008) }have informed later game iterations (Bagley & Shaffer, 2009) in addition to technological (Hatfield &

Shaffer, 2008) and methodological (Shaffer et al., 2009; Shaffer & Serlin, 2004) innovations.

Reflection in the Engineering Practicum

Thus, creating an engineering epistemic game requires an intimate understanding of the reflective participant structures within an engineering practicum. Engineering practicum settings are commonly seen in undergraduate engineering capstone or cornerstone courses that provide students with a realistic engineering design experience (Dym, Agogino, Eris, Frey, & Leifer, 2005). Originally included in the curriculum as a response to industry requests for more robustly prepared engineering graduates, students in these courses typically work in teams to solve real-world design problems specific to their engineering discipline under the guidance of a professor (Dym & Little, 2000; Miller & Olds, 1994; Todd, 1993; Tompkins et al., 2002). Students brainstorm ideas, identify constraints, research existing products, build prototypes, and evaluate their designs in order to understand the nuances of the engineering design process. They meet regularly with their teammates and professors to provide updates, share suggestions, and get feedback, thus experiencing the collaborative nature of the profession. They write reports, give oral presentations, and participate in formal design reviews to develop the communication skills essential for success. They keep a detailed design notebook to become familiar with the rigorous demands of engineering documentation for legal and patent purposes (Burghardt, 1999; Dym & Little, 2000). These activities, as well as others modeled after the actual professional practices of engineers, come together to form a powerful and authentic experience for undergraduates through which they begin to develop a deeper understanding of what it means to be an engineer.

In order to identify key reflective participant structures to be replicated within an engineering epistemic game, an epistemography of a particular undergraduate engineering design course was conducted (Svarovsky & Shaffer, 2006a, 2006b). The published version of this work can be seen in Chapter 4 of this dissertation. The study explored whether design meetings and design notebooks supported and fostered reflection within the engineering practicum – and if so, whether and how they helped undergraduates develop engineering skills, knowledge, values, and epistemology. Ethnographic techniques were used to follow a student design team as they worked with an actual client to design a biomedical device, including the observation of team meetings, the generation of field notes, and the acquisition of course artifacts such as reports, presentations, and design notebooks. Interviews and focus groups were also conducted with team members, professors, and other students from the course in order to gain a broader understanding of the practicum experience. Based on an initial coding scheme developed from descriptions of practice in the literature (Burghardt, 1999; Dym & Little, 2000) and the definition of an epistemic frame (Shaffer, 2006a), the qualitative data from the design meetings and student design notebooks were analyzed for instances of engineering skill, knowledge, values, and epistemology. Codes were refined throughout the process of analysis, as is typical in grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998) research.

The results of this study suggested that both design meetings and design notebooks were effective tools for reflection in the engineering practicum that emphasized engineering skills, knowledge, and values in different amounts. More importantly, in both the design meetings and the design notebook, epistemic statements about engineering were highly correlated with references to engineering skills, knowledge, and values, thus suggesting at least some initial development of a coherent and structured epistemic frame happened within the these two activities(Svarovsky & Shaffer, 2006a, 2006b). Given Schon's work (1987) and Shaffer's (2005) investigation of a journalism practicum, one might expect the design meetings – which involved novices in reflective discussion with more seasoned mentors – to function as a reflective participant structure that fostered epistemic frame development. Identifying the design notebook as a reflective participant structure required the application of the theory of *distributed mind* (Shaffer & Clinton, 2006), which allowed the construct of a reflective participant structure to be extended to include not only person-person, but also person-tool, interactions.

Anecdotal evidence from student focus groups and interviews revealed that working with the client contributed heavily to the authenticity of the course and the development of engineering ways of thinking within the undergraduates(Svarovsky & Shaffer, 2006a, 2006b). While not a reflective participant structure, this contextual component appeared to not only legitimize the practicum experience, but it appeared to serve a compelling pedagogical role as well. Thus, three key activities from the practicum – meeting with design advisors, maintaining a detailed design notebook, and working with clients – each showed great promise for fostering the development of engineering ways of thinking for players within an epistemic game.

Finally, the qualitative coding processes used in this study led to a series of working definitions for each of the five engineering epistemic frame elements, as follows:

- *Engineering Skills*: brainstorming, comparing alternatives, interpreting feedback, communicating with teammates, keeping a design notebook.
- *Engineering Knowledge*: Appropriate use of professional terms of art (such as "prototype", "design matrix", or "design alternative") and scientific vocabulary specific to design problem.

- *Engineering Identity*: Engineer as innovator, engineer as inventor, engineer as interpreter (of client need), engineer as presenter and communicator, engineer as someone who tinkers with devices.
- *Engineering Values*: the importance of creating an optimized and reliable design, the importance of adhering to client need, the importance of developing several design alternatives.
- *Engineering Epistemology*: ruling out a design because it is too costly, evaluating and choosing design alternatives based on the design matrix; evaluating tradeoffs in making a design decision or prototype recommendation.

These working definitions could then be repurposed into an initial coding scheme for data collected within an engineering epistemic game.

Learning through Engineering Design

In addition to having a thorough understanding of how a particular reflective practicum helps novice professionals develop an epistemic frame, epistemic game designers must identify or develop a computational simulation, or *epistemic game engine* (Hatfield & Shaffer, 2006), that can make authentic professional practices accessible to young people. Simulations are a form of computational microworld, which can be defined as "environments where people can explore and learn from what they receive back from the computer in return for their exploration" (Hoyles, Noss, & Adamson, 2002). Microworlds contain an embedded set of relationships from a particular domain, and as a student interacts with the microworld, she is able to investigate these relationships by repeatedly articulating her ideas in the microworld and interpreting the microworld's response. As students test and revise their projects in the microworld, they also test and revise their understanding of the embedded domain. Previous studies (Bertz, 1997; Resnick, 1997; Wilensky, 2001) have shown open-ended projects using such tools can be a rich and motivating way for students to develop mathematical and scientific understanding.

The computational tool to be used in an engineering epistemic game should allow pre-college students to engage in iterative and authentic components of the engineering design process. In actual practice, professional engineers often use computer simulations in the early stages of the design process to engage in multiple (or rapid) iterations of the design-build-test (DBT) cycle: the process by which engineers incrementally plan, construct, evaluate, and redesign elements of an emerging design (Elger, Beyerlein, & Budwig, 2000). As engineers start to work on a new problem with unfamiliar parameters, the DBT cycle is one of the ways in which they come to understand the physical systems with which they are working (Dym & Little, 2000). Therefore, the game engine for an engineering epistemic game would ideally be a computational simulation that allowed young people to engage in multiple iterations of the DBT cycle while facilitating the development of their scientific understanding about the physical world around them.

The learning mechanisms involved in using a high number of iterations of the DBT cycle to develop scientific understanding may potentially be explained by the theory of *islands of expertise* (Crowley & Jacobs, 2002) which, described above in the discussion of the epistemic frame hypothesis, are built cumulatively as a result of short conversations of explanatory talk known as explanatoids. Similar to explanatoids, the iterations of the DBT cycle that students would carry out in the game engine may potentially function in an analogous manner to explanatoids, providing opportunities for the incremental development of scientific knowledge.

In order to evaluate the effectiveness of a particular computational tool as an epistemic game engine for a game based on engineering, a 10-hour pilot of the game was developed in which players engaged in a series of design challenges using SodaConstructor, an online spring-mass modeling system available at sodaplay.com (Svarovsky & Shaffer, 2007). The goals of this study were to examine whether middle-school-aged students could learn concepts in physics as a result of working on engineering design problems using a particular computational tool – and if so, how that learning took place. During the experiment, fifth and sixth grade students attempted to solve increasingly difficult engineering design challenges using SodaConstructor. Students worked both individually and collaboratively, reflecting on and sharing designs through activities similar to those from the Learning by Design curriculum (Kolodner, 1997; Kolodner et al., 1998; Kolodner et al., 2003). Pre- and post-interviews were conducted with each participant and then transcribed for data analysis. Video segments taken during the workshop were also transcribed and used for data analysis. Results from the study suggested that students did develop their understanding of the "center of mass" concept while working on design challenges within SodaConstructor. More importantly, the analysis of the in-game qualitative data suggested that rapid iterations of the design-build-test cycle – in a manner similar to informative conversational segments within informal learning environments (Crowley & Jacobs, 2002) – progressively linked students' interest in the design activities and understanding of the concept of center of mass. Thus, in the same way professional engineers use simulations in practice to develop their understanding of the real world, students were able to use SodaConstructor to cultivate their understanding of a key concept in physics.

Digital Zoo

Based on the preliminary studies described above, the engineering epistemic game Digital Zoo was created. During gameplay, middle school students role-play as biomechanical engineers, using SodaConstructor to develop character prototypes for an upcoming animated film. Following the epistemic frame hypothesis (Shaffer, 2006a; Shaffer et al., 2009), the game was designed to engage players in an authentic engineering learning environment which included a set of participant structures seen in the undergraduate engineering practicum. The objective of the game was to help middle school girls develop their understanding of the different engineering epistemic frame elements as well as to begin to explore how and when engineering ways of thinking may be emphasized during the game. In particular, the design experiment aimed to identify specific activities in the game that evoked player reflection about engineering values and epistemology, and the linkages between those frame elements and other components of the engineering epistemic frame. This analysis is a necessary first step in examining the mechanisms of learning within Digital Zoo, which will be followed in later studies by a more in depth analysis of the qualitative data in order to more fully explore how players potentially developed and internalized the different epistemic frame elements during the game.

Thus, this study of Digital Zoo was intended to answer the following specific research questions:

1. Do middle school girls develop their understanding of the engineering epistemic frame as a result of playing Digital Zoo?
2. If so, are there specific participant structures within the game that evoke reflection about specific epistemic frame elements and the linkages between them? If so, which participant structures evoke reflection about engineering values and epistemology?

By addressing these research questions, this design experiment can make potential contributions to two different academic communities. This work can have implications for the learning sciences community by providing an example of how to integrate qualitative and quantitative analysis techniques – and Epistemic Network Analysis in particular – in order analyze complex learning over time. In addition, this study can have implications for the broader engineering education community by providing an example of a K-12 engineering environment that not only addresses the first two principles outlined by the National Academy of Engineering, but also the third (and potentially most important) principle focused on the development of engineering thinking within pre-college students. Moreover, through the use of Epistemic Network Analysis, this work can identify potentially useful participant structures that evoke reflection on engineering values and epistemology for young people, and as such shed light on specific activities that may be useful to include in other K-12 engineering programs.

The next chapter outlines the methods for the study, describing the specific techniques used during the *design*, *implementation*, and *analysis* phases of Digital Zoo. In particular, the mixed methods approach to the analysis of *in situ* data is explained in careful detail. Through the integrated use qualitative and quantitative techniques, key relationships between the context of the game and player reflection on engineering values and epistemology were explored, thus leading to the results of this work as seen in Chapter 4.

CHAPTER 3

METHODS

As mentioned in the previous chapters, this study of Digital Zoo follows in the tradition of educational design experiments (Brown, 1992; Collins, 1992), which involve the iterative development, evaluation, and refinement of learning theories (Barab, 2004; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; diSessa & Cobb, 2004). Learning environments that are specifically designed to test variations or components of the epistemic frame hypothesis are called *epistemic games* (Shaffer, 2006a, 2006b), which allow researchers to explore whether, *and how,* young people might be able to develop an epistemic frame by role playing as novice professionals. Using both social and computational simulation, epistemic games recreate a particular practicum experience for players, engaging them in cycles of *action* and *reflection-on-action* in an effort to facilitate the development of particular skills, knowledge, identity, values, and epistemology of a particular profession. Results from one iteration of a game inform the *design phase* of the next, leading to the progressive refinement (Collins, Joseph, & Bielaczyc, 2004) of different aspects of the game environment, and if appropriate, specific parts of the epistemic frame hypothesis. Similar to the design-build-test cycle in engineering (Elger et al., 2000), after a game is fully designed, it moves into the *implementation phase* to be tested with players, and then finally transitions to the *analysis phase,* which examines both the learning outcomes and processes of the game.

The Design Experiment History of Digital Zoo

Digital Zoo was designed to be an epistemic game based on the profession of engineering intended for a middle school audience. During the game, players role play as biomechanical engineers who are developing character prototypes for an upcoming animated film. Working under the guidance of a design advisor, players work in teams on client-based problems, using a computer simulation to design and test prototypes to meet the client's needs.

First Preliminary Study: SodaConstructor as Epistemic Game Engine

The development of Digital Zoo was a multi-stage process that included two formative studies, which are presented in the Appendix. In the first study (Svarovsky & Shaffer, 2007), a 10-hour pilot of the game was developed in which players engaged in a series of design challenges using SodaConstructor, an online spring-mass modeling system available at sodaplay.com. The goal of this study was to examine the effectiveness of SodaConstructor as an epistemic game engine (Hatfield & Shaffer, 2006) that made the engineering design process accessible to middle school students. The appropriateness of the tool was investigated by exploring whether middle school aged students could learn concepts in physics as a result of working on engineering design problems– and if so, how that learning took place.

Results from the study suggested that students did develop their understanding of the "center of mass" concept while working on design challenges within SodaConstructor. More importantly, the analysis of the in-game qualitative data suggested that rapid iterations of the design-build-test cycle – in a manner similar to informative conversational segments within informal learning environments (Crowley & Jacobs, 2002) – progressively linked students' interest in the design activities and understanding of the concept of center of mass. Thus, in the same way professional engineers use simulations in practice to develop their understanding of the real world, students were able to use SodaConstructor to cultivate their understanding of a key concept in physics. As such, the tool was selected as the epistemic game engine for Digital Zoo.

The results of this study showed that students were able to demonstrate the development of a specific engineering skill, engaging in the DBT cycle, as well as an understanding of a specific piece of engineering knowledge, the concept of center of mass. However, they showed little evidence of developing other parts of the engineering epistemic frame. These results are consistent with the findings of several other studies, in particular those reviewed by the National Academy of Engineering in their report on K-12 engineering education, which suggest that while design can indeed be used to develop scientific knowledge, narrowly focused interventions do not adequately help young people develop engineering ways of thinking. As such, more investigation of how this type of complex learning happened for real-world engineers (or rather, real-world engineers in training) was needed to inform game design.

Second Preliminary Study: Epistemography of the Engineering Practicum

While the 10-hour pilot game was helpful in the evaluation of SodaConstructor as a computational tool that made engineering design accessible to young people, additional formative work was required in order to more authentically recreate and represent the ways in which novice engineers developed epistemic frames. Therefore, an epistemography of a sophomore-level engineering design course (Svarovsky, in submission) was conducted. Ethnographic techniques were used to follow a student design team as they worked with an actual client to design a biomedical device, including the observation of team meetings, the generation of field notes, and the acquisition of course artifacts such as reports, presentations, and design notebooks. Interviews and focus groups were also conducted with team members, professors, and other students from the course in order to get a broader understanding of the practicum experience. Based on an initial coding scheme developed from descriptions of practice in the literature (Burghardt, 1999; Dym & Little, 2000) and the definition of an epistemic frame (Shaffer, 2006a; Shaffer et al., 2009), the qualitative data from the design meetings and student design notebooks were analyzed for instances of engineering skill, knowledge, values, and epistemology. Codes were refined throughout the process of analysis, as is typical in grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998) research.

The results of the epistemography suggested that both design meetings and design notebooks were effective tools for reflection in the engineering practicum that emphasized engineering skills, knowledge, and values in different amounts. More importantly, in both the design meetings and the design notebook, epistemic statements about engineering were highly correlated with references to engineering skills, knowledge, and values, thus suggesting the initial development of a coherent and structured epistemic frame within the two activities (Svarovsky, in submission). Given Schon's work (1987) and Shaffer's (2005) investigation of a journalism practicum, one might expect the design meetings within the practicum to function as a reflective participant structure that fosters epistemic frame development. However, identifying the design notebook as a reflective participant structure requires the application of the theory of distributed mind (Shaffer & Clinton, 2006), extending the construct of a reflective participant structure to include not only person-person, but also person-tool, interactions. Anecdotal evidence from student focus groups and interviews indicated that working with the client contributed heavily to the authenticity of the course and the development of engineering ways of thinking within the undergraduates (Svarovsky & Shaffer, 2006a; 2006b). As such, these three participant structures – meeting with design advisors, maintaining a detailed design notebook, and working with clients – each showed great promise for fostering the development of engineering ways of thinking within an epistemic game.

Finally, the qualitative coding processes used in this study led to a series of working definitions for each of the five engineering epistemic frame elements, as described in the previous chapter. These working definitions could then be repurposed into an initial coding scheme for data collected within an engineering epistemic game.

Design Phase of Digital Zoo

Digital Zoo was designed to test the epistemic frame hypothesis for a specific group of young people, middle school girls, engaging in the learning practices of a specific profession, engineering. In addition to understanding the learning outcomes of gameplay, there was a particular emphasis on identifying which activities in the game elicited reflection on engineering values and epistemology. Therefore, the research questions associated with the study were:

1. Do middle school girls develop their understanding of the engineering epistemic frame as a result of playing Digital Zoo?
2. If so, are there specific participant structures within the game that evoke reflection about specific epistemic frame elements? If so, which participant structures evoke reflection about engineering values and epistemology?

A 60-hour version of Digital Zoo was developed based on the findings of the two preliminary studies. Results from the epistemography influenced the decision to include two key reflective participant structures, design meetings and design notebooks, within an authentic engineering setting that included client-based problems and interaction. Results from the 10-hour study influenced the decision to use SodaConstructor as the epistemic game engine. Finally, although not empirically explored through a preliminary study, the design decision to make the environment exclusively for girls was made based on the current research around girls' commonly negative perceptions of engineering and technology-focused activity.

These decisions shaped the context for the game environment, which was intended to simulate that of an engineering firm housing four different design teams. Each team consisted of a group of junior engineering associates working under a more senior engineer functioning as a design advisor. One of the firm's clients, an animation studio, asked the engineers to develop wire frame character prototypes for an upcoming animated film featuring a range of ambulatory bug-like creatures such as those seen in *A Bug's Life*. The clients needed the project completed in three weeks and anticipated regular updates on the engineers' progress.

The action sequence for the game engaged players in three cycles of design, one cycle each week. This decision was made in order to be able to conduct repeated measures on players at different moments of the design process. Each week, the players would receive an increasingly difficult "problem statement" from their fictitious client, leading up to the final request of designing a series of ambulatory wire-frame structures that demonstrated emotion through particular types of movement. During the first two design problems, the girls would begin each week exploring different concepts in physics through a series of design challenges that concentrated on the exploration of a particular character feature, such as the torso or leg. The latter part of the week would be dedicated to iteratively designing, building, and testing solutions to the client's weekly problem statement. Finally, at the end of each project week, they would interface with the clients and present their work.

Throughout the game, players reflected on their design activities within a digital design notebook (created and maintained with PowerPoint). The notebook did not contain specific questions for students to answer during the game. Instead, there were two template pages – one for recording ideas from brainstorming, as seen in Figure 1, and one for recording design work from SodaConstructor, as seen in Figure 2.

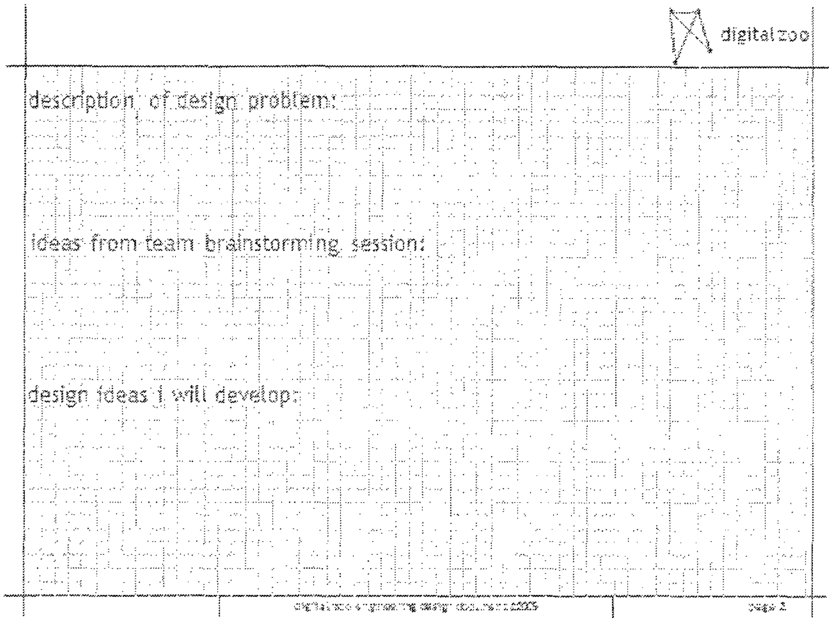

Figure 1. Template page for recording brainstorming ideas.

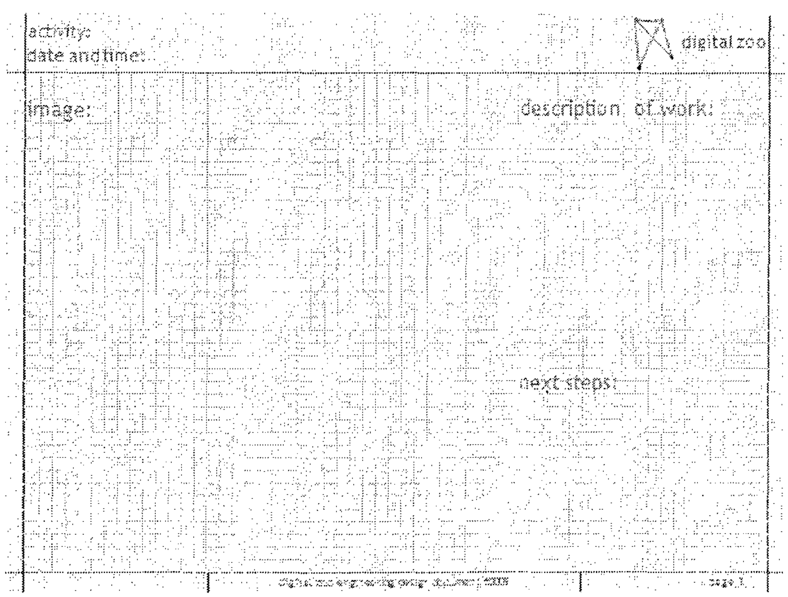

Figure 2. Template page for recording design work from SodaConstructor.

Working in teams of three under the guidance of a design advisor, the players participated in at least two design meetings a day to brainstorm ideas, receive feedback, compare ideas, and engage in prototype design and testing on SodaConstructor. The questions asked during design meetings were structured after the design meetings in the practicum, which engaged undergraduates in reflection on the work. For example, design advisers often asked what players were having trouble with in their designs or if they had any advice to share with their teammates about their design work. The game guide used by design advisers during Digital Zoo, which includes specific questions and concepts to focus on during specific activities, can be found in Appendix B.

During a typical day in the game, all players and design advisers would gather together at the beginning of the day for a design briefing with the entire firm. Then, a brief exploration activity would commence, where players would investigate a specific concept which would be one of the primary ideas for the day. Players would then be issued design work, brainstorm ideas with the team, and then create their designs on SodaConstructor. After working on designs for a period of time, players would gather in their teams for a design meeting, where they discussed and potentially evaluated their work. At the end of the day, the entire firm would gather for a concluding design briefing to conclude the session. Table 1 outlines the agenda for a typical day in the game.

Time	Activity
8:00	design briefing: overview of day
8:15	exploration activity
8:30	design briefing: introduce first design task
8:45	brainstorm ideas
9:00	design time
9:30	design meeting with teammates and design advisor
9:45	design briefing
10:00	documentation time and break
10:15	design briefing & brainstorming: introduce second design task
10:30	design time
11:00	design meeting with teammates and design advisor
11:15	design briefing: discuss engineering concept
11:30	design evaluations
11:45	design briefing: discuss findings or progress, and plan for tomorrow

Table 1. Itinerary for a typical game day during Digital Zoo.

Implementation Phase of Digital Zoo

A prototype of the 60-hour version of Digital Zoo was played in the summer of 2005, and the full scale version was played the following summer by ten middle school girls. The players were recruited with the help of a campus outreach program, and all had previously participated in summer enrichment opportunities within the 1-2 years prior to the implementation of Digital Zoo. The players came from diverse backgrounds, with four of the girls being people of color.

In addition to the middle school students who played the game as junior engineers, additional project staff inhabited other roles in the game context. Four undergraduate engineering students, who had each been through at least one engineering design course as well as training in epistemic game mentoring practices, acted as design advisors throughout the game. A total of six graduate students with expertise in biomechanics played the role of "client" at some point in the game, with two clients appearing regularly at the end of each week. The lead researcher of Digital Zoo also played the Project Manger role in the firm, keeping the game moving forward through the designed sequence of activity.

Although the game was structured for a three week time line, it was implemented over a total of four weeks in the summer of 2006 due to the summer holidays. The first two design projects were uninterrupted, with gameplay occurring during the first two weeks of the program for four hours every morning Monday through Friday. Unfortunately, the timeline – and thus, the activity structure – for the third and final design project was required to be substantially altered due to programmatic scheduling constraints around the summer holidays. In order to limit uncontrolled variability from these schedule fluctuations, only the data from first two weeks will be used in the analysis of learning processes within the game. Table 2 outlines the schedule of activities and concepts included in the first two weeks of the game. Each day of the game, specific concepts from the engineering epistemic frame were targeted for development.

	DESIGN CHALLENGES			CLIENT PROBLEM	
	Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
Week 1	Design meetings	Design notebook	Design alternatives	Problem statements	Design matrix
Concepts	Cross bracing	Center of mass	Center of mass	Cost constraints	Design presentation
Week 2	Reverse engineering	Performance specs	Identifying tradeoffs	Design for reliability	Expanded design matrix
Concepts	Gait	Muscle timing	Different types of gait	Design evaluations	Communicating justifications

Table 2. Schedule for the first two weeks of the game.

Data Collection

In order to answer the research questions, several forms of data were collected before, during, and after gameplay. Pre-, post-, and follow up interviews were conducted with each player, with the pre-interview being administered immediately before the start of game play, the post-interview immediately after the conclusion of gameplay, and the follow up interview approximately three months after the end of the game. During the game, copies were made of player-produced work, design meetings and conversations were recorded, and occasional videos and photos were taken during gameplay. Research meetings after each game session were recorded and the research team generated field notes when appropriate. By the end of the design experiment, the data set included over three hundred and fifty audio files, thirty video files, five hundred digital notebook pages, and numerous drawings, photos, and other artifacts.

METHODOLOGICAL FRAMEWORK FOR DATA ANALYSIS

Certainly, having an overwhelming amount of "messy data" at the end of a design experiment is nothing new to design researchers (Brown, 1992; Dede, 2004). Design experiments involve the study of complex phenomena over time, and capturing these events requires researchers to make sophisticated and repeated measurements that involve the collection of diverse forms, and large quantities, of qualitative data. While design researchers often engage in reflection and initial analyses of data during the experiment (Collins et al., 2004), the bulk of the analysis typically occurs after the experiment has ended.

Mixed Methods

Because design experiments seek to simultaneously generate, refine, and verify learning theory, they are particularly well positioned for mixed methods approaches (Hoadley, 2004; Teddlie & Tashakkori, 2003). Of course, some researchers – particularly those who remain entrenched in qualitative versus quantitative "paradigm wars" (Gage, 1989; Teddlie & Tashakkori, 2003) – may disagree with such an integrated methodological approach. For example, purely qualitative methodologists may disagree with any sort of quantification of qualitative data, suggesting that doing so imposes researcher bias on the work and therefore the data would not be allowed to "speak." Alternatively, purely quantitative methodologists might object to any use of statistical techniques with the small sample sizes typically found within design experiments. While finding common ground between these two paradigms can be quite challenging (Denzin, 2008), mixed methods researchers can begin to alleviate at least some of these concerns by stating the constraints, affordances, and limitations of their methodological choices up front. For example, mixed methodologists can acknowledge that they do lose some data richness by quantifying codes. However, a great degree of qualitative richness can be preserved through the thoughtful development of an emergent coding scheme that is well articulated and consistently applied (Chi, 1997; Sandelowski, 2001). A mixed methodologist can also acknowledge that statistical analyses of repeated measures require specific conditions and assumptions, and that the results of such analyses cannot be generalized to other populations. However, statistical analyses can help uncover patterns and trends within the data, thus potentially shedding light on underlying processes and relationships. Indeed, mixed method researchers can begin to bridge the gap between the qualitative and quantitative methods by thoughtfully considering and articulating the tradeoffs associated with incorporating an array of techniques from different paradigms.

Verbal Analysis (VA)

Design researchers commonly work with different types of observational and recorded data collected from real-world learning environments for the purposes of examining learning in naturalistic settings. Chi's (1997) clear and straightforward guide to Verbal Analysis describes a highly integrated mixed methods approach where both qualitative and quantitative techniques are used to explore learning in context. In contrast to some mixed methods studies that segregate qualitative and quantitative methods to different portions of a study (such as those that use qualitative data to interpret quantitative results), Chi's method combines qualitative and quantitative techniques in a more blended way. By coding verbal data using the constant comparative method (Glaser & Strauss, 1967; Strauss & Corbin, 1998) and then comparing frequencies of codes quantitatively (and often with the use of statistical techniques), Verbal Analysis allows researchers to use multiple tools to uncover and warrant grounded patterns and trends within the data. In her description of the method, Chi outlines techniques for organizing, segmenting, and reducing verbal data, developing a robust coding scheme, identifying the appropriate granularity for analysis, operationalizing the coding of data, conducting the actual analysis, and drawing inferences from the results. Applicable to a broad spectrum of verbal data including audio and video recordings of group conversations, individual activity, clinical interviews, and focus groups, Verbal Analysis can be easily adapted and utilized in a wide range of educational studies and design experiments (see, for example, (Atman & Turns, 2001; Nathan, Eilam, & Kim, 2007; Steinkuehler & Duncan, 2008).

Verbal Analysis served as the foundation for the data analysis methods used in the study of Digital Zoo. The determination of learning outcomes followed the technique quite closely, with the organization, segmentation, coding, quantification, and comparison of pre-, post-, and follow-up interviews for each player. However, uncovering the learning processes within the game required the extension of Chi's work in three specific ways. First, Verbal Analysis techniques were applied to different types of non-verbal data, such as artifacts produced by players during the game. Second, a new quantification technique, Epistemic Network Analysis (Shaffer et. al, 2009), was applied to coded data in order to further identify and characterize the patterns of learning – and more specifically, the patterns of reflection on epistemic frame elements and the linkages between them – within the game. Finally, after the statement of a grounded theory on when particular epistemic frame elements and linkages were emphasized in the game, a fixed effects logistic regression model (Allison, 1996; Cox, 1972) was used to conduct an intra-sample statistical analysis (Shaffer & Serlin, 2004), which provided an additional warrant for qualitative claims regarding the learning processes within Digital Zoo.

Extending Verbal Analysis, Part One: Different Forms of Qualitative Data

There were several different types of *in situ* data collected during Digital Zoo, including video recordings of different game activities; audio recordings of design meetings, mentor consultations, presentations, and research team meetings; photos taken by the research team at various points during the game; ethnographic field notes generated by the research team; players' digital design notebooks; players' notes and sketches; and final design posters generated by players. Of these different forms of data, some were collected more regularly than others, thus capturing the activity within the learning environment in a more systematic way and ultimately providing a better, more consistent qualitative sample of the phenomena being analyzed. One key example is the engineering design notebook maintained by each player, in which design work was documented in detail. In addition to the text written by the player, various non-verbal components of the notebook, such as images and markings, also provided context and information relevant to the player's thinking at that moment in the game. As such, the coding techniques of Verbal Analysis were extended to these other forms of non-verbal data in order to more fully understand the player's experience throughout the game. A single coding scheme, which consisted of the five epistemic frame elements of skill, knowledge, identity, values, and epistemology, was used to code all forms of *in situ* data included in the analysis of learning processes.

Extending Verbal Analysis, Part Two: Epistemic Network Analysis

After qualitative data is coded in Verbal Analysis, the frequencies of particular codes can be tabulated and compared in order to help researchers see patterns and trends in the data. Although counting code frequencies in Digital Zoo would provide information about how many times specific frame elements appeared in the game, this analytic technique does not directly align with the theoretical framework of the study, and as such, is not particularly revealing. However, Digital Zoo is based on the epistemic frame hypothesis (Shaffer, 2005; Shaffer et al., 2009), which suggests that frame elements are bound together and connected as the frame is formed . Therefore, the tallying of individual frame element codes would likely be less useful than examining the number and frequency of connections between different frame elements over a given period of time. Epistemic Network Analysis (Shaffer et al, 2009) provides a method for conducting this type of exploration, employing techniques analogous to those frequently used in Social Network Analysis that look at complex relationships within dynamic systems.

Instead of examining the connections and relationships between people, Epistemic Network Analysis (Shaffer et al., 2009) examines the connections and relationships between different elements of the epistemic frame. Of course, frame elements are not independent actors like guests at a social event, but using social network analysis techniques (Newman, 2003) to model the development of the relationships between them can still be a helpful way to understand how different frame elements are connected over time. In the analysis of *in situ* data from Digital Zoo, the five major frame elements of engineering skill, knowledge, identity, values, and epistemology were the "guests" at the epistemic "social event", and the analysis explores connections and relationships between these frame elements over time.

Because Epistemic Network Analysis is such a new technique, it is useful to take a moment to define the variables and equations that were used in the ENA calculations for Digital Zoo. The engineering epistemic frame, *EEF*, is characterized by individual frame elements, f_i, where i=*S*,*K*, *I*, *V*, or *E* for skills, knowledge, identity, values, and epistemology respectively. At any time *t*, and any player, *p*, there will be a "snapshot" of data, D^p_t, which will contain the evidence of player p using one or more of the epistemic frame elements. Moreover, the complete game history of player p will be represented as the collection of snapshots, $D^{p}{}_{1...e}$, where t=1 is the first snapshot seen at the start of the game, and t=e is the final snapshot seen at the end of the game for one given player. The connections between epistemic frame elements, f_i, for player p at time t can be quantified by creating an *adjacency matrix*, $A^{p,t}$, a construct taken from social network analysis:

$$A^{p,t}{}_{i,j} = 1 \text{ if } f_i \text{ and } f_j \text{ are both in } D^{p}{}_{t} \quad . (1)$$

This process can be continued for each design alternative, and then the epistemic network for a particular player can be quantified by summing, for each pair of frame elements, the number of times both elements are recorded in the same design alternative. In other words, for any player, p, a cumulative adjacency matrix, F^{p}, can be constructed by summing the adjacency matrices, $A^{p,t}$, for a given time period that starts at t=a and ends at t=b:

$$F^{p,t[a:b]} = \sum_{n=a}^{b} A^{p,n} \quad . (2)$$

Once the adjacency matrices are generated, specific quantities that provide information about the nature of the overall epistemic frame as well as the relationship between the individual frame components can be calculated. For example, it may be useful to analyze the centrality, or "connectedness" of the individual frame elements, f_i. Within social network analysis, actors become more central to the social network the more frequently and strongly connected they are to other actors. Thus, in Epistemic Network Analysis, the more central an epistemic frame element, the more tightly bound it is to the other frame elements. In order to eventually calculate the relative centrality, *R*, of a particular frame element, it is first necessary to initially quantify the "connectedness" of each frame element within an epistemic network, *F*. The connectedness, or weight, *C*, of an individual frame element, *fi*, within epistemic network, F, is calculated as its sums of squares centrality *C(fi)*:

$$C(f_i) = \sqrt{\sum_j (F_{i,j})^2} \quad .(4)$$

The sums of squares centrality of a frame element can have values of zero or greater, and provides an absolute measure of the "connectedness" of a particular element within an epistemic network. The relative centrality, *R*, of a particular frame element, f_i, is then calculated by dividing its weight, C, by the heaviest weight, C_{max}, within the epistemic network, *F*:

$$R(f_i) = \frac{C(f_i)}{C_{max}(F)} \text{ x } 100 \quad .(5)$$

The relative centrality of a frame element can have values ranging from zero to 100, and provides a ratio of a particular element's connectedness to that of the most connected element in the network at a given moment in time.

Thus, Epistemic Network Analysis is a flexible technique that can be used to examine linkages between frame elements over a defined time period. Using ENA instead of simply tallying code frequencies allows the researcher to consider the connections between frame elements, thus allowing for a more aligned representation of complex, highly interconnected learning. By using ENA to examine linkages to frame elements during specific periods of time within Digital Zoo, it was possible to identify when particular frame elements – such as engineering values and epistemology – were more or less emphasized during gameplay. As such, ENA provided a way to characterize and measure players' learning during particular game activities, and was therefore instrumental in the cultivation of a grounded theory of learning within the game.

Extending Verbal Analysis, Part Three: Intra-Sample Statistical Analysis

Once a potential grounded theory is stated, it is necessary to warrant the claims it suggests, including the particular differences, relationships, or trends it explains within the qualitative data. In Verbal Analysis, the quantification of qualitative data allows for the use of statistical methods to warrant such claims. The samples of work presented in Chi's (1997) article on Verbal Analysis use statistical tests to examine mean differences on average frequency values calculated from multiple participants' data. In the analysis of Digital Zoo, this specific technique was used to determine learning gains for the entire group of players, comparing the mean frequencies of specific codes from pre- to post-interview with a paired t-test. While applying a statistical test in this way is effective in determining learning outcomes across subjects, it is often more interesting to explore the individual trajectories of participants within the *in situ* data – through some type of repeated measure, within-subjects analysis – in order to get a sense of how the learning process unfolded within the learning environment. Though she agrees that these "single-subject" analyses would be quite interesting, Chi does not specifically address how to use statistical methods for this purpose.

Generally speaking, the challenge in using statistical methods within qualitative inquiry has historically been the small number of subjects being studied. Statistical tests gain power and create stronger warrants for claims by increasing sample size. On the other hand, within the qualitative research paradigm, claims are often warranted by the presence of theoretical saturation (Glaser & Strauss, 1967; Schwandt, 2001; Strauss & Corbin, 1998), a condition where additional qualitative data collection or analysis no longer generates new insights but instead only serves to confirm patterns already seen and identified in the data. In both paradigms, stronger warrants come from "more data": in quantitative studies, "more data" implies more subjects and a higher "n", while in qualitative studies, "more data" implies richer and more frequent data collected on the same small number of subjects. Recognizing these commonalities, Intra-Sample Statistical Analysis (ISSA) (Shaffer & Serlin, 2004) provides a different way of using statistical techniques on qualitative data that has been repeatedly collected on a small number of subjects, as is typical in naturalistic inquiry.

ISSA has three components that make it quite useful in analyzing large amounts of systematically collected and coded qualitative data. First, ISSA uses qualitative observations as the unit of analysis within a statistical model, not individual subjects, as is most often the case with statistical analyses in educational settings. Instead of running an analysis on a sample of people in order to generalize patterns within the data to an ideal human population, ISSA runs an analysis on a sample of observations in order to generalize patterns to the "ideal population of observations" – all of the possible observations made by a researcher or team of researchers within a given setting – that could be made on a particular set of people in a specific context. Second, by requiring researchers to control for Type I errors due to repeated sampling, ISSA allows researchers to view observations as exchangeable units of analysis. For example, researchers could examine associations between contextual variables and specific learning outcomes using a fixed effects logistic regression model (Allison, 1996; Cox, 1972) in which they would control for the effects of individual students and time, thereby rendering the observations as functionally independent and suitable for statistical analysis. Third, ISSA warrants qualitative claims about theoretical saturation. As stated above, theoretical saturation is said to be reached when additional data no longer contributes any new insights about a concept (Glaser & Strauss, 1967; Schwandt, 2001; Strauss & Corbin, 1998). By statistically supporting inferences about patterns of activity for a particular set of people within a specific context, ISSA suggests that any additional observations made of the same people in similar contexts would produce similar patterns.

Thus, in analyzing the results of ISSA, it is imperative for the qualitative researcher to return to her qualitative lens when interpreting the findings of the statistical tests. Intra-Sample Statistical Analysis uses quantitative techniques to shed additional light on the qualitative patterns found in the qualitative data, as well as provides additional justification for the qualitative claims of theoretical saturation. ISSA cannot, nor does it aspire to in any way, provide a method for making purely quantitative claims about the qualitative data. In other words, when conducting ISSA, statistically significant quantities generated by statistical tests and regressions should be examined and compared, but only in a qualitative sense, examining the valence or directionality of specific relationships and their statistical significance, but not their specific magnitude. In fundamentally qualitative research, such as the work presented here, the nature of the type of inquiry and the research questions being asked place more value on the qualitative, not quantitative, information about patterns within the data that statistical methods can produce.

For example, when conducting a logistic regression during ISSA, the logit coefficients produced by a model would be first be examined for statistical significance. Then, the significant coefficients would be interpreted based on whether they were positive (above zero) or negative (below zero). Positive logit coefficients would indicate that an increase in the value of the specific predictor would be more likely to be associated with a desired outcome, while a negative logit coefficient would indicate that the same increase in the value of the predictor would be less likely to be associated with the desired outcome. Interpreting the results of a logistic regression in this way instead of focusing on the quantitative magnitudes of the logit coefficients (or the resulting odds ratios) allows ISSA to be used appropriately to further warrant qualitative patterns.

DETAILED DESCRIPTION OF DATA ANALYSIS IN DIGITAL ZOO

Based on the methodological framework described above, the data analysis for Digital Zoo consisted of a two-part, multi-step process which examined both learning outcomes and learning processes for the participants. In Part One, Verbal Analysis was used to determine the overall learning outcomes of epistemic game play by comparing data from the pre-, post-, and follow up interviews conducted with each player of Digital Zoo.

In Part Two, Verbal Analysis served as the foundation for the analysis of *in situ* data collected during gameplay, but the original techniques were extended in the three ways outlined in the previous section. As stated earlier, due to the schedule fluctuations in the third week of the game, only the data from first two weeks of Digital Zoo was used in the analysis of learning processes. The analysis of the *in situ* data led to a specific theory of learning within Digital Zoo that identified key participant structures that tended to elicit player reflections of engineering values and epistemology and the linkages between these elements and other components of the epistemic frame.

Outcome Data

As several other epistemic game design experiments have done(Bagley & Shaffer, 2009; Beckett & Shaffer, 2004; Hatfield & Shaffer, 2006), overall learning gains as a result of playing Digital Zoo were determined by comparing player responses from pre-, post-, and follow up interviews with Verbal Analysis. Designed as clinical interviews, the pre-, post-, and follow up protocols each contained a wide range of questions, asking players to explain concepts in engineering and physics, provide opinions about far-transfer problem scenarios (Shaffer, 2004b), and engage in design assessment activities. While no two of the protocols were identical, several questions were repeated on all three instruments in order to be comparable during analysis.

After all of the interviews were completed, the matched-pair questions were coded for the five epistemic frame elements of Skill, Knowledge, Identity, Values, and Epistemology. The coding scheme used in this process, outlined in Table 3, was derived from the results of the epistemography, which outlined a set of working definitions for each of the frame elements. The operational definition of the code describes what specifically was coded for in the interview data, while the description of the code provides examples of the comments or references that warranted the application of the code during analysis.

Code frequencies were tallied, and the mean number of references per student from pre- to post-interview were compared with a paired-sample t-test. Learning gains were indicated by a statistically significant positive difference between pre- and post-interview question means. After this initial comparison, the same analytical techniques were used to compare player responses from post- to follow up interview, conducted three months after the conclusion of the epistemic game, to look for any sustained learning outcomes.

Code	Operational Definition	Description
Skills	References to engineering abilities or competencies	Brainstorming, comparing alternatives, interpreting feedback, communicating with teammates, keeping a design notebook, DBT cycle
Knowledge	Appropriate use of professional terms of art and scientific vocabulary	Design alternative, center of mass, cross bracing, swing phase, stance phase, even gait, antalgic gait
Identity	References to roles held by player or engineers as professionals	Engineer as innovator, engineer as communicator, engineer as presenter, engineer as someone who tinkers with devices
Values	References to concepts that are important to engineering practice	Creating an optimized and/or reliable design, adhering to client need, developing several design alternatives
Epistemology	References to professionally accepted justification for engineering activity	Ruling out a design because it is too costly, evaluating tradeoffs when making a decision

Table 3. Coding scheme with engineering-specific epistemic frame elements used for coding outcome data.

The indicator for a sustained learning outcome was a statistically significant positive difference between pre- and follow-up interview question means, as determined by a paired sample t-test. Finally, anecdotal data collected in a series of programmatic evaluation questions in the post-interview were coded for common themes and sentiments from the players about their game experiences and views on engineering.

Process Data

The *in situ* data collected during Digital Zoo was analyzed in order to uncover key facets of the learning mechanism found within the game. Using Verbal Analysis as a foundation, the analysis unfolded in a multi-step process involving preparing the data for analysis, establishing a robust coding scheme, operationalizing the coding, using both qualitative and quantitative techniques to generate a grounded theory, and providing a statistical warrant for the resultant claims of the analysis.

Organization, Selection, and Reduction of Data

A large amount of qualitative *in situ* data was collected during Digital Zoo, as described above. Initially, this data needed to be organized and inventoried to get a sense of the scope, depth, and richness of the data collected. This process began by examining an overall game itinerary and numbering each game segment in chronological order, so that the opening game activity was labeled as 1 and the final game activity being labeled as 79. Each piece of *in situ* data was then tagged with the number of the particular game activity in which it was actually collected.

After cataloging the data set, the process of data selection and reduction began as outlined in Verbal Analysis methodology. After examining each type of qualitative data for its relevance to the research question and its quality (primarily measured in its richness and the systematic nature of its collection), the copies of players' digital design notebooks and the recordings of the design meetings between players and design advisors were chosen to be included in the present analysis of Digital Zoo. This data selection and reduction is a type of *theoretical sampling,* which Schwandt describes as the selection of particular types of data that the researcher believes "that 'what goes on there' is critical to understanding some process" and that it may be "particularly revelatory" towards issues and concepts the researcher is interested in (Schwandt, 2001) p.232). In this case, the choice to include the audio recordings of design meetings and the copies of the digital design notebooks in this analysis was grounded by the early ethnographic work that informed game design (Svarovsky, in submission) that identified design meetings and design notebooks as reflective participant structures that contributed to epistemic frame development in the practicum – and thus were specifically recreated within Digital Zoo.

Qualitative Coding of Data and Determination of Appropriate Grain Size

After the data to be included in the analysis was selected, it was coded using a coding scheme that was slightly modified from the one used to code the outcome measures above. The descriptions of the codes remained the same, but because of the nature of the *in situ* data – which attempts to capture action and reflection on action in context, during the game – it was necessary to refine the operational definitions of the codes in order to better analyze what and how players were learning in the game. The revised coding scheme and examples from the data are presented in Table 4.

After the coding scheme was established, it was necessary to determine an appropriate unit of qualitative analysis for the *in situ* data. Chi (1997) describes this as finding a proper "granularity" for the analysis that allows for the coding scheme to be applied and patterns to be uncovered. If the qualitative unit of analysis is too large (choosing a granularity that is too coarse), too many instances of codes would be identified in each unit, thus making comparison amongst units unrevealing. On the contrary, if the qualitative unit of analysis is too small (choosing a granularity that is too fine), the instances of codes would so sparse that, once again, the comparison of units would be unrevealing.

Code	Operational Definition and Description	Example from Data
Skills	**References to, *or evidence of,* engineering abilities or competencies** (brainstorming, interpreting feedback, communicating with teammates, DBT cycle, etc.)	"I added feet to my stable figure. When I added gravity the feet collapsed, but the body didn't budge. I am going to add more braces to make the feet more stable."
Knowledge	**Appropriate use of professional terms of art and scientific vocabulary** (design alternative, center of mass, uneven gait, antalgic gait, etc.)	"Here I made an eight legged figure that has an uneven gait. Its uneven gait is very noticeable. I made the figure have a lot of supports so that the body will be very stable."
Identity	**References to roles held by player or engineers as professionals** (engineer as innovator, engineer as communicator, engineer as someone who tinkers with devices, etc.)	"It kinda made me think about how engineers... probably have to make presentations to a lot of clients too…it made me feel good when that guy thought mine was cool."
Values	**References to, *or evidence for the use of,* concepts that are important to engineering practice** (creating an optimized and reliable design, adhering to client need, developing several design alternatives, etc.)	"Here I tried a whole new idea. I wanted to come up with something sturdy and I wanted to come up with something that the client might like. He stood when the gravity was turned on. Now I will try another idea for the client."
Epistemology	**References to, *or evidence for the use of,* professionally accepted justification for engineering activity** (ruling out a design because it is too costly, evaluating and choosing design alternatives based on the design matrix; evaluating tradeoffs when making a decision, etc.)	"My final [design] recommendation is "Hyperactive Kenny" because…his [user] rating is only a little lower, he fits the scene better than the other Kenny, he did better on the user and sloped terrain test, [and] he meets the client's requirements."

Table 4. Coding scheme with engineering-specific epistemic frame elements used for coding *in situ* data.

The analysis of Digital Zoo required the examinations of connected frame elements, and therefore the appropriate granularity for a qualitative unit of analysis would be one that potentially allowed multiple frame elements to be coded at once. However, the grain size must also be able to accommodate instances where only one – or none – of the frame elements is present. As an initial attempt, a sample of data was segmented at the "game activity" level, where one unit of analysis consisted of all of the data within one game activity for one player. This unit proved to be too coarse, since all of the units had at least one frame element coded and the overwhelming majority of them had more than one coded. A second attempt examined a sample of data at the "utterance" level, where each turn of speaking was identified as a unit of analysis. Not surprisingly, this unit had the opposite problem and proved to be too fine, with almost all of the units having only one frame element coded, if at all.

After a few additional attempts at segmenting the data, the *design alternative,* defined as one potential solution to a particular design problem, emerged as a potentially fruitful unit of qualitative analysis for Digital Zoo. Within different game contexts, the beginning and end of a design alternative was denoted in different ways. For example, in design meetings, design alternatives were identified by the players, who brought specific design alternatives from their design work to discuss with teammates and design advisors. However, in the documentation of design work within the design notebook, design alternatives were marked by the identification of a design goal (such as solving a particular design challenge, sub-challenge, or issue) design moves (steps taken to address the design challenge), and design concept stability (most often signaled by the player moving on to another design goal or a substantially different approach). Data segmented at the design alternative level yielded a range of frame element instances during coding, accommodating both the total absence as well as the multiple presence of frame elements in different units. Thus, the design alternative appeared to be at the appropriate granularity for analytical comparison.

Construction of Design History Prototypes and IRR

Once a coding scheme and appropriate grain size for analysis were established, the qualitative data for each player in Digital Zoo needed to be reorganized and resegmented into *design histories* (Chi, 1997; Shaffer, 2004b) in order to achieve an analytic representation that allowed for the exploration of player reflection on specific frame elements over time while simultaneously being aligned with the epistemic game hypothesis being tested in the design experiment. Because the theory of learning that was built into Digital Zoo suggested that epistemic frames were developed through cycles of action and reflection on action within a practicum setting, it was necessary to organize the qualitative data in a way that represented this process. Thus, using the data selected for analysis in the present study (design meeting transcript segments and design notebook pages), design histories for each player were constructed. Each design history contained all of the data pieces that captured or demonstrated one player's action and reflection on action, thus providing a record of that player's experience within the game.

Three design history prototypes involving the data from one, three-player team were constructed in order to examine the effectiveness of the data representation. The construction of each design history began with the creation of a "temporal grid" that had 79 initial segments, one for each game activity experienced within Digital Zoo. Next, all of the data that captured or demonstrated some part of a particular player's experience were taken from the qualitative data set and placed into the grid in the corresponding temporal segment. After Player A's actions and interactions within the game were represented in this way, a second stream of data, representing Player A's reflection on action, was added also to the temporal grid. Finally, after all of the data representing Player A's game experience was poured into the temporal grid, the design history was prepared for coding by dividing each temporal (game activity) segment into design alternatives.

After the three design history prototypes were assembled and coded, the validity of coding process was checked through an Inter-Rater Reliability (IRR) analysis. A professional engineer was trained on the qualitative coding scheme using a small sample of design history data, and then he proceeded to independently code one tenth of randomly selected data from the three design history prototypes. The codes assigned by both the primary coder and the professional engineer were compared and correlated, resulting in a statistically significant value of 0.85 for Cronbach's Alpha ($p<0.01$), thus satisfying the requirement of being above the 0.70 value established in the literature (Nunnally & Bernstein, 1994) as an acceptable level of agreement. After determining the applicability, appropriateness, and reliability of the qualitative analysis methods (which included the coding scheme, qualitative unit of analysis, and design histories in Digital Zoo, the remaining design histories for the other seven players were constructed and coded.

Initial Epistemic Network Analysis

After the coding process was completed, there was a design history for each player containing a specific number of design alternatives that had specific codes from the engineering epistemic frame attached to it. At this point, the data was ready to undergo an initial quantitative Epistemic Network Analysis that examined player reflections on the engineering epistemic frame over time.

While ENA is capable of calculating several quantities that can characterize an epistemic network, the research questions being addressed in Digital Zoo suggested a focus on the relative centralities of the different frame elements – and in particular, the frame elements of values and epistemology that highlighted engineering ways of thinking. Relative centrality is a measure of how "connected", or emphasized, a particular frame element is relative to the other frame elements being considered. By using the equations for ENA listed above, the relative centralities of each frame element over the course of the game for each player can be calculated from her coded design history. Because each relative centrality data point could be traced back to a particular design alternative within a particular game activity, it was possible to begin discerning patterns within the data, such as which activities tended to yield spikes in (or high levels of) the relative centrality of particular frame elements. After qualitatively comparing patterns across players, notebook-based reflection and client-focused activity appeared to emerge as specific activities that were associated with high levels of relative centrality for engineering values and epistemology.

Epistemic Network Analysis of Macrostructures

Given the importance of design meetings, design notebooks, and client centered activity in the epistemography, it is not completely surprising that these particular participant structures tended to elicit player reflection on specific elements of the epistemic frame. However, in order to more fully characterize the relationships between these activities and engineering values and epistemology, it was necessary to engage in another round of Epistemic Network Analysis. For the second round of ENA, the design alternatives in each player's design history were grouped into eight *macrostructures* (Gee, 2005). For clarity, a system of notation was developed for the macrostructures in order for the reader to quickly be able to identify its particular context during the game.

The notation for the macrostructures first divided each player's design history into the two design projects, essentially dividing the design history into the first and second weeks of the game. Macrostructures including a "1" in its name will be from the first week of the game, and those with a "2" will be from the second week. The next grouping divided each design project segment by the focus of the work: the design challenge-focused activity, observed during the first half of the project, and the client-focused activity, observed during the second half of the project. Macrostructures including a "Ch" in its name will be from the design challenge focused portion of the week, and those with a "C" will be from the client-focused portion of the week. Finally, the last grouping divided each activity segment by the type of reflection being done: meeting/discussion based reflection or notebook-based reflection. Macrostructures including a "D" in its name will refer to meeting/discussion based reflection, and those with an "N" will refer to notebook-based reflection. By dividing each design history three times, the eight macrostructures were produced as seen in Table 5.

Macrostructure Number	Activity Focus	Type of Reflection	Design Project Number	Macrostructure Name
One	Design challenges (Ch)	Meeting / Discussion based (D)	1	ChD1
Two	Design challenges (Ch)	Notebook based (N)	1	ChN1
Three	Client (C)	Meeting / Discussion based (D)	1	CD1
Four	Client (C)	Notebook based (N)	1	CN1
Five	Design challenges (Ch)	Meeting / Discussion based (D)	2	ChD2
Six	Design challenges (Ch)	Notebook based (N)	2	ChN2
Seven	Client (C)	Meeting / Discussion based (D)	2	CD2
Eight	Client (C)	Notebook based (N)	2	CN2

Table5. Macrostructure features and names used in Epistemic Network Analysis.

Once each of the ten players' design histories were divided into eight segments, a data file in SPSS containing eighty cases was created. Each case was tagged with contextual information, including which player the case belonged to, which design project it was a part of, whether or not the data was from client-focused activity, and whether it was meeting or notebook-based reflection. Then the data from each case was subjected to the ENA routines described above, resulting in the calculated relative centralities of each frame element for each segment. The values for these numbers were then entered into the appropriate case within the SPSS file. After the Epistemic Network Analysis of the macrostructures was completed, the calculated relative centralities for engineering values and epistemology were again preliminarily examined qualitatively across the eighty cases. Plots of average relative centralities versus the eight macrostructures reinforced the working theory that engineering values and epistemology were particularly emphasized both in client-focused activity and notebook-based reflection.

Intra-Sample Statistical Analysis

The claims stating higher relative centralities of engineering values and epistemology were associated with client-focused activity and notebook-based reflection were grounded in the qualitative data. Moreover, because these claims were reinforced through a second round of more detailed Epistemic Network Analysis, they appeared to be warranted through the presence of *theoretical saturation* (Glaser & Strauss, 1967; Schwandt, 2001; Strauss & Corbin, 1998). At this point in the overall analysis of the *in situ* data, an Intra-Sample Statistical Analysis was conducted in order to provide additional insight into the qualitative patterns found in the data and additional justification for the claims of theoretical saturation.

While ISSA outlines how statistical analyses might be used in qualitative studies with small sample sizes but large numbers of observations, it does not identify a particular statistical method that must be applied to the data. However, given the requirement to control for Type I error, a form of regression analysis where specific effects can be easily controlled seemed to be an appropriate choice. Common regression models include linear regression, which can be used with continuous outcome variables, and logistic regression, which can be used with dichotomous outcome variables. Deciding which regression technique was more appropriate for Digital Zoo required the consideration of several factors, including the types of outcome variables associated with each model, what information the results of the analysis would convey, and the extent to which those results would address the original research questions of interest.

Continuous versus Dichotomous Forms of Regression

In both the linear and logistic regressions, all 80 of the cases would be included in the analysis. Dichotomous dummy variables for each of the 10 players and time would be included in order to create a fixed effects model. Dichotomous dummy variables for two participant structures of interest, client-focused activity and notebook-based reflection, would also be included. In linear regression, the outcome variables are typically continuous, and thus the actual calculated relative centralities of a particular epistemic frame element would be chosen as the outcome (dependent) variable. The resulting coefficients in the model would predict the additive change in the outcome variable due to a change of a given predictor. In contrast, logistic regression requires dichotomous outcome variables in order to compute a solution to the model. Dichotomous outcomes are commonly represented with zeros and ones, where zero indicates the desired outcome did not occur, while a one indicates it did occur. Unlike linear regression that predicts a specific amount of change in an outcome variable, logistic regression predicts the probability of the outcome variable given a change in value of a particular predictor.

Given the qualitative nature of the research questions in Digital Zoo, the information provided by the logistic regression model seems to be more useful. While linear regression provides a sense of how much relative centrality will increase or decrease based on the change in value of a predictor, that information does not address the research question as well as an examination of the patterns of when high or low levels of relative centrality occur, and in particular, when and if specific activities are associated with periods of high centrality. Moreover, the results of logistic regression are fairly easy to interpret, as the logit coefficients in the model shed light on the relationships between the desired outcome and specific predictors. A positive coefficient a given predictor indicates that outcome is more likely to occur given a positive change in the predictor, and a negative coefficient indicates that the outcome is less likely to occur given the same change.

Of course, the primary challenge in choosing logistic regression for the ISSA of Digital Zoo was the need to translate a continuous variable, relative centrality, into a dichotomous one. Each calculated relative centrality would be compared to some threshold value and translated into either a "1" if it was greater than or equal to the threshold value or a "0" if it was not. In so doing, numerical information would be lost, and all that would remain in the analysis would be the ones and zeros that indicated whether a particular relative centrality was "high" (above the threshold) or "low" (below the threshold). While this may seem like a drastic price to pay for the use of this statistical technique, it is important to keep the advantages of logistic regression – and extent to which the results and models it produces address the particular research questions of given study – in mind. Researchers in several fields, including epidemiology (Ragland, 1992) and criminology (Farrington & Loeber, 2000), also dichotomize continuous outcome variables in order to use logistic regression as a tool for illustrating associations between different variables.

Fixed Effects Logistic Regression

In a sense, translating the calculated relative centralities of each frame element calculated during Epistemic Network Analysis into a dichotomous outcome variable was analogous to qualitatively coding these numbers. By comparing relative centrality values to a specific threshold value and assigning a "1" in the dummy variable column if the relative centrality value was greater than or equal to the threshold value and a "0" if it was not, the relative centrality values were essentially coded into "high centrality" and "low centrality" categories. The threshold values were calculated by determining the mean relative centrality for each frame element of each player across all eight macrostructures. For example, Player A would have one threshold value for the relative centrality of epistemology, which would be equal to the mean relative centrality of epistemology for Player A calculated across all eight macrostructures. Player A would have different threshold values, calculated in an analogous manner, for relative centralities of the other four frame elements. Calculating threshold values in this way compares a player's reflections on frame elements within a given macrostructure to her individual reflections on the frame over the course of the game.

After all threshold values were calculated, the calculated relative centralities for each of the 80 cases in the SPSS data file were compared to the appropriate threshold and translated into a "1" or "0", thus rendering the data file ready for logistic regressions. For each epistemic frame element, a fixed effects logistic regression model was created, each with a series of blocks that examined a series of predictors, which included dummy variables for each of the players, a dummy variable for time called the Design Project Variable, an Activity Focus Variable, and a Type of Reflection Variable. Each of the 80 cases in the SPSS file was tagged with the appropriate set of dummy variables representing the player, week, focus of activity (client-focused activity was assigned a "1", design challenge/non-client-focused activity, "0"), and type of reflection (notebook-based reflection was assigned a "1", meeting/discussion based reflection, "0"). Table 6 outlines the different dummy variables and how they were assigned.

These models were used to generate logit coefficients which provided a measure of how associated specific predictors were with high relative centrality values for a particular frame element. In so doing, these regressions helped to further explore which participant structures tended to elicit reflection on specific frame elements and linkages, and thus provided additional, statistical warrants for the qualitative claims of theoretical saturation identified earlier in the analysis process.

	ASSIGNED VALUE	
DUMMY VARIABLE	**1**	**0**
Player *i* *(i = A through J)*	Case is from design history of Player *i*	Case is not from design history of Player *i*
Design Project Variable	Observed during Week 1	Observed during Week 2
Activity Focus Variable	Observed during periods focused on client activity	Observed during periods focused on design challenges (non-client)
Type of Reflection Variable	Observed within design notebook	Observed during design meeting

Table 6. Dummy variables used in fixed effects logistic regression.

Returning to the Qualitative Lens

After conducting the regressions and reviewing the logit coefficients generated by the model, quantitative information produced by the statistical tests was interpreted with a qualitative lens. Statistically significant logit coefficients were examined and compared, but only in a qualitative sense by observing whether they were positive or negative to determine the nature of the relationships between the predictors and the desired outcome. In the same way that the fundamentally qualitative nature of this work and the research questions of this study drove the decision to ultimately dichotomize a continuous outcome variable, the logit coefficients produced by the logistical regressions must also be valued for their *qualitative*, not quantitative, value.

Echoing the caveats about ISSA stated earlier in this chapter, these analyses were *not intended* to provide and attach specific quantitative values to the fundamentally qualitative patterns observed in the data. Rather, the quantitative values – and the logit coefficients in particular – generated by these analyses can provide valuable information about the general nature of the relationships between centralities and participant structures, such as suggesting that players may be more likely to reflect on one frame element and its linkages within a particular activity in the game than in another within the game. By returning to the use of the qualitative lens throughout the more quantitative portions of this analysis, the grounded and descriptive nature of this work – and the contextual richness of the types of data found in design experiments more generally – is preserved.

In the chapter that follows, the results from the entire study are presented, describing both the learning outcomes and learning processes for players of Digital Zoo that were determined through the use of the methodological techniques presented here. The verbal analysis (Chi, 1997) conducted on the pre-, post-, and follow up data suggested that players were able to develop the elements of the engineering epistemic frame as a result of gameplay. The Epistemic Network Analysis (Shaffer et al., 2009)of the *in situ* data revealed patterns in the players' reflections on engineering values and epistemology, which were then further explored and warranted by the intra-sample statistical analysis (Shaffer & Serlin, 2004) and the use of fixed effects logistic regression.

In addition a discussion of the findings of the study, the limitations and implications of this methodology will be presented in Chapter 5. While the mixed methods approach used in this work provided a fruitful set of techniques for examining complex learning outcomes and processes in a naturalistic setting, key lessons have been learned that can inform the ways in which these methods are used in the future. As such, it is essential to reflect on the tradeoffs involved in utilizing this approach, as well as the potential implications this work may have for the broader learning sciences community.

CHAPTER 4

RESULTS

This study asks whether middle school girls are able to develop their understanding of engineering epistemic frame elements as a result of playing Digital Zoo, and if so, whether specific participant structures within the game elicited reflection on specific frame elements – and in particular, engineering values and epistemology. The results of this work are therefore presented in two parts. In Part One, learning outcomes are described, highlighting the engineering skills, knowledge, identity, values, and epistemology players developed in Digital Zoo. In Part Two, learning processes during gameplay are examined, focusing on the relationships between specific participant structures and players' reflection on particular frame elements and linkages within the frame.

Part One: Learning Outcomes of Gameplay

Overall, the results from the pre- and post-interviews suggest that players were able to develop engineering skills, knowledge, identity, values, and epistemology as a result of playing Digital Zoo. As stated in the previous chapter, matched pair questions on each of the interviews probed players' understanding of the different epistemic frame elements, asking them to define key concepts, articulate their views, and engage in engineering tasks. In the pre-interviews, many of the players' responses to the matched pair questions incorrectly characterized or described the different aspects of engineering practice, suggesting a limited understanding of the individual frame elements. However, in the post-interviews, players' responses were more accurate, specific, and sophisticated, demonstrated by the significant increase in the number of correct references to each frame element across the set of matched pair questions from pre- to post-interview. Moreover, the results from the follow up interviews indicate that learning gains observed immediately after the game ended (in the post-interview) were still present three months later. The learning outcomes associated with each of the frame elements are presented below, including the results of paired sampled t-tests and excerpts from player interviews.

Skills

References to engineering skills increased significantly from pre- to post-interview (mean pre = 0.9, mean post = 3.1, $p<0.01$, Figure 4.) This learning gain was maintained through the follow up interview as well (mean pre = 0.9, mean follow up = 2.7, $p<0.01$, Figure 4). For example, when asked what engineers do, one player responded, "they create stuff." After the game, the same player provided a more articulate answer, stating:

> "Well they design stuff and execute it... They have to first look at the problem letting them know what their design is for, what's it got to do, and then a lot of trial and error. If they are trying to make something, and it fails, they just do something a little bit different to see if that works, and keep changing things. Eventually [they] come up with a result... and then they've got to do it all over again. Make an alternative and see if that comes out better. Maybe because they had all that trial and error, it might be easier the second time. Then present, present, present [to teams and clients]."

This player describes several skills involved in an engineering design process, including understanding the problem statement, the design-build-test cycle, developing multiple design alternatives, and presenting work in design and client meetings.

Knowledge

References to engineering knowledge increased significantly from pre- to post-interview (mean pre = 1.5, mean post = 6.6, $p<0.01$, Figure 4.) This learning gain was maintained through the follow up interview as well (mean pre= 1.5, mean follow up = 6.2, $p<0.01$, Figure 4). For example, when one player was asked to define the concept of "center of mass" during the pre interview, she responded, "It's like the center of the object?" In the post interview, the same player said,

> "It's the center where everything balances. (pause) Well, it's not always the center.... [it is] the point where everything balances... something could be a structure where it's built kind of awkwardly... The center wouldn't always be the right place because things might be hanging off [one edge]."

Here, the player has a more sophisticated understanding of center of mass, realizing that it is not merely the geometric center of an object and that having an uneven weight distribution would potentially shift the center of mass to a different location. In another matched-pair question, players were asked to define the concept of gait. One player, who stated she didn't know what gait was in the pre interview, responded in this way on the post interview:

> "It's the way you walk. If you have an even gait that means you are walking evenly, like at an even pace. But if you have, let's say, an antalgic gait then you might be limping or walking a different way than you normally would."

In this response, the player not only demonstrates her understanding of the concept of gait, but goes on to provide different examples of gait that were used within the context of the game.

Identity

References to engineering identity increased significantly from pre- to post-interview (mean pre = 1.8, mean post = 5.1, $p<0.01$, Figure 4.) This learning gain was maintained through the follow up interview as well (mean pre= 1.8, mean follow up = 5.2, $p<0.01$, Figure 4). For example, when asked if she had ever thought of herself as an engineer in the pre interview, one player said, "No." In response to the same question in the post interview, the same player said:

> "Not until the day, like I was thinking about it yesterday, when we were like starting to design… the presentations, the client meetings, and making what they asked for in the problem… Yeah. And meeting their needs for that design."

Out of the eight players that responded positively to this question in the post interview, six of them reported some form of interaction with the client as the reason they felt like an engineer, with the other two players identifying the use of computers and technology.

Players also demonstrated more understanding of an engineer's professional identity after gameplay. For example, when asked what it meant to be an engineer, one player in the pre interview responded, "I don't know." The same player, in the post interview, said:

> "I think it means to help people. Doctors help people, too, but engineers can help people in different ways, making their life easier and making sure the environment is okay, things like that. Someone had to design the car. So, kind of designing things that people need… like backpacks, shoes, bikes, and lights."

This player's response is particularly interesting for two reasons. Not only is the player more descriptive in her characterization of the engineering profession after the game, she also articulates specific ways engineers help people that are different from other professions like medicine.

Values

References to engineering values increased significantly from pre- to post-interview (mean pre = 1.8, mean post = 4.1, $p<0.01$, Figure 4), and this increase was maintained through the follow up interview (mean pre = 1.7, mean follow up = 4.1, $p<0.01$, Figure 4). For example, when asked to describe what engineers care about during the pre interview, one player said, "I don't know, science?" The same player responded in this way on the post interview:

> "Well obviously their family and stuff, but probably what their client's going to think. They want to put the client's needs first, and they probably just want to make it something that's original. Something else that isn't out there… maybe if they're designing [a product], they don't want it to look like every other single one."

With this response, the player describes two specific engineering values: the importance of understanding and addressing the client's needs, and creating an original and innovative design solution.

Epistemology

References to engineering epistemology increased significantly from pre- to post-interview (mean pre = 0.3, mean post = 0.9, $p<0.01$, Figure 4.) This learning gain was not only maintained in the follow up interview, it actually increased (mean pre = 0.3, mean follow up = 1.6, $p<0.01$, Figure 4). For example, during each interview, players were presented with information on three different choices for seating on some form of public transportation (bus, subway, or train) in a large city. Players were asked to identify the best option and explain their selection. In the pre interview, one player identified and explained her choice in this way:

> "I think this one... it doesn't seem like it would be very comfortable, but it is small and it has a 4 star safety rating. This one looks very comfortable but it only has a 3 star safety rating and only 36 units [can fit]. This one doesn't look comfortable, but it has a 4 star safety rating and plus it's not too expensive... I guess it's kind of like the happy medium."

In the post interview, the same player said:

> "Hold on... I'm not done yet. Ok, I think it's this one, the ARAC Seat, because it can fit 52 units, which is more than either one because they have Coachman Deluxe, it has 40, and the other one is 45, and this one can hold 52, plus it has... the same safety rating as this one and a better safety rating than this one. Granted it's not as comfortable as this one, but it looks a lot more comfortable than this one, and it actually costs less. The seats can't flip up when they're not in use, but that doesn't really matter. I don't know, like why would you really need them to flip up since you can only fit a certain number [of units] in there anyway? So it looks like it's really easy to clean, which would be good so that they don't get dirty. And it's the same price as this one. I just looked at them and compared. I knew that one wasn't going to be it because it has a luxury rating of, who cares about [that]? It's a train, why would you want a comfort rating of 6 stars if it's only a 3-star safety rating? I wouldn't really feel safe with that. And also it's very costly at $105. Then I compared between these two... I just compared the number of units that fit the price, and the safety rating, and *then* looked at the special features, and kind of figured out which one was best."

In the pre-interview response, the player examines the information and chooses the "mid-range" product that neither too expensive nor the most comfortable, without providing additional reasoning behind her choice. However, in the post-interview, she not only asked for more time to make her decision, but she was also able to more fully articulate the tradeoffs she considered in her choice. In particular, she initially focused on the key design features (the number of units that could fit in the train, the safety rating, and the price) before considering additional information provided in the product descriptions.

Players were also presented with a design task and asked to create a flowchart outlining the steps they would take to build a structure that could hold perform a certain task, such as bearing the most weight. The number of links between different steps increased significantly from pre to post interview, (mean pre=3.8, mean post = 6.6, $p<0.01$). The number of steps included in the process also increased significantly from pre to post interview (mean pre = 4.2, mean post= 6.5, $p<0.01$). These differences were also seen in the follow up interview, though the average numbers of links (mean pre=3.8, mean follow up= 4.8, $p<0.05$) and steps (mean pre = 4.2, mean follow up = 5.2, $p<0.05$) did decrease slightly from the post interview levels.

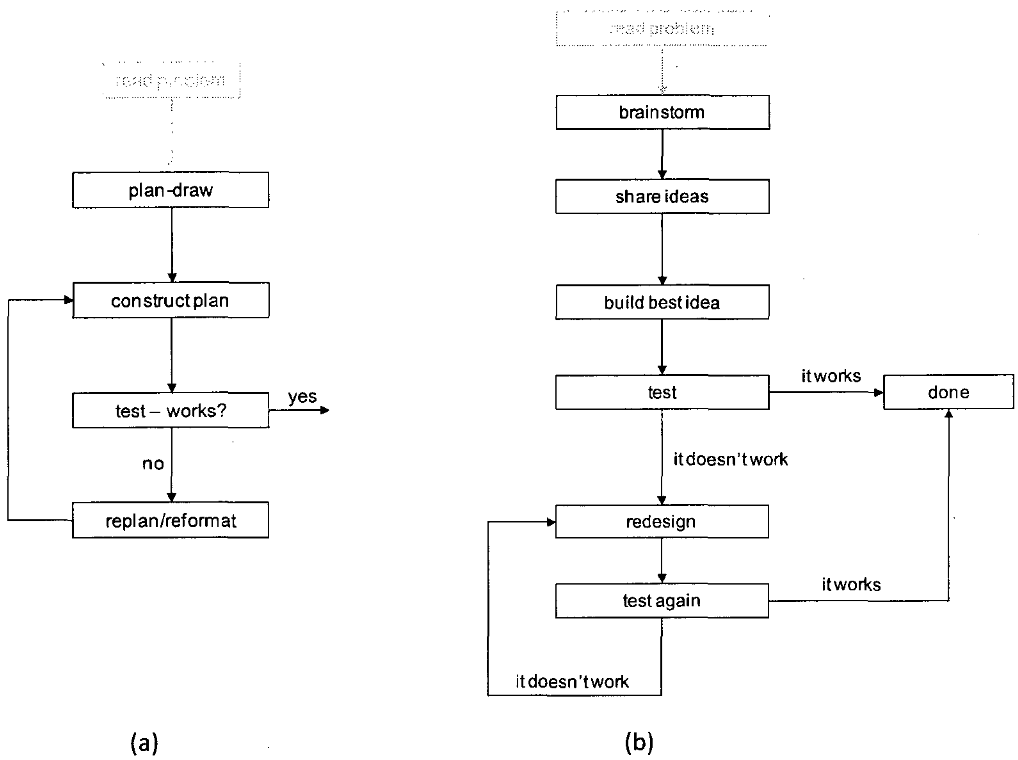

Figure 3. One player's flow chart responses from pre and post interview.

For example, one player drew the flowchart in Figure 3a in response to the design task prompt during the pre interview. She then drew the flowchart in Figure 3b during the post interview. Her flowchart in the post interview contains additional steps that were not there in the pre interview, such as brainstorming, sharing ideas, and focusing on building the best idea in order to test it. Figure 3 illustrates the differences in the number of references to each of the frame elements in the pre, post, and follow up interviews:

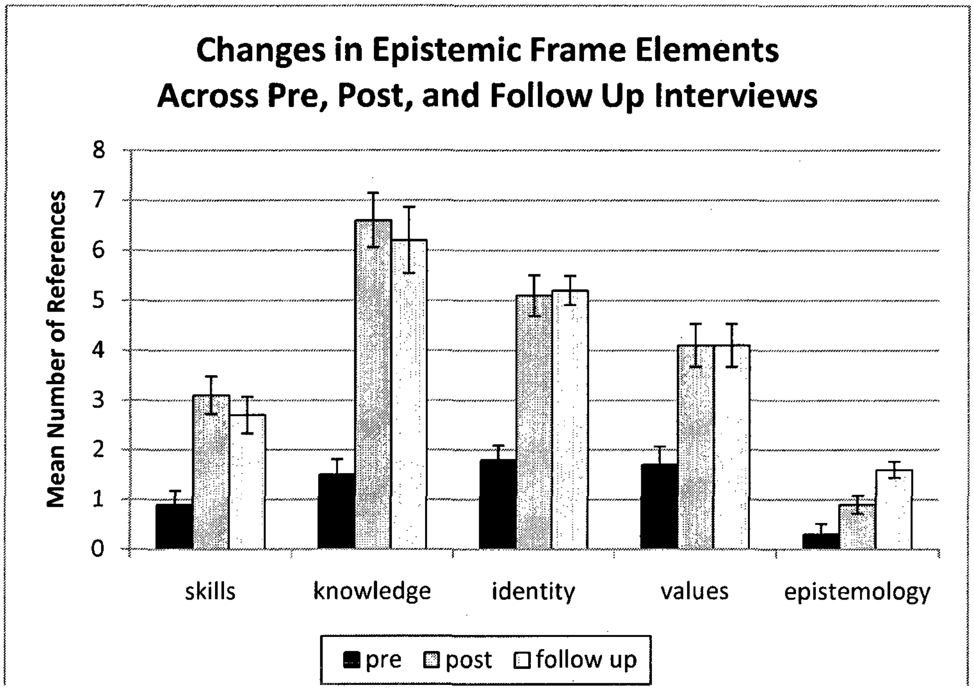

Figure 4. Differences in epistemic frame references across pre, post, and follow up interviews.

The statistically significant increases from pre- to post-interview, and the extent to which those increases were sustained in the follow up interview, can be seen in Figure 4. As such, it summarizes the results presented above, which suggest that players were able to begin to develop the engineering epistemic frame as a result of playing Digital Zoo.

Part Two: Relationships Between Frame Elements and Game Activities

The analysis of the *in situ* data collected during Digital Zoo provides insight into how and when players reflected on different frame elements and linkages within the engineering epistemic frame during gameplay. The second research question asks whether specific participant structures were associated with players' reflections on specific frame elements, and in particular, engineering values and epistemology. Overall, players' reflections appeared to emphasize engineering skills and knowledge throughout the two week data set, while engineering identity appeared to be mostly emphasized at the beginning of the game. In contrast, reflections that emphasized engineering values and epistemology seemed to be concentrated within certain participant structures during the game.

As described in Chapter 3, these trends were initially examined with Epistemic Network Analysis (Shaffer et al., 2009), which examined players' reflections on different frame elements over time by calculating specific comparable quantities. Two of these quantities, *relative centrality* and *sums of squares centrality*, provide a measure of how much an element is emphasized over a period of time – the higher the centrality of a particular element the more "connected" or referenced it is within a given timeframe.

Given the importance of design meetings, design notebooks, and client-focused activity in the epistemography that informed Digital Zoo, the *in situ* data from the game was segmented along these dimensions, resulting in eight macrostructures. For the reader's ease of reference, the macrostructure names and definitions are listed in Table 7 below, copied from the previous chapter. Thus, by conducting Epistemic Network Analysis on each of these segments for each of the players, the centralities of different frame elements across different activity structures could be explored. Noticeable patterns were uncovered, as presented below, and then further examined with fixed effects logistic regression (Allison, 1996; Cox, 1972).

Macrostructure Number	Activity Focus	Type of Reflection	Design Project Number	Macrostructure Name
One	Design challenges (Ch)	Meeting / Discussion based (D)	1	ChD1
Two	Design challenges (Ch)	Notebook based (N)	1	ChN1
Three	Client (C)	Meeting / Discussion based (D)	1	CD1
Four	Client (C)	Notebook based (N)	1	CN1
Five	Design challenges (Ch)	Meeting / Discussion based (D)	2	ChD2
Six	Design challenges (Ch)	Notebook based (N)	2	ChN2
Seven	Client (C)	Meeting / Discussion based (D)	2	CD2
Eight	Client (C)	Notebook based (N)	2	CN2

Table7. Macrostructure features and names used in Epistemic Network Analysis.

Average Relative Centralities of Skills, Knowledge, and Identity

Throughout gameplay, the relative centralities of engineering skills and knowledge followed similar trajectories. Both of these frame elements started out highly central, and then remained so throughout the first two projects of the game as seen in Figure 5 and Table 8 below. These calculations from the Epistemic Network Analysis suggests that both skills and knowledge were strongly emphasized from the start of the game and then continued to be central within player's reflections throughout Digital Zoo.

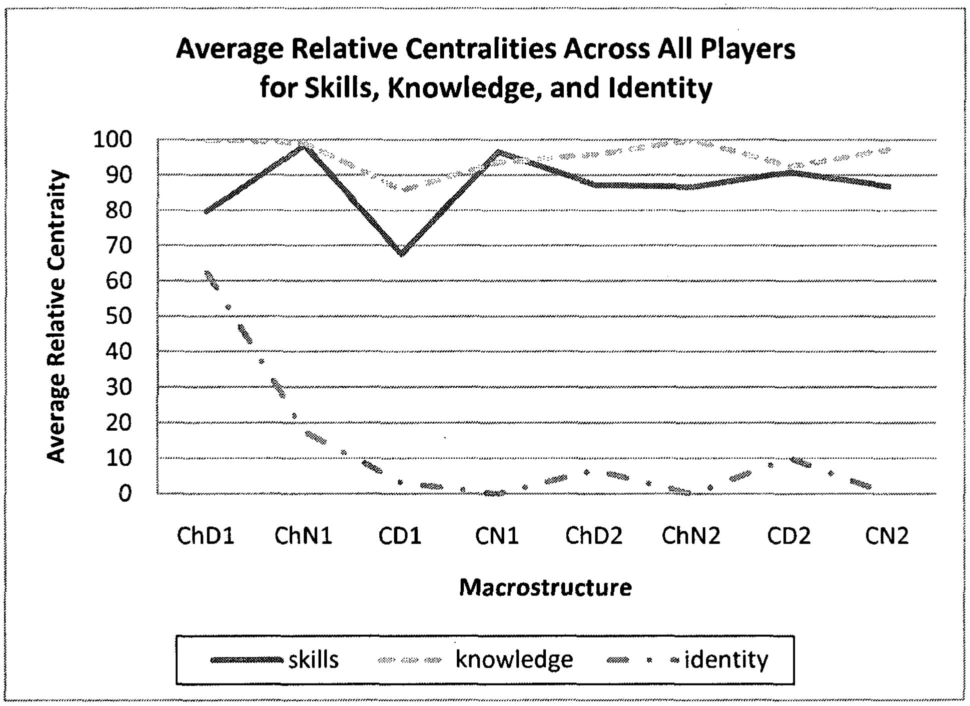

Figure 5. Initial Epistemic Network Analysis across macrostructures for skill, knowledge, and identity.

Both skills and knowledge demonstrate a low point in relative centrality during macrostructure CD1, which occurred during the client-focused activity and meeting based reflection during the design project 1. Because the sums of squares centralities of skills and knowledge in CD1 are similar to those in ChD1, this dip may explained by the increase in the centrality of other frame elements – particularly values and epistemology – during this macrostructure, as seen in Figure 6 and Table 8 below.

The relative centrality of identity starts off at a high level at the beginning of the game in ChD1, and then quickly drops and remains low for the rest of the game. These relative centralities suggest that engineering identity was mostly emphasized during the initial stages of Digital Zoo and then not strongly emphasized afterwards. Players' explicit references to engineering identity were uncommon after the first few days of the game, which resulted in the low relative centrality numbers for that particular frame element as seen in Figure 5.

Average Relative Centralities of Values and Epistemology

Unlike the relative centralities of engineering skills, knowledge, and identity that tended to be either consistently high or consistently low throughout most of the game, the relative centralities of values and epistemology appeared to follow a different pattern.

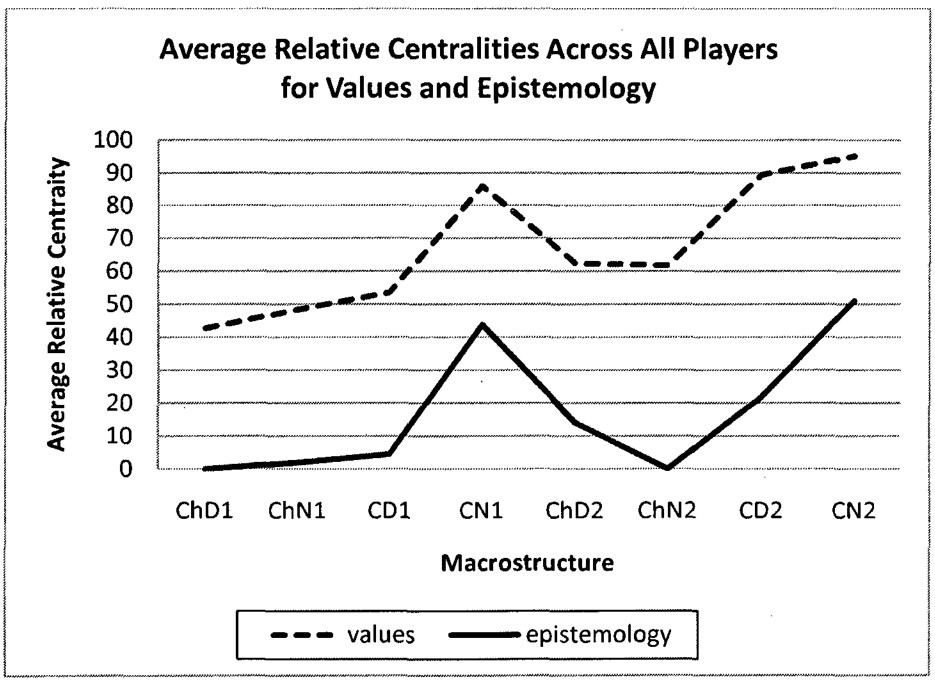

Figure 6. Initial Epistemic Network Analysis across macrostructures for values and epistemology.

These frame elements seemed to become more central during client-focused activity and notebook-based reflection during the CD1 and CN1 macrostructures, as seen in Figure 6 and Table 8 below. While both frame elements decreased in centrality after the conclusion of the first client project, they rose again at the start of the second project, as seen in the CD2 and CN2 macrostructures in Figure 6 and Table 8 below.

These patterns suggest that players' reflections on engineering values and epistemology are tied to Client-focused Activity and Notebook Based Reflection.

	Average Relative Centralities				
Macro structure	Skills	Knowledge	Identity	Values	Epistemology
ChD1	79.76	100.00	62.22	42.76	0.00
ChN1	98.42	99.07	17.58	48.32	1.95
CD1	67.57	85.84	3.16	53.54	4.47
CN1	96.55	93.69	0.00	85.89	43.83
ChD2	87.26	95.84	6.63	62.43	14.13
ChN2	86.72	100.00	0.00	61.79	0.00
CD2	90.85	92.47	9.97	89.44	21.81
CN2	86.86	97.24	0.00	95.16	51.07

Table 8. Average Relative Centralities across the eight macrostructures of the game.

Additional analysis of the relative centralities for values and epistemology was conducted in order to probe further into the relationships between these frame elements and specific participant structures. The average relative centralities for both frame elements were computed across non-client (design challenge) and client-focused activity, as seen in Figure 7. Both frame elements appeared to be more central during client-focused activity than in non-client-focused activity.

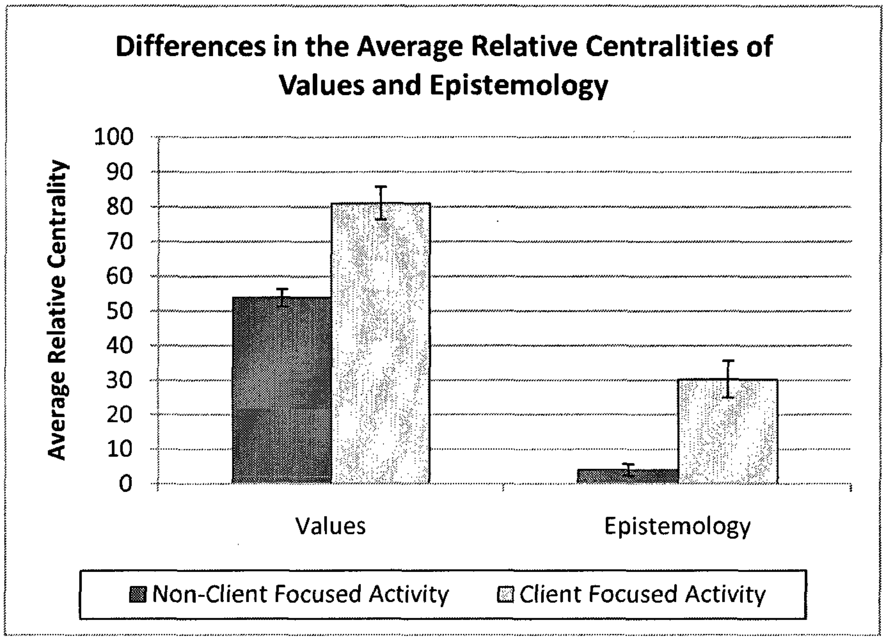

Figure 7. Average relative centralities for values and epistemology across client and non-client-focused activity.

Similarly, in order to better characterize the relationships between the relative centralities of values and epistemology and the different types of reflection present in Digital Zoo, the average relative centralities for both frame elements were computed across meeting/discussion based reflection and notebook-based reflection, as seen in Figure 8.

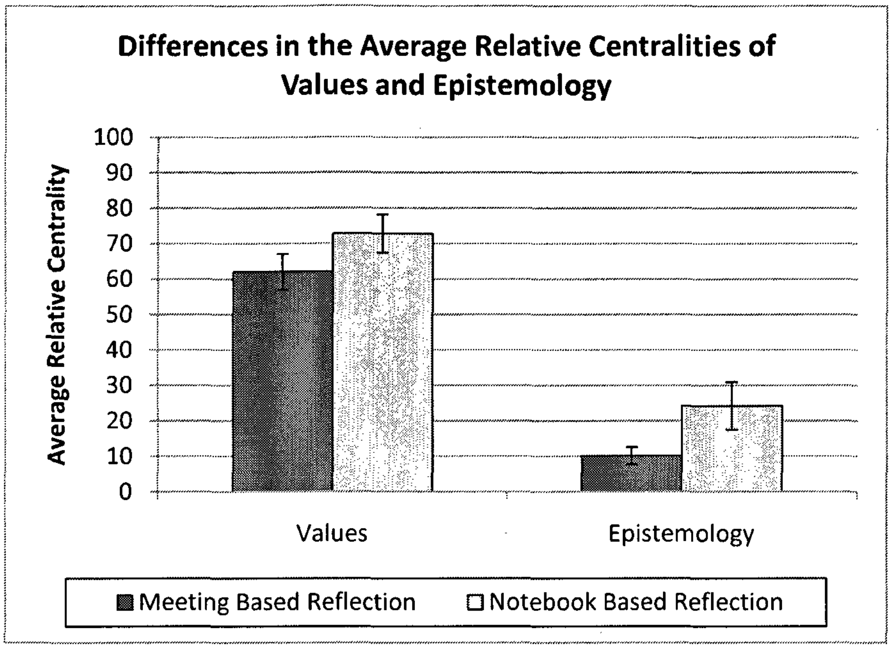

Figure 8. Average relative centralities for values and epistemology across meeting and notebook based reflection

While both frame elements appeared to be more central during notebook-based reflection than during meeting based reflection, the differences were not as pronounced as with the client-focused activity. In addition, the relative centrality of engineering values did not appear to be as impacted by notebook-based reflection as the relative centrality of engineering epistemology.

Intra-Sample Statistical Analysis through Logistic Regression

The patterns identified in the previous section suggest that similar to undergraduates in the engineering practicum, the players in Digital Zoo reflected on key elements of the engineering epistemic frame within the notebook and during client-focused activities. In order to further explore these trends in relative centrality, the *in situ* data was also examined with fixed effects logistic regression.

As mentioned in the previous chapter, it should be noted that these statistical analyses are used only to further explore the patterns found in the qualitative analysis, and confirm qualitative claims about theoretical saturation. In other words, these analyses are *not intended* to provide and attach specific quantitative values to the fundamentally qualitative patterns observed in the data. Rather, the quantitative values – and logit coefficients in particular – generated by these analyses can further warrant the qualitative patterns observed earlier within the analysis. For clarity, Table 9 from the previous chapter, which describes the different predictors included in the models, is also presented here for clarity.

	ASSIGNED VALUE	
DUMMY VARIABLE	**1**	**0**
Player *i* (*i* = *A through J*)	Case is from design history of Player *i*	Case is not from design history of Player *i*
Design Project Variable	Observed during Week 1	Observed during Week 2
Activity Focus Variable	Observed during periods focused on client activity	Observed during periods focused on design challenges (non-client)
Type of Reflection Variable	Observed within design notebook	Observed during design meeting

Table 9. Dummy variables used in fixed effects logistic regression.

Models I and ***II*** look at the relationships between client-focused work, different types of reflection, and the frame elements of engineering values and epistemology.

Model I was a 3-block regression that focused on high relative centralities for values as an outcome and included dummy variables for the players, the Design Project Variable (DPV), the Activity Focus Variable (AFV), and the Type of Reflection Variable (TRV) as predictors. The model produced significant logit coefficients for the Design Project Variable (1.27, $p<0.05$, block 3, Table 10) and the Activity Focus Variable (1.50, $p<0.01$, block 3, Table 10). No significant logit coefficients for the Type of Reflection Variable were produced by the regression.

The significant logit coefficient for DPV suggests that players were more likely to emphasize engineering values during the second design project than in the first. The significant logit coefficient for AFV suggests that players were more likely to emphasize engineering values during client-focused activity than design challenge focused activity. Moreover, the higher logit coefficient for AFV indicates that client-focused activity is has a stronger association with the relative centrality of engineering values than the second week of the project. In addition, the model did not produce a significant logit coefficient for the Type of Reflection Variable, indicating that the type of reflection (either meeting based or notebook-based) did not have a significant effect on the players' reflections on engineering values.

Model II was a 3-block regression focused on high relative centralities for epistemology as an outcome and included dummy variables for the players, DPV, AFV, and TRV as predictors. The model produced significant logit coefficients for both the Activity Focus Variable (3.07, $p<0.01$, block 3, Table 11) and the Type of Reflection Variable (1.75, $p<0.01$, block 3, Table 11). These significant logit coefficients suggest that both client-focused activity and notebook-based reflection were important to players' reflections on engineering epistemology during Digital Zoo. Because the logit coefficient for the Activity Focus Variable in block three of ***Model II*** is larger than that of the Type of Reflection Variable, it appears that working with the client may have been more of a catalyst for epistemology than reflection in the notebook.

Models I and ***II*** reinforce the associations seen in the previous section between the focus of game activity, the type of reflection being conducted, and player reflections on engineering values and epistemology. The significant logit coefficients in these models further warrant the patterns seen in Figures 6 and 7 above, suggesting that working on a client based project was more effective than working on design challenges in helping players reflect on engineering values and epistemology. In addition, reflecting on design work within the design notebook seemed to be more effective than reflecting in a design meeting in helping players focus on engineering epistemology. Thus, the analysis of *in situ* data from Digital Zoo sheds light on some of the key learning processes found within the game. The results indicate that engineering skills and knowledge remained highly central across the eight macrostructures of the game, suggesting that these frame elements were emphasized throughout Digital Zoo. Engineering identity appeared to be a focus early on in the game, but then this frame element seemed to taper off after the first macrostructure. Most interestingly, the relative centralities of both engineering values and epistemology seemed to rise and fall with specific activities during gameplay. These patterns were further warranted through intra-sample statistical analysis (Shaffer & Serlin, 2004) and the use of fixed effects logistic regression (Allison, 1996; Cox, 1972). These models produced logit coefficients that characterized the positive associations between client-focused activity and engineering values, as well as those between client-focused activity, notebook-based reflection, and engineering epistemology.

MODEL I: High Relative Centralities of Values as Outcome																
	Logit Coefficients													Model Summary		
Block	Const	p1	p2	p3	p4	p5	p6	p7	p8	p9	Design Project Variable	Activity Focus Variable	Type of Reflection Variable	Cox & Snell Pseudo R^2	Nagelkerke Pseudo R^2	-2 Log Likelihood
0	0.41															
1	0.00	0.63	0.00	0.00	0.00	-0.55	0.00	-0.55	0.00	-0.55	***1.10****			0.09	0.19	100.37
2	-0.73	0.69	0.00	0.00	0.00	-0.62	0.00	-0.62	0.00	-0.62	***1.23****	***1.45*****		0.18	0.24	91.91
3	-1.14	0.72	0.00	0.00	0.00	-0.64	0.00	-0.64	0.00	-0.64	***1.27****	***1.50*****	0.79	0.20	0.27	89.59

* $p<0.05$; ** $p<0.01$

Table 10. Logistic regression model exploring the relationship between the relative centrality of engineering values, client-focused activity, and the type of reflection during gameplay.

	MODEL II: High Relative Centralities of Epistemology as Outcome															
	Logit Coefficients													Model Summary		
Block	Const	p1	p2	p3	p4	p5	p6	p7	p8	p9	Design Project Variable	Activity Focus Variable	Type of Reflection Variable	Cox & Snell Pseudo R^2	Nagelkerke Pseudo R^2	-2 Log Likelihood
0	***-0.51****															
1	-0.86	-0.60	0.53	0.00	0.53	0.00	0.00	0.00	-0.60	0.00	0.67			0.05	0.07	101.70
2	***-2.57****	-0.81	0.77	0.00	0.77	0.00	0.00	0.00	-0.81	0.00	0.94	***2.68*****		0.30	0.41	77.33
3	***-3.80*****	-0.94	0.86	0.00	0.86	0.00	0.00	0.00	-0.94	0.00	1.07	***3.07*****	***1.75*****	0.37	0.51	69.03

* $p<0.05$; ** $p<0.01$

Table 11. Logistic regression model exploring the relationship between the relative centrality of engineering epistemology, client-focused activity, and the type of reflection during gameplay.

The results presented in this chapter suggest that players from Digital Zoo were able to begin to develop the engineering epistemic frame, and that client-focused activity and notebook-based reflection were key activities in the learning environment that cultivated two specific engineering ways of thinking. In the next chapter, a discussion of both the findings and methodology of this work is presented, including a description of the limitations and implications of this study for engineering education, educational design research, and the broader K-12 education community. A trajectory of future research, stemming from the results uncovered in the present study, is also described, which outlines an ambitious and relevant line of inquiry that explores complex learning in multiple engineering contexts across the K-20+ educational spectrum.

CHAPTER 5

DISCUSSION AND FUTURE DIRECTIONS

In this study, a design experiment (Brown, 1992; Collins, 1992) was conducted in order to test a particular theory of learning, the epistemic frame hypothesis, within an immersive, technology-supported learning environment, the engineering epistemic game Digital Zoo. A secondary focus of this work was to examine the utility of a particular mixed methods approach to analyze data collected from a design experiment, featuring the use of Epistemic Network Analysis (Shaffer et al., 2009)as a tool for exploring *in situ* data collected about complex forms of learning within naturalistic settings. Specifically, this work asks whether middle school girls are able to develop their understanding of engineering epistemic frame elements as a result of playing the game, and if so, whether specific participant structures within the game elicited player reflection on specific frame elements –in particular, engineering values and epistemology – and the linkages between these elements and the other components of the frame.

Summary of Findings

The research questions for Digital Zoo were addressed with a two-part, multistage analysis. In response to the first question which asked about players' learning outcomes from the game, the results from pre-, post-, and follow up interviews show that players were, in fact, able to develop their understanding of the different engineering epistemic frame elements. References to each of the five frame elements in matched pair questions increased significantly from pre- to post-interview, and these elevated levels were sustained through the follow up interview three months after the game was completed. As such, these findings uphold the epistemic frame hypothesis (Shaffer, 2006a; Shaffer et al., 2009), which suggests players would be able to develop engineering skills, knowledge, identity, value, and epistemology as a result of engaging in authentic engineering activity within a simulated practicum context.

Shifting away from the learning outcomes of the game to the investigation of the learning processes in Digital Zoo, the second question asked whether player reflection on specific frame elements was linked with specific parts of the game context, particularly for engineering values and epistemology. The exploration of this data was conducted with an integrated mixed methods approach, which featured the use of a new quantification technique, Epistemic Network Analysis, which can be used to characterize and assess complex learning over time.

The initial Epistemic Network Analysis of *in situ* data showed that three of the frame elements – engineering skills, knowledge, and identity – did not appear to be tied to a specific type of activity. Engineering skills and knowledge appeared to follow similar trajectories in the game, being emphasized from the opening moments of the game and throughout the rest of Digital Zoo. Engineering identity, on the other hand, appeared to be strongly emphasized at the beginning of Digital Zoo, and then was not particularly relevant after the opening days of the game. The trajectories of these frame elements were reported in the results, but not examined further in the present study.

However, player reflections on the other two frame elements, engineering values and epistemology, did appear to vary with certain types of activity. Specifically, there appeared to be relationships between values, epistemology, client-focused work, and notebook-based reflection. These patterns were further explored with intra-sample statistical analysis and fixed effects logistic regression, which provided additional warrants for the qualitative relationships between specific frame elements and participant structures observed in the earlier stages of analysis.

The results from the logistic regression analysis indicate that players were more likely to reference engineering epistemological while reflecting in the notebook than while reflecting with teammates during the design meetings, as seen in Model II in the previous chapter. This suggests that the notebook fostered more player reflection on engineering epistemology than the meetings did for the players in the game. In addition, this finding indicates that the notebook acted as a reflective participant structure that engaged players in connected engineering epistemology to the skills, knowledge, and values of engineering practice. The use of a notebook was also a reflective participant structure in the undergraduate practicum that combined these four elements for the students in the design course (Svarovsky & Shaffer, 2006a). Thus, these results are aligned with a specific feature of the epistemic frame hypothesis, which suggests that the epistemic frame is developed by engaging in the reflective participant structures of the professional practicum. By including the notebook in the game, players were able reflect on engineering epistemology and connect it to other frame elements, just as the undergraduates did in the practicum.

Additional logistic regression indicated that players were more likely to address and emphasize engineering values and epistemology during client-focused work, as seen in the logit coefficients produced by the fixed effects logistic regression in Models I and II in the previous chapter. These findings suggest engaging in work related to solving a client's problem helped the players reflect on the linkages between engineering epistemic frame elements by binding engineering epistemology and values together with the other frame components. This result is consistent with the sentiments of the undergraduates from the engineering practicum, who anecdotally linked their engineering learning to the presence and role of the client in their practicum experience. Thus, these findings are once again aligned with the epistemic frame hypothesis, which argues that a recreation of the practicum setting within in an epistemic game will help young people form linkages between the elements of an epistemic frame.

Interpretation of Findings

The results of this study indicate that Digital Zoo helped young people develop an understanding of engineering that included not only the basic skills and scientific knowledge associated with engineering design, but also engineering ways of thinking. Through the use of an integrated mixed methods approach, player reflections on epistemic frame elements during Digital Zoo was examined. Engineering skills and knowledge appeared to be developed throughout the game, while engineering identity formation was emphasized only at the beginning of the game. Player reflections on engineering values appeared to be associated with client-focused activity, and reflections on engineering epistemology was tied to both client-focused activity and notebook-based reflection.

Developing the Five Epistemic Frame Elements

Based on the results of the study, this work has several repercussions for a wide range of educators moving forward. The learning outcomes of Digital Zoo indicate that epistemic gameplay based on the profession of engineering can not only help young people develop not only basic engineering design skills and scientific knowledge, but also engineering ways of thinking. In contrast to many of the current programs focused on K-12 engineering education, Digital Zoo addressed the three principles for K-12 engineering education issued by the National Academy of Engineering, which suggested that these learning environments should a) emphasize engineering design; b) incorporate the development of appropriate math, science, and technology skills; and c) promote engineering habits of mind (National Academy of Engineering, 2009). By addressing all three principles, Digital Zoo is set apart from several of the other programs surveyed by the NAE that tended to overemphasize the first two of these principles and thus present an "uneven" representation of the profession to young people.

Moreover, Digital Zoo showed that this development of the engineering epistemic frame can specifically happen for young women. This finding that girls are able to successfully link the different facets of engineering practice together during epistemic gameplay is important in light of the literature that suggests girls typically dislike "narrowly focused technical work" (Denner et al., 2005). Connecting design skills and scientific knowledge with the other elements of the epistemic frame suggest that girls in Digital Zoo were able understand engineering practice within a broader context, beyond the confines of an isolated engineering design cycle. Over time, this could lead girls to develop additional engagement and interest in engineering activity. Also, by engaging in a broader range of engineering practices, girls can be exposed to facets of the profession that they may not have been aware of previously, which can help correct misconceptions and reduce the effects of negative stereotypes associated with the profession (Ambady et al., 2004; Eccles et al., 1999).

Identifying Specific Activities that Foster Reflection on Values and Epistemology

Beyond demonstrating players' increased understanding of the different frame elements, Digital Zoo also identified two essential activities in the game, notebook-based-reflection and client-focused activity, which specifically elicited player reflections engineering values and epistemology. These findings have already generated follow-up questions and analyses to be conducted in the immediate future with the same data set used in this study. The current analysis of Digital Zoo allowed for the determination of *when* specific reflection was happening during the game, but further work is needed to explore *how* that reflection is connected to the learning that happened in those contexts. Returning to the qualitative data to begin to answer the "how" question can not only provide more information about the mechanisms of learning within Digital Zoo, but this analysis can also directly inform the design of the next iterations of the game, perhaps by highlighting additional features to test in the learning environment. Because revisiting the qualitative data has both theoretical and pedagogical advantages, this work will begin in the near future.

One particularly interesting result from this study is that client-focused activity is *not* a reflective participant structure as it is recreated in Digital Zoo. Instead of being directed to focus on reflection through one specific activity or task, client-focused activity encompassed a range of activities – some reflective, some not – that were intended on meeting the needs of the client. This is noteworthy because while the epistemic frame hypothesis argues that an epistemic game should be a recreation of the practicum in general, the theory only specifically defines one type of practicum activity – the reflective practicum structure – as contributing to frame development. However, in Digital Zoo, client-focused activity had a pronounced effect on players' reflections on values and epistemology. Thus, exploring potential reasons for these effects may give rise to the identification of another practicum component that would be useful to include in future iterations of the game and authentic learning environments more broadly.

In addition to informing the next cycle of epistemic game design and potentially advancing the epistemic frame hypothesis, identifying these key participant structures in the game has pedagogical significance for K-12 educators who are developing engineering experiences for pre-college students. Including these types of activities in concert with engineering design work can specifically help young people develop engineering ways of thinking, and thus help programs more fully address the three principles outlined by the NAE. Moreover, this study can suggest new ways to educators to engage young people in specific professional practices. In Digital Zoo, players kept an electronic design notebook on PowerPoint, which made the documentation of digital design work much easier. As such, repurposing presentation software for documentation purposes may also be useful for other K-12 educators to consider when designing their own experiences.

Another point to consider is that while client-focused activity helped players focus on engineering values and epistemology, the clients were not actual, real clients with real needs and real deadlines. They were adults who were role playing as clients, just like the girls role playing as engineers. However, the findings from Digital Zoo suggest that focusing activity in the game on these clients – imaginary or otherwise – still emphasized these key frame elements. This implies that other K-12 engineering environments may also have success in fostering engineering values and epistemology by adding other adults role playing as clients to the context of a particular intervention.

Example of Methodological Integration for the Assessment of Complex Learning

Digital Zoo also provided a compelling example of methodological integration in its approach to the analysis of *in situ* data from the game. The study highlighted the utility of Epistemic Network Analysis (Shaffer et al., 2009) in exploring and characterizing complex thinking and learning in real world learning environments over time. As such, this technique provides a potentially valuable tool for other educational design researchers who seek to measure and evaluate learning *in situ*, which is quite commonly the case within a design experiment. Epistemic Network Analysis has several traits that make it a powerful tool for analysis. First, it is theoretically grounded by the epistemic frame hypothesis. This allows for both the definition of complex learning, the epistemic frame, and how it is developed, in the binding of frame elements cumulatively over time. Second, it generates several quantities that can be used to understand and identify patterns in the data. Although relative centrality was the dominant epistemic network concept used here, other quantities such as the weighed density of the epistemic network (how tightly bound or connected the frame elements are together) can provide useful and insightful information as well.

Epistemic Network Analysis also provides a sophisticated bridge between qualitative and quantitative techniques. The quantities calculated by the technique are grounded in qualitative data, because the numbers that go into the algorithms are the code frequencies from the initial qualitative analysis. However, the quantities calculated by the technique can also be fed into an intra sample statistical analysis (Shaffer & Serlin, 2004) for the further investigation and warranting of any trends in the data. Any of the quantities can be plotted over time, thus providing a visual representation that can be qualitatively assessed for additional patterns such as common spikes or declines. Once these patterns are observed, they can be linked back to a specific time period within the learning environment, and as such providing another way to examine learning. Thus, Epistemic Network Analysis has the potential to be a transformative tool for the assessment of learning. By integrating qualitative and quantitative techniques in an effective and impactful way, Epistemic Network Analysis allows for the preservation of data richness while providing the utility of numerical analysis.

Finally, the specific ways in which this study, fundamentally *qualitative* in nature, used statistical techniques for the purposes of qualitative inquiry, should be noted. At two points surrounding the intra-sample statistical analysis of the *in situ* data from the game, quantitative information was deliberately examined and interpreted with a qualitative lens, once during the dichotomization of the continuous outcome variables for the purposes of implementing logistic regression, and then again when the logit coefficients produced by those regressions were only viewed qualitatively as "positive" or "negative". In both instances, numerical information was intentionally disregarded, which may suggest the loss of valuable quantitative information.

However, a return to the *qualitative* nature of this work suggests that a qualitative filter can, and in some cases must, be applied when using and interpreting the results of quantitative tools. Surrounding the use of ISSA (Shaffer & Serlin, 2004)in this study, a deliberate choice was made to dichotomize the continuous outcome values of the relative centralities of the different frame elements. Indeed, while this choice had a practical dimension, in that it was required in order to use logistic regression in a later step, this choice also has other methodological dimensions as well. Returning to Chi's (1997) method of Verbal Analysis, one key step in her technique is the need to identify the appropriate grain size for analysis in order to create a fruitful window into the data. In dichotomizing the outcome variable, a coarser analysis of the relative centralities was conducted. However, this level of coarse granularity was more meaningful and informative to the research questions being asked than a finer level of analysis would have been. The *in situ* portion of study asked whether specific participant structures within the game elicited player reflection on specific frame elements – and in particular, engineering values and epistemology. As such, the fundamental goal of this qualitative work was to identify and characterize meaningful relationships between the reflections on particular frame elements and particular features of the game context in a qualitative manner. It cannot, and does not, seek to specially measure the exact strength of these relationships between learning and context in a quantitative sense.

In a similar way, the logit coefficients produced by the fixed effects logistic regression were interpreted with a qualitative lens, characterizing certain participant structures to be "more" or "less" likely than others to be associated with player reflections on specific frame elements. In contrast to the optional choice to dichotomize, this methodological decision was not optional, due to the assumptions involved with Intra Sample Statistical Analysis and its purpose in using statistical tests to warrant qualitative claims about the patterns in the data. However, as in the previous case with the dichotomization, the *qualitative* nature of the study suggests that the *qualitative* information from statistical tests would be more aligned with, and more directly address, the qualitative research questions being asked. In other words, the questions of this study did not seek the exact measurement of how many more times one activity was likely to promote the reflection on engineering values or epistemology. Instead, this study was interested in getting a sense of which activities in the game may be more or less likely to foster these ways of thinking, which could then inform and potentially improve the design of future learning environments. Thus, by returning to the use of the qualitative lens throughout the more quantitative portions of this analysis, the grounded and descriptive nature of this work – and the contextual richness of the types of data found in design experiments more generally – can be preserved.

Limitations of This Study

There are several limitations to this work that must be considered, both to properly contextualize the study and also inform future work. First of all, there were only ten players that participated in this version of the epistemic game, and therefore the effects on the players in the study cannot be effectively generalized to a larger population. However, the results from this design experiment of Digital Zoo will feed into the successive iterations, eventually leading to large scale development and implementation in the future. Another limitation comes from the way in which the outcome data was collected in the study. The question protocols used in the pre-, post-, and follow-up interviews were not structured in a way to effectively measure the connections between frame elements, but only the development of individual frame elements. These protocols were crafted and administered before Epistemic Network Analysis was developed, and as such, were not designed to elicit responses that demonstrated the extent to which players bound the frame together. Certainly, the next iteration of the design experiment will include a much stronger emphasis on questions and tasks that will more accurately assess the connections players make between frame elements.

Reflecting on the methodological choices made in the analysis of *in situ* data, there were several issues that impacted the scope and depth of the study. First, the *in situ* data selected for the analysis described in this study only came from the first two weeks of the game, and not all three. This decision was made because first two weeks (which include the first two design projects) of the game were very similar in structure while flow of activity the third week was disrupted due to summer holidays. While focusing on the first two weeks reduced the uncontrolled variability in the study, the third week – and final design project – would have likely yielded additional interesting information. A second issue involves the appropriate granularity of the coding scheme used to qualitatively analyze the data. Certainly it would be possible to continue refining the coding scheme such that specific types of engineering skill, as well as specific types of engineering knowledge, identity, values, and epistemology could be teased apart, thus resulting in a more complex, finer-grained coding scheme with subcategories for each frame element. Exploring the data in this way would logically be a follow-up study to the one described here.

In a similar vein, a third issue that should be considered was the decision to focus on the relative centralities of frame elements as outcome variables. Epistemic Network Analysis also produces weighted density as a quantity that can characterize an epistemic frame, but that information was not used in this study and therefore might also be interesting to explore in future work. A fourth issue involves the use of Epistemic Network Analysis to measure only the players' reflections on epistemic frame elements and linkages, and not their actual learning and internalization of these concepts. While a causal claim cannot be made with the methods and data used in this study, a follow up investigation that more carefully explores the qualitative data, the role of the design advisor, and the types of prompts used in the game is planned in order to more fully understand the learning processes within the game.

Finally, the choice to use a fixed effects logistic regression for the Intra-Sample Statistical Analysis mandated the dichotomization of a continuous outcome variable which resulted in the loss of some numerical information. While the advantages of logistic regression justified this choice, it would certainly be useful to identify other statistical methods that would not require such a transformation.

Implications

Despite these limitations, the work presented in this study has several implications. First, the type of learning demonstrated in the results of Digital Zoo is just the type of complex, interconnected, systems-thinking types of learning that tomorrow's engineering and technical professionals will need in order to be competitive in the global marketplace. Creating meaningful and powerful engineering experiences like Digital Zoo for young people can not only help them be more prepared for engineering work upon reaching college, but it may help more young people consider entering the field – young women in particular. By correcting the negative and inaccurate stereotypes surrounding engineering, more girls may realize that engineering is, indeed, about helping people and improving the quality of life through innovations – and as such, they may be more motivated to choose it as a career path after finishing high school (Eccles et al., 1999).

Second, this work has several pedagogical implications for engineering educators across the K-20+ spectrum. At the K-12 level, including the notebook-based reflection and working with a client may help foster the development of engineering ways of thinking for young people engaged in design activity. Moreover, the construct of an epistemic frame can provide a more operationalized definition of engineering practice for pre-college educators, which can contribute to the more informed selection of learning objectives. Similarly at the undergraduate level, insights gleaned from Digital Zoo can inform faculty's pedagogical choices, particularly around the inclusion of a client in the engineering practicum. For example, a first year or cornerstone practicum experience designed for undergraduates could also benefit from having a client involved in the learning environment, even if the client is merely an actor playing the part for the course, as the clients in Digital Zoo were role playing in the game. Some university faculty may be hesitant to engage in the often slow and difficult process of securing actual clients who have legitimate needs that students in introductory engineering courses could actually meet. By having someone portray a client, the professor would have more control over the type of problems being posed to students, as well as the option to train the client to interact with students in specific ways that may be instructive (difficult client, unfocused client, etc.). In addition, undergraduate degree programs can use the construct of an epistemic frame to plan and inform the department curriculum, providing faculty with another way to characterize the profession.

Third, exploring the epistemic frame hypothesis within the actual profession of engineering can play an essential role in understanding the current state of the profession, which can in turn impact the undergraduate and graduate training of engineers as well as the conceptualization of what tomorrow's engineer will need to be competitive. The profession of engineering, like any large community of practice, will be comprised of smaller communities within it , such as the different disciplines of engineering, a multinational engineering corporation, or a local green engineering startup company. Each of these communities has its own culture, and thus its own epistemic frame. Conducting additional work to understand the different frames in these contexts can help the engineering community collectively define a better frame, or set of frames, that can guide the development of engineers for the future.

Finally, the demonstration of the utility of Epistemic Network Analysis in this work also has implications for the educational community writ large. For too long, the methods of assessment have driven the educational standards and climate in this country. As a result, there has been an increasingly dramatic emphasis on knowledge, and to a lesser extent, skill, in American classrooms. These "basics" are easily accessed in comparison to more complex forms of learning, and as such have come to dominate the curriculum in our schools. However, in order to for tomorrow's engineers to be competitive in the global job market, and for our nation to maintain an advantage in technical capacity, young people must begin to develop more complex forms of knowing, doing, and thinking at a much earlier stage in their educational careers, in order to be prepared effectively for the challenges of the future. By providing a way to characterize and measure the type of learning needed in the 21st century, Epistemic

Network Analysis can begin a conversation around how new types of assessment tools can promote new types of learning in today's schools. Given the increasing rates of international competition and technological change in our increasingly connected global society, finding ways to teach our nation's children how to innovate and adapt in order to be successful citizens of tomorrow can easily be considered the educational imperative of our generation.

The Road Ahead

The series of studies presented in this dissertation demarcate a theoretical and methodological foundation for a trajectory of research focused on engineering education across the K-20+ spectrum from a learning sciences perspective. Using the epistemic frame hypothesis, Epistemic Network Analysis, and the results of the work described here, a series of research questions related to learning and engineering can be iteratively explored through the use of design experiments at different levels of education and professional practice.

The present study of Digital Zoo has generated several new or refined lines of inquiry to be pursued moving forward. A particularly compelling question that emerged from the data centers on the findings that suggest client-focused activity is strongly associated with player reflection on engineering values and epistemology. Exploring the role of the client in both reframing gameplay and in developing engineering ways of thinking in Digital Zoo can potentially lead to new understanding about the practicum itself, and how the presence of a client – role playing or genuine – can affect and contextualize professional activity and developing engineering ways of thinking within the practicum setting. Certainly, this inquiry will inform the next cycle of Digital Zoo, but it can also be used to inform other K-12 and undergraduate engineering learning environments as well. Moreover, investigating the role of the client, or stakeholder, reader, or patient, depending on the profession, both in actual practice and during an undergraduate practicum – may be fruitful as well. When combined with a client study of Digital Zoo, this could expose the different ways in which the client contributes to engineering learning and practice.

A second line of inquiry stemming from the work presented here will explore the effects of Digital Zoo, and future interventions like it, on girls and their perceptions of engineering. One component of this work would likely involve a longitudinal study of girls participating in engineering epistemic games or other out-of-school engineering learning environments in order to uncover any long term effects of these interventions, particularly on career choice. Another component of this line of inquiry would explore the identity development of girls and women in various authentic engineering learning contexts, how it is connected to other elements of the epistemic frame, and how a particular element of the frame is built, connected, and shaped. By more fully understanding how girls and women construct and develop identity in educational engineering settings, more thoughtful decisions about pedagogy and methods of encouragement, support, and mentoring of women in engineering may be developed.

Finally, a third line of inquiry focused on methodology originates from the current work. Related to the previous point of exploring identity, creating metrics and methods for measuring identity development more accurately within a learning environment could be useful not only for this research trajectory but for others interested in similar questions as well. Moreover, exploring different data collection techniques, including the refinement of the pre-, post-, and follow-up interview protocols from this epistemic game, in order to capture more of the interconnectedness of expertise and other forms of complex learning would be a fruitful direction to pursue. Particularly in light of the constantly increasing need to educate young people in how to be creative, innovative, and communicative, developing new and more effective metrics for sophisticated forms of learning will be a central element in the trajectory of research described here.

Thus, in reflecting on the emergent questions from the study, a series of interesting lines of inquiry have been identified as future directions for this work moving forward. The research agenda described above is ambitious and relevant, potentially making multiple key contributions both the field of learning sciences as well as engineering education, within the larger goal of ultimately better preparing and increasing the number of talented engineering and technology professionals for the future.

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APPENDIX A: Preliminary Studies

This appendix contains the text from three published pieces that describe the two preliminary studies that informed the design of Digital Zoo. The first paper, *SodaConstructing Knowledge Through Exploratoids*, appeared in the Journal of Research in Science Teaching. This publication presents the findings from the 10-hour pilot study used to explore the usefulness of SodaConstructor as an epistemic game engine for Digital Zoo.

The two following pieces are peer-reviewed conference papers that describe the findings from the epistemography of engineering practice conducted on an undergraduate engineering design course. The first paper, *Design Meetings and Design Notebooks as Tools for Reflection in the Engineering Design Course*, was presented at the 2006 ASEE/IEEE Frontiers in Education Conference. The second paper, *Engineering Girls Gone Wild: Developing an Engineering Identity in Digital Zoo*, was presented at the 2006 International Conference of the Learning Sciences.

SodaConstructing Knowledge Through Exploratoids

Citation:

Svarovsky, G. N., & Shaffer, D. W. (2007).

SodaConstructing Knowledge through Exploratoids.

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Abstract

In this paper we describe a preliminary study that integrates research on engineering design activities for K-12 students with work on microworlds as learning tools. Here we extend these bodies of research by exploring whether—and how—authentic recreations of engineering practices can help students develop conceptual understanding of physics. We focus on the design-build-test cycle used by professional engineers in simulation-based rapid modeling. In this experiment, middle school students worked for 10 hours during a single weekend to solve engineering design challenges using SodaConstructor—a Java-based microworld—as a simulation environment. As a result of the experiment, students learned about center of mass. Our data further suggest that in the process of simulation-based modeling, rapid iterations of the design-build-test cycle progressively linked students' interest in the design activities and understanding of the concept of center of mass. We suggest that these rapid iterations of the design-build-test cycle functioned as *exploratoids*: short fragments of exploratory action in a microworld that cumulatively develop interest in and understanding of important scientific concepts.

Children are born engineers. Everything they see, they want to change. They want to remake their world.... They want to move dirt and pile sand. They want to build dams and make lakes. They want to launch ships of sticks. They want to stack blocks and cans and boxes. They want to build towers and bridges.

—Henry Petroski, "Early Education" (2003, p. 1)

Petroski (2003) argues that young people are "born engineers" because of their natural tendencies to explore, build, and create. Though their thinking does not use the mathematical formalisms associated with traditional engineering practice, children enjoy engaging in the essential activity of professional engineers: the design of useful artifacts. Previous studies have shown that engineering design activities can be a fruitful context for students to develop important science skills and understandings through the pursuit of personally meaningful projects (Fortus, Reddy, & Dershimer, 2003; Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998).

However, most existing design-based curricula for pre-college students center on students solving engineering problems with physical materials. The resulting tangible products that result can be a motivating factor for students (Sadler, Coyle, & Schwartz, 2000), but working with physical materials also limits the design work students can do—and thus the insights students gain through design activities. Projects using physical materials can be expensive, dangerous, and/or require sophisticated equipment. The time needed to build a real object can make it difficult to cover topics in depth.

Practicing engineers face similar concerns over funding, safety, and time, particularly when dealing with new problems. In such situations, engineers often use computer simulations in the early stages of the design process. Simulations are less expensive, faster, and safer, so engineers can compare several design ideas before committing to a prototype. That is, simulations help engineers understand a problem by increasing the iterativity of the *design-build-test (DBT) cycle*: the process by which engineers incrementally plan, construct, evaluate, and redesign elements of an emerging design (Elger, Beyerlein, & Budwig, 2000). Engineering design is characterized by shorter and more frequent DBT cycles when problems are difficult or complex (Dym & Little, 2000).

The problem that professional engineers face when solving novel problems is similar to the problem faced by students dealing with an engineering challenge for the first time. The theory of *pedagogical praxis* (Shaffer, 2004b) suggests authentic recreations of professional practices can provide a useful framework for designing technology-based learning environments. Building on this theory, we hypothesize that solving engineering design challenges using a computer simulation may help middle school students understand key concepts in physics. Our goal in the preliminary study we present here is to examine whether this hypothesis is correct, and if so, to explore the cognitive processes at work in such a learning environment.

In this paper, we describe *Berta's Tower*: a learning environment in which middle school students use SodaConstructor, a spring-mass modeling simulation, to develop prototypes for a cantilevered structure later constructed on a large scale out of string and PVC pipes. (This project is named after Berta di Bernardo, who provided the money to build one of the most famous and dramatic examples of the principles of static physics: the Cathedral Bell Tower in Piza, Italy—now more commonly known as the Leaning Tower of Piza.) We examine the outcomes and processes of learning of 12 students during 10 hours of virtual engineering design work. Although we use statistical techniques and a traditional pre-test/post-test design, our study is fundamentally qualitative in nature: we seek to explain the experience of these students in a learning environment modeled on the practices of engineers working in a novel domain. Specifically, our research questions are:

RQ-1: Do middle school students develop understanding of center of mass through virtual engineering design challenges using a computer simulation?

RQ-2: If so, what is the mechanism involved in this learning process?

Theoretical Framework

Engineering design

At the most basic level, engineering is the application of scientific and mathematical principles to address real-world problems. The engineering design process through which such problems are solved has been described in detail in the engineering literature (Birmingham, 1997; Bucciarelli, 1994; Dym, 1994; Dym & Little, 2000; Elger et al., 2000; Pahl & Beitz, 1996; Petroski, 1985, 1994, 1996; Pionke & Parsons, 1998; Schon, 1987; Vincenti, 1990). Briefly, engineers take an initial definition of the problem and go through three stages of design work: *conceptual design, preliminary design,* and *detailed design* to produce a final design plan, from which the solution to the problem is constructed (Dym & Little, 2000). In the conceptual design stage, engineers brainstorm design alternatives as potential solutions to the problem. In the preliminary design stage, these alternatives are modeled, analyzed, and tested, leading to the selection of one design with which to move forward. In the detailed design stage, the selected alternative is refined into a final design plan.

Although not all studies of engineering design agree with the detail of this general model of the design process, here we are focusing on a specific element of engineering design that is a central part of any account of the work of practicing engineers. In particular, we concentrate on the *design-build-test* (DBT) cycle (Elger et al., 2000; Pionke & Parsons, 1998). The DBT cycle is an iterative process through which engineers develop and evaluate design alternatives. In each iteration of the DBT cycle, engineers *design* a solution to the problem at hand, *build* a prototype of the proposed design, and then *test* the prototype to determine its potential effectiveness. In the early stages of any engineering design project, engineers engage in frequent, rapid iterations of this cycle of prototyping, testing, and revision before committing to a final design idea. As engineers start to work on a new problem with unfamiliar parameters, the DBT cycle is one of the ways in which they come to understand the physical systems with which they are working (Dym & Little, 2000; Petroski, 1985). In this paper, we look at this key aspect of the practice of engineering design and examine whether and how younger students can use a similar process to develop scientific understanding.

Engineering at the pre-college level

Creating activities for younger students based on engineering design is not a novel idea. A number of K-12 learning environments modeled on the engineering design process have been developed to provide fruitful contexts for pre-college students to investigate the world around them. In extracurricular programs such as Odyssey of the Mind and the Junior Engineering Technical Society, students work in teams to achieve an engineering goal, typically presented in the form of a civil or mechanical engineering design problem. For example, a classic design challenge from Odyssey of the Mind is to build a structure out of balsa wood that can support as much weight as possible. Students work on solutions for most of the academic year, competing on the regional, national, and ultimately international levels. Engineering competitions have also been incorporated into classroom activities in a variety of contexts, such as bridge building and device building (see, for example Bernsten, 1995; Borja, 2001; Hurley, 1996; Sadler et al., 2000; Tucker, 1998). Joint ventures between universities and industry such as the Infinity Project and Project Lead the Way (Mathias-Riegel, 2001) have created programs aimed at increasing awareness and interest in engineering at the high school level. These initiatives are intended to introduce younger students to engineering activities as a way of recruiting the next generation of engineering professionals.

One particularly interesting, successful, and well-documented program using the design process as a vehicle for developing student understanding of science is the Learning by Design curriculum (Kolodner, 1997; Kolodner et al., 1998; Kolodner, Gray, & Fasse, 2003). Learning by Design (LBD) consists of 2- to 8-week units in which students learn scientific concepts by creating a solution to a design challenge. For example, in the 8-week Vehicles in Motion unit, students learn about forces and motion by designing balloon-powered cars. During each unit, students engage in a series of activities known as LBD rituals (Kolodner et al., 2003), such as "pin-up sessions", "messing about", and "whiteboarding". These rituals are situated in a version of the design process that revolves around brainstorming, conducting experiments, sharing design ideas with peers, building and testing prototypes, and optimizing a solution through re-design. Student learning is scaffolded by these activities, allowing them to develop conceptual scientific knowledge throughout the LBD unit.

Although programs such as these provide students with an effective learning environment based on the engineering design process, engaging in the DBT cycle with real materials can be expensive and time consuming , thus reducing the number of prototype designs that can be tested (Birmingham, 1997; Dym & Little, 2000; Love, 1980). Practicing engineers face the same constraints when prototyping with physical materials. In these circumstances, professional engineers often use simulations to develop their understanding about the physical systems with which they are working—and as a testing ground for their initial design ideas.

Simulations are computational systems that model the natural[1] world (Edwards, 1995). By providing a virtual representation of a physical system, simulations allow users to engage in inquiry that is otherwise impractical or even impossible. For example, civil engineers test the effects of strong winds on a skyscraper design by creating a simulation to observe the amount of wind shear the structure can withstand (Dym & Little, 2000). Chemical engineers use simulations to test pressure and temperature settings for reactor vessels and determine the resulting effects on the process output (Bequette, 1998). Through the use of such tools, engineers reduce the cost in time and materials of each iteration of the DBT cycle. Thus they can increase the number of design iterations—and as a result, their potential understanding of the problem at hand.

In this study, we examine whether and how middle school students can learn about concepts in physics through design activities by following the engineering practice of rapid prototyping using simulations. Our first research question is: Do middle school students develop understanding of center of mass through virtual engineering design challenges using a computer simulation? We hypothesize that just as engineers understand a novel problem through repeated iterations of the DBT cycle, students will develop understanding of the center of mass through repeated, short cycles of design and testing in a computer simulation environment. We base this hypothesis on the theory of *pedagogical praxis* (Shaffer, 2004b) which suggests that

[1] Simulations in engineering (and in education) often model social systems as well—or the social interactions within a physical system, as is the case when engineers and architects model traffic patters on proposed bridges, roads, or tunnels. Because of the nature of our particular experiment, we focus here on simulations of physical systems.

authentic professional practices can be useful models for students to develop understanding in traditional domains such as physics.

Microworlds

Following from this first research question, our second research question asks: What is the mechanism involved in this learning process? We draw our hypothesis for this question from theoretical work on simulations as tools for learning.

Simulations are a form of computational *microworld*, which Hoyles, Noss, and Adamson (2002) define as "environments where people can explore and learn from what they receive back from the computer in return for their exploration". Previous studies (Bertz, 1997; Cope & Simmons, 1994; Gifford & Gifford, 2000; Miller, Lehman, & Koedinger, 1999; Ravaglia, Suppes, Stillinger, & Alper, 1995; Resnick, 1997; Wilensky, 2001) have shown open-ended projects using such tools can be a rich and motivating way for students to develop mathematical and scientific understanding. In this study, we focus on two key factors associated with student learning with microworlds: *autoexpressivity*, a property of the tool, and *expressivity*, an affordance users experience when interacting with the tool.

Autoexpressivity. Microworlds possess an embedded set of relationships from a particular domain, thereby allowing users to investigate these relationships within a virtual setting (Edwards, 1995; Noss & Hoyles, 1996) by repeatedly articulating ideas in the microworld and then interpreting the microworld's response. In other words, students explore the relationships within a domain by testing out their ideas in the microworld and then observing the resulting feedback —a process similar to the learning that takes place within the engineering DBT cycle. A key feature of microworlds is that the feedback provided by the simulation depends on the way in which a student has used the relationships and concepts from the domain being modeled (Papert, 1980). Microworlds are therefore *autoexpressive* (Noss, Healy, & Hoyles, 1997; Noss & Hoyles, 1996), meaning the behavior of the tool reflects the extent to which the student can represent the underlying domain principles with the grammar of the tool. As students test and revise their projects in the microworld, they also test and revise their understanding of the embedded domain. For example, Noss and Hoyles (1996) describe how one student came to understand ratio as a multiplicative (rather than an additive) relationship through developing a LOGO program to construct a BIGHOUSE. The student tried to write the program BIGHOUSE by modifying a previous program called HOUSE. The student changed each of the dimensions of HOUSE by the same amount. However, BIGHOUSE did not produce the appropriate image until the student had been consistent in using multiplication rather than addition to increase the dimensions of the structure. In the process, the student came to understand the mathematical principle that multiplication by a constant preserves proportion while addition by a constant does not.

Expressivity. Generally speaking, microworlds make it easy for students to create, manipulate, and test prototypes with few constraints on their design imagination. Not all of their design ideas will work, but they are free to explore the design space and incorporate personal design choices into their work. When microworlds are used in open-ended activities, they allow students to develop understanding through *expressive* projects: that is, projects that allow students to explore their own individualized design decisions, to create solutions that are inventive, unique, and personalized. This freedom to explore can be both meaningful and motivating for students, affording them a sense of control and personal investment in their inquiry (Noss et al., 1997; Noss & Hoyles, 1996; Papert, 1980, 1993; Shaffer, 1997, 2004b).

Islands of Expertise

In this study, then, we will explore what happens when students conduct rapid iterations of the engineering DBT cycle to solve expressive problems using an autoexpressive tool. We propose to explain this process using the theory of *islands of expertise*. Crowley and Jacobs (2002) suggest that young children develop scientific understanding by creating islands of expertise: topics "in which children happen to become interested and in which they develop relatively deep and rich knowledge" (p. 333). These islands of expertise develop through small, seemingly insignificant—yet collectively transformative—conversations between parent and child: short fragments of explanatory talk where the parent provides information to the child on a topic of interest which Crowley and Jacobs refer to as *explanatoids*. As the child comes to understand more about the topic from each interaction, he or she becomes more interested in the topic—leading to further conversations and deeper understanding. These individually unremarkable interactions cumulatively provide a motivating and powerful connection between interest and understanding (Shaffer, 2004a).

Here we propose to extend this framework beyond parent-child interactions and apply it to the context of students working with microworlds. In exploring our second research question regarding the mechanisms by which students learn through rapid prototyping in a simulation environment, we hypothesize that the short explorations students carry out in microworlds function in a manner similar to explanatoids, cumulatively forging a powerful linkage between interest and understanding of scientific ideas.

Method

The Berta's Tower Project conducted two workshops for 12 middle school students in the spring of 2003. Each workshop occurred over a single weekend for a total of 10 hours of instruction over 2 days.

Participants

For each workshop 6 students were recruited with the help of school administrators and teachers from middle schools in an urban Midwestern city. All participants were volunteers who were informed that they were doing a workshop on engineering and physics. The students came from a variety of socio-economic backgrounds. There were ten males and two females; five participants were students of color. The first workshop consisted of 7th graders; the second workshop consisted of 6th graders.

Description of tool

The participants in this study used the SodaConstructor microworld (http://www.sodaplay.com), a Java-based spring-mass modeling system that allows users to create structures in a virtual design space and test them against gravity. Registered users can save their work in a personal account, email their structures to others, and contribute their work to the SodaZoo (a publicly accessible storage area for interesting designs).

SodaConstructor provide users with three design elements: fixed point masses (displayed as a small square on the screen), free point masses (displayed as a small circle), and springs (displayed as lines). Fixed masses remain stationary on the screen when simulated, whereas free masses and springs can be subjected to the force of gravity; and when gravity is turned on, free masses and springs fall to the bottom of the display unless they are structurally supported.

During the workshops, the students utilized two modes of the tool. In CONSTRUCT mode, students built their structures, placing springs and masses into the design space by selecting from a drop-down menu and clicking in the design space to position the selected object. Students tested their constructions by switching to SIMULATE mode, which would subject their structures to the force of gravity. Students moved back and forth between CONSTRUCT and SIMULATE modes, saving their work in their personal SodaConstructor accounts prior to testing.

Workshop activities

Students chose design teams of 2 or 3, and each team worked on SodaConstructor in different areas of the computer lab on a series of engineering design problems created by the researchers and civil engineering undergraduates. There were 7 major design challenges given to the students: (1) build anything that stands up when you SIMULATE, (2) build a multi-story structure, (3) build a structure that leans, (4) build a multi-story structure that leans, (5) build a base for an irregularly shaped object, (6) build a cantilever, and (7) build a cantilever with the biggest "span to base" ratio. These design problems were meant to develop student understanding of concepts in engineering and physics. In particular, the challenges were intended to help students learn about the design-build-test cycle from engineering as they iteratively piloted their design ideas, and about center of mass[2] as they discovered design choices that would make their structures stand in SIMULATE mode.

[2] In this paper, we define the center of mass as the point in an object where the sum of all torques is equal to zero and rotational equilibrium is achieved.

Following the general activity model of the Learning by Design curriculum (Kolodner et al., 2003), students worked individually (each on his or her own computer) to produce designs to address each challenge. Midway through each problem, students discussed their progress within their design team. These conversations focused on (a) sharing successful and unsuccessful designs, and (b) formulating ideas general principles about the nature of the domain that could guide their design work. Students then refined and redesigned their structures. At the end of each challenge, students chose their personal "best design" to display on their computer for a 10-minute virtual poster session. At the conclusion of the viewing session, students and workshop leaders came together for a whole group discussion focusing on the designs and on the important concepts introduced by the challenge. Students reported on their successful, as well as unsuccessful, design experiences, and were asked to explain why they thought their solutions to the design challenges worked and what they would have done differently if they had more time. Students were also encouraged to ask questions about and comment on each other's work.

Data Collection

Interviews. Students were given 30-45 minute clinical interviews (Denzin & Lincoln, 1998; Ginsburg, 1997) before and after the workshop. In interviews, students were asked to define the center of mass, identify the location of the center of mass for a series of pictures, and answer two conceptual physics textbook problems. The textbook problems were non-mathematical and more conceptual by design, therefore students were able to give responses in both the pre- and post-interviews. Students were asked to justify or explain their answers. During the post-interview, students were also asked about their experiences using SodaConstructor and in the workshop overall.

Video. During the workshop, student activities and interactions were captured on video by a member of the research team. The video data were not systematically collected; therefore, no quantitative analysis was done on the excerpts. However, the data were useful in providing specific examples of the events or processes identified in the post-interviews.

Data analysis

Pre- and post-interviews from the workshops were transcribed and divided into sections: (a) definitions of the center of mass; (b) identification of center of mass in pictures; (c) conceptual physics textbook problems; (d) experiences using SodaConstructor; (e) experiences in the workshop overall. Names were removed from the transcripts and replaced with coded identifiers.

Categories for coding the transcripts were developed from the theoretical framework outlined above. Ten analytic categories were used: correct center of mass references, incorrect center of mass references, scientific answer justification, intuitive answer justification, testing, iteration, expressivity, autoexpressivity, positive comments about SodaConstructor, and negative comments about SodaConstructor. Table 1 provides definitions used for each code, as well as a sample response from interviews representative of the data coded for that category.

Table 1. *Analytic codes used in data analysis of interview transcripts.*

Code	Definition	Examples from transcripts
Correct center of mass reference	Use of the term "center of mass" correctly in a complete statement	Center of mass is like not the middle, but the point where weight is divided evenly. The weight is distributed on both sides.
Incorrect center of mass reference	Use of the term "center of mass" incorrectly in a complete statement	Center of mass how much mass there is...the strongest mass.
Scientific answer justification	Scientific-based comments supporting answers to textbook questions	The center of mass of the [cantilevered] board is between the supports [in contact with the ground], so it's stable and it won't tip over.
Intuitive answer justification	Non-specific and/or general comments supporting answers to textbook questions	It just tips because that's what boards do... I just think it would do that.
Testing	Comments about testing the designs in the gravity-enabled environment	We designed a thing and we think like it's going to stand up but then it doesn't.
Iteration	Comments about repeated design activity	We built it again and again [on SodaConstructor]!
Expressivity	Comments about incorporating personal design choices into work	[SodaConstructor] was cool and you could do anything – build anything you want!
Autoexpressivity	Comments about learning as a result of uncovering embedded relationships within SodaConstructor	I think once you get used to it, it's easy and fun. When you're first learning it, a lot of your stuff falls over because you don't realize you have to connect certain things and make it stable. But I think once you learn it, it's easier and it's more fun.
Positive Comments about SodaConstructor	Positive comments about SodaConstructor and its use	[SodaConstructor] is very creative and fun!
Negative comments about SodaConstructor	Negative comments about SodaConstructor and its use	Sometimes using [SodaConstructor] got boring.

In order to maximize consistency of coding, each transcript section was coded separately, with the order of the student excerpts within each section randomized. Two independent passes of coding were completed.

Once coding was complete, trends and patterns were identified in student responses within a grounded theory framework (Glaser, 1978; Lincoln & Guba, 1985; Strauss & Corbin, 1998). Once patterns were identified, frequencies were tallied for each code. Descriptive statistics were calculated, and paired t-tests were used to compare pre- and post-interview means across both workshops with N=12. Significant differences were then used as supplementary support for previously established qualitative findings.

Results

We present the results from Berta's Tower in two parts. We first address Research Question 1: Do middle school students develop understanding of center of mass through virtual engineering design challenges using a computer simulation? In answering this question, we examine student gains in conceptual physics understanding.

We then turn to Research Question 2: If so, what is the mechanism involved in this learning process? We use a video case to describe the design work of two students during the workshop. We then look at interview data to explore whether the learning processes outlined in the video case more generally exemplifies the experiences of participants in these workshops.

RQ 1: Do middle school students develop understanding of center of mass through virtual engineering design challenges using a computer simulation?

References to Center of Mass. Student references to center of mass across all questions increased significantly both in overall number and correctness from pre- to post-interview (paired t-test, mean difference +11.5 in correct references, $p<0.01$).

For example, when asked for their definition of the center of mass or center of gravity, one student responded in the pre-interview: "Maybe where it's like the strongest of gravity…?" However, during the post interview, the same student said:

> "Center of mass is like not the middle, but the point where weight is divided evenly. The weight is distributed on both sides...Center of mass is like where most weight is equal. Kind of like the place where you put your finger and balance something on it without falling. Pretty much where all the weight is equaled out and you can balance... it doesn't have to be in the middle. It can be a side. It depends I guess what the object looks like. The shape of it... where there's more weight."

Moreover, students were able to use their understanding of the concept of center of mass in other contexts. In post interviews, 67% of the students (8/12) made a reference to center of mass in connection with a personal experience outside the workshop, such as one student who described the center of mass of a construction crane he passed on the way to school.

Conceptual physics textbook problems. The students demonstrated a significant increase in scientific justifications of their answers to textbook problems (paired t-test, mean difference +5, $p<0.01$) and a significant decrease in intuitive justifications from pre- to post-interview (paired t-test, mean difference -2, $p<0.01$) from pre- to post-interview. For example, one problem said: "A man balances on his two hands with his feet in the air. Then he lifts his right hand off the floor and stands on the left one alone. How must his body shift if he is to keep from falling?"

During the pre-interview, one student answered, "I don't know what to say. He just picks up his hand and maybe leans over...? I'm not sure why, that's just what I think – he will fall over to this side."

In the post interview, the same student said:

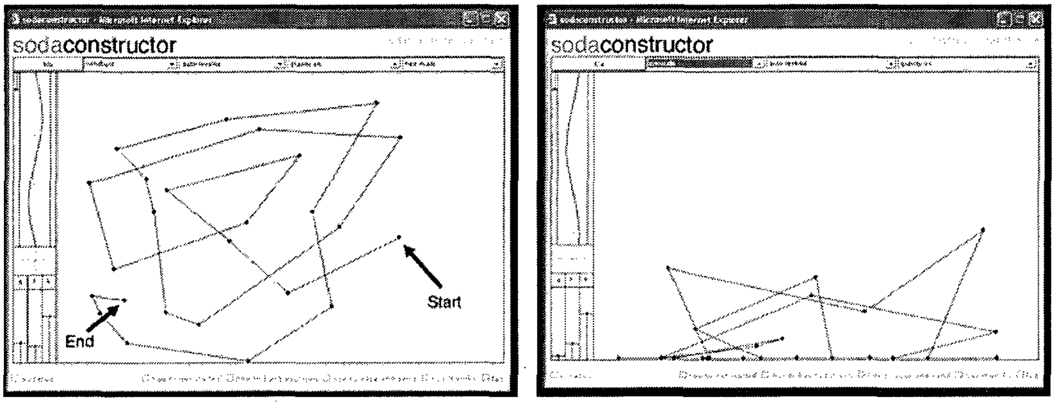
> "This goes like that *(draws the shifting figure)*...he'd have to shift over to the left side to make sure that his center of mass is over his arm and hand and lines up. He'd fall over if he didn't do any shifting because the center of mass would still be over here - I think he would fall over. I think he would have to even out [his weight] by moving to the left side."

In other words, during the Berta's Tower workshops, students developed their understanding of center of mass, a fundamental concept in physics, and were able to use more scientifically-based reasoning when defending their answers to textbook physics problems.

RQ-2: What is the mechanism involved in this learning process?

Video Case. We next present a brief video case study as a window into the means by which two students developed their understanding of center of mass and interest in developing spring mass structural models using SodaConstructor during the workshop. The case study presents four excerpts from the work of a design team of two sixth grade boys, Carl and Rick.

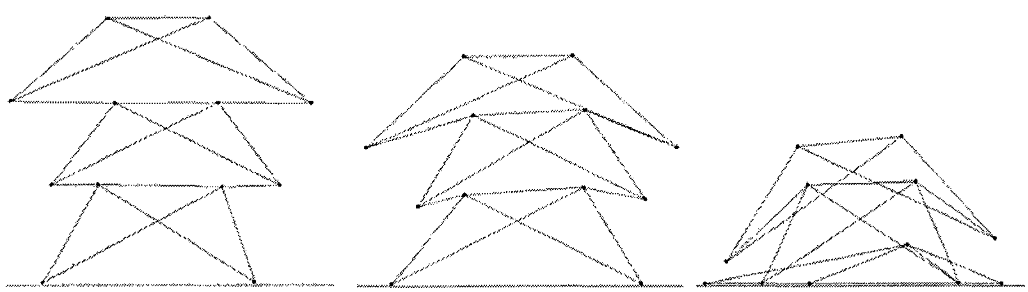
Excerpt one: Expressivity and interest. Soon after the workshop started, the students were introduced to the SodaConstructor microworld. Carl and Rick both immediately opened design windows, and began rapidly placing masses on the screen. Carl said: "Wow, you can build anything! This is so cool! " Carl's first design (Figure 1a) collapsed, however, when he moved from CONSTRUCT to SIMULATE mode (Figure 1b).



(a) (b)

Figure 1. Carl's first design in SodaConstructor in CONSTRUCT (a) and SIMULATE (b) modes.

Excerpt two: Interest and iteration. Carl and Rick were working at their own computers on the second design challenge, which asked them to "build a multi-story structure"—that is, a structure consisting of several shapes stacked on top of each other. Rick's first design in response to the challenge is shown in Figure 2a. Figures 2b and 2c show what happened when he simulated his design.



(a) (b) (c)

Figure 2. Rick's first attempt at solving a design challenge. 2a is his structure in CONSTRUCT mode, where it is not yet subjected to the force of gravity. 2b is the result of switching to SIMULATE mode and activating gravity; the structure begins to crush, and the final equilibrium state is seen in 2c.

Rick then reloaded his saved design (Figure 3a) in order to modify it. The conversation between Rick and Carl that ensued illustrates both the highly iterative nature of the design-build-test cycle and the high level of enthusiasm students had for the process.

Rick: *(while building)* This is cool... I want to do this all the time...I could do this all day.

Carl: *(looking at Rick's screen, see Figure 3a below)* This [design] is amazingly better. Tell me when you simulate it.

Rick: Alright.

Carl. Oh, that's not going to work.

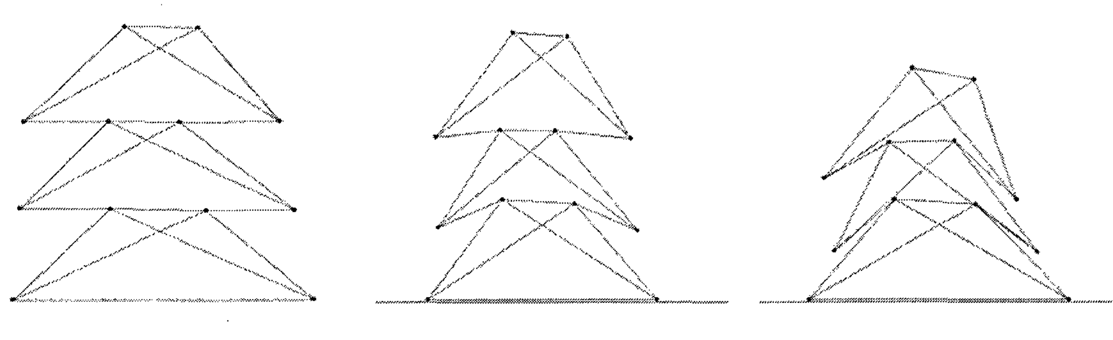
Rob: It might not work because I made the top triangle to big

Carl: Simulate it!

Rick: I have to save it first -

Carl: *(louder)* Simulate it!

Rick: *(describing the results, see Figures 3b and 3c)* Woo it works!



(a) (b) (c)

Figure 3. Rick's second attempt to solve the design challenge. Once again, 3a shows his design in CONSTRUCT mode, 3b is when he first SIMULATEs, and 3c is the final equilibrium position.

As a comparison of Figures 2 and 3 shows, Rick decided to modify each of the stories, making them more uniform, which included narrowing the top story and widening the base of the bottom story. This second design did not collapse as much as the first, and Carl noted the second iteration "stood up more" than the previous one, which pleased Rick. However, Rick wanted to minimize the "droop" of the three-story structure. In a final iteration of the DBT cycle, he added members along the side of the structure, again saved it in CONSTRUCT mode, and then simulated it with success (see Figure 4).

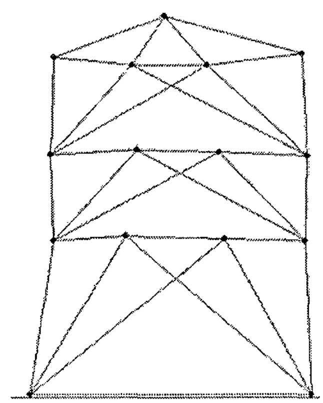


Figure 4. Rick's third iteration of the design challenge. This figure is in SIMULATE mode. There were no changes from CONSTRUCT to SIMULATE modes, because the structure was stable.

Excerpt three: Autoexpressivity and understanding . During this part of the workshop, Rick and Carl were working on the "Overturn" design challenge in which they loaded a pre-designed but half-completed structure of irregular shape (see Figure 5) into the CONSTRUCT mode and were asked to build a base for it by only connecting to the two lowest points on the object.

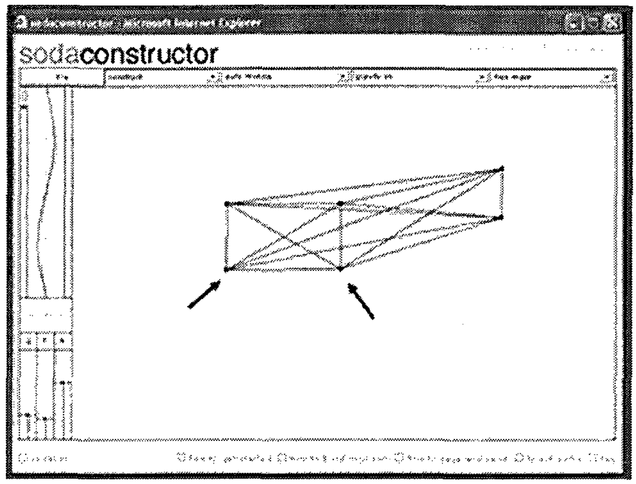


Figure 5. Overturn design challenge, saved file. Students loaded this partially completed design into the CONSTRUCT mode and were asked to build a base for it by only connecting to the two lowest points of the structure, denoted by the arrows.

In the design work that followed, Carl came to understand the critical relationship between the center of mass of an object and its base in determining stability.

Carl: *(referring to Figure 6a)* This won't work.

Rick: Try it!

Carl: *(pause)* Ok, I'll try it, oh wait, I should save it first.. I still don't think this will work... let's try it (*simulates design and it falls over, Figure 6b*)...Grrr... Oh, I

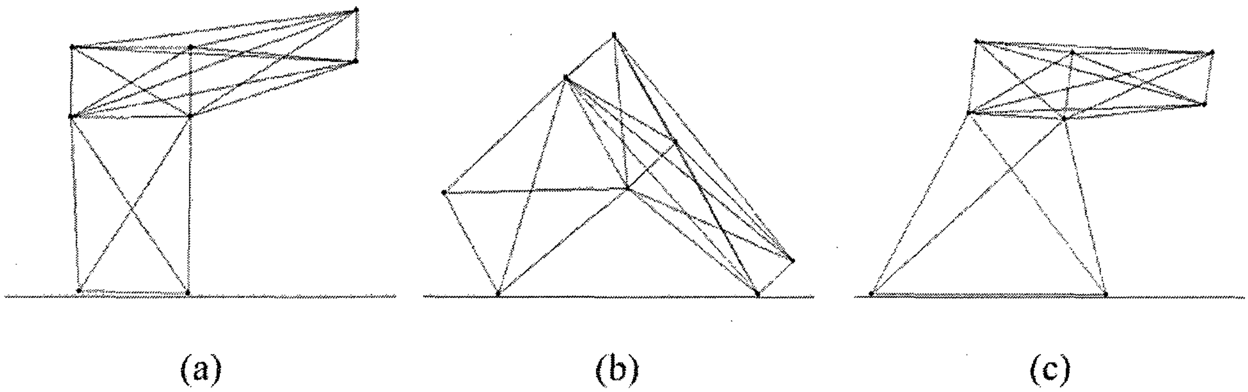


Figure 6. Two iterations of Carl' design cycle. 6a shows his first design in CONSTRUCT mode, and 6b is the result in SIMULATION mode. 6c shows his revised design in SIMULATE mode. There were no changes in 6c from CONSTRUCT to SIMULATE mode because the structure was stable.

In Carl's first design the base was too narrow to support the top half of the structure. After observing the design fall, he recognized he needed to widen the span base in order to include the center of mass within its horizontal boundaries and thus prevent tipping.

Excerpt four: Expressivity, autoexpressivity, and iteration. The last video excerpt comes near the end of the workshop. The students' final design challenge on SodaConstructor was to create a cantilever[3] with both the widest span and the narrowest base possible. Rick decided he wanted to build his cantilever on a tall foundation, extending to the left and to the right. He began by building a wide slab supported at the center by narrow base, as seen in Figure 7.

[3] A cantilever is a structure that extends outward from its foundation, such as a street light, diving board, or construction crane

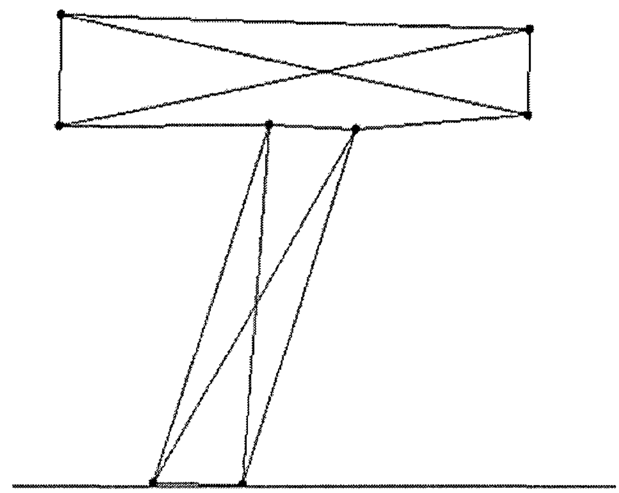


Figure 7. Rick's initial design for the cantilever.

Rick simulated this design and it fell over to the right. He reloaded it and modified it by rebuilding the cantilever, adding more members and connecting each mass in the slab to at least four other masses. After he simulated this design, which stood for a few seconds before slowly falling over to the right, he said, "With the extra supports it actually works; it bends over a little bit more than before...But I think it fell because the center of mass is a little more on this side when I was making it... yeah, now it's further out, so I think that was probably it." Rick continued to modify his design by reloading saved iterations of his work and making incremental changes: adding more members to the slab, reconstructing the base, adding a second story, adding vertical supports to the slab. Once he had a stable design that did not easily collapse or tip over, Rick started to lengthen the cantilever arms to increase the span-to-base ratio. In his last iteration (see Figure 8), he added weight to the back half of his cantilever in order to shift the center of mass to the left. At the end of the design challenge—and a total of 19 versions of his design—Rick was able to build a structure with a span-to-base ratio of 6:1. (Rick's final 6 designs and corresponding dialogue are presented in the Appendix.)

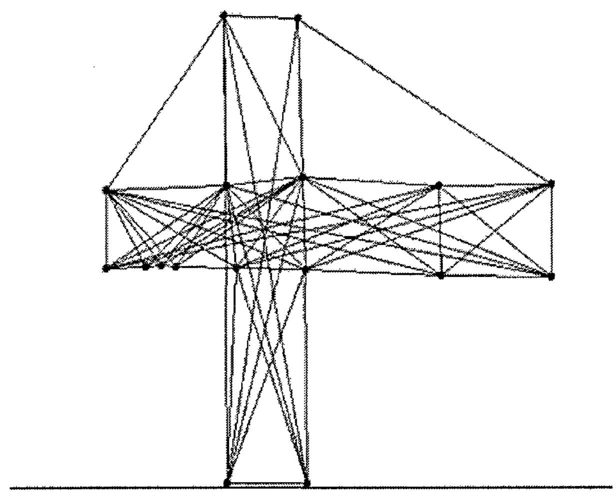


Figure 8. Rick's 19th and final version of the cantilever.

What we see in this excerpt from Rick's design work is that Rick's initial design decision to have a cantilever supported in the middle and extending in both directions was preserved through 19 design-build test cycles At the same time, the autoexpressive feedback from SodaConstructor helped Rick develop the understanding of center of mass and its relationship to the design of cantilevered structures that he needed to implement that design decision as a response to an engineering challenge. In other words, the highly-iterative process of rapid prototyping in an autoexpressive computational microworld made it possible for Rick to incrementally develop scientific understanding in the context of an expressive and personally-motivating project.

Interview Data. The video case illustrates the process through which Carl and Rick iteratively developed an understanding of the concept of the center of mass and interest in designing complex structures through expressive projects in the autoexpressive SodaConstructor environment. In this section, we look at data from the post-interviews to examine the extent to which the themes from Carl and Rick's work—of autoexpressivity, iteration, expressivity, and the linkages between them—were common in the experience of the participants in Berta's Tower.

Autoexpressivity. Students were asked if SodaConstructor was "easy" or "hard" to use. Although 92% (11/12) of students believed that SodaConstructor was "easy to use", 58% (7/12) claimed that SodaConstructor was "hard at first." When asked for clarification, students gave reasons that had little to do with the actual interface of the tool. Rather, the responses indicated the embedded constraints of the domain as problematic when initially using the tool. For example, one student replied:

> "It was hard at first because it was kind of hard to get it to stand. You had to like build, I think members, they were called members – no, cross members. We had to add cross member sometimes to like make it stand."

Another student said:

> "I think once you get used to it, it's easy and fun. When you're first learning it, a lot of your stuff falls over because you don't realize you have to connect certain things and make it stable. But I think once you learn it, it's easier and it's more fun."

In the post-interview, students made no mention of the functional features of the tool, such as the different modes or the interface, as being difficult to master. Instead, the students saw the underlying complexity of the embedded domain as the main obstacle in learning to use the tool. That is, they equated learning how to use SodaConstructor with learning how to make a structure stand. As was the case for Carl and Rick in the video case, students were able to access and explore the domain of physics through their work in SodaConstructor.

Iteration. SodaConstructor allowed students to easily refine their designs. By saving their work before going to SIMULATE mode, the students could reload their design in CONSTRUCT mode after testing it in order to make revisions, thus beginning a new iteration of the design-build-test cycle. As Rick demonstrated in the fourth video clip, students could engage in the DBT cycle at a fast pace, refining their work in response to graphical feedback with ease. The mean number of saved designs in the students' SodaConstructor accounts was 27.3, suggesting that SodaConstructor supported high iterations of the design-build-test cycle for all workshop participants.

Expressivity. As in Carl's statements from the first video clip, 67% (8/12) of the students said that the freedom SodaConstructor allowed when combining design elements was one of their favorite features of the tool. Because the SodaConstructor design space is a blank canvas, the students were able to incorporate personal design choices into their solutions, as we saw Rick doing in the fourth video excerpt. In addition to being motivating and interesting for the students, this expressivity created a sense of ownership and empowerment during their inquiry. As one student stated,

> "You just click and then you could move it wherever you wanted and it didn't take too long and make kind of a big building...It was cool and you could do anything...it's just fun to mess around and stuff."

Autoexpressivity and iteration. When asked what best helped them to learn, 75% (9/12) of the students indicated the ability to test their structures in SIMULATE mode and viewing the results was most helpful. The visual output provided by SodaConstructor helped students identify necessary revisions to improve their designs. In her post-interview, one student clarified what was most instrumental in her learning process throughout the workshop:

> "Visually, like building the cantilevers and on Soda-Constructor and seeing instead of just hearing it...like being able to test it out...Because you were able to see the mistakes you made and what you could do to help this."

In other words, the pairing of autoexpressivity and iteration allowed students to test and refine their ideas in the context of the design-build-test cycle, thus building understanding and interest in the same way Rick and Carl did throughout the video case.

Expressivity and iteration. In addition, 58% of the students (7/12) identified the combination of the freedom to be expressive and the ability to test their designs as the best feature of SodaConstructor. One student had been working with the tool on a library computer before the interview started, and the researcher asked him what he liked best about it. He replied:

> Um, because it was, I thought it was really cool to like just to make stuff – like whatever you want – and see if it would stand... like right now I was like making buildings and stuff to just try it out.

Linking autoexpressivity and expressivity to build interest and understanding through iterative projects. The number of students who identified both expressivity and testing as their favorite aspects of SodaConstructor suggests there is a close connection between building personally meaningful designs and testing them in the tool's simulated gravity environment. As was demonstrated by Carl and Rick's enthusiasm in the second video clip, what was interesting, fun, and motivating for 58% of the students was the pairing of expressivity and iteration: the ability to build what they wanted and see if it "worked"—and thus to understand something about the nature of the center of mass and the behavior of structures under gravity more generally. That is, as was the case for Carl and Rick in the video excerpts, there appears to have been salient relationships among the autoexpressivity of the tool, the iterations of the design-build-test cycle, and the expressiveness afforded by the tool to the student demonstrated in this learning environment.

Discussion

In response to our first research question, then, our data suggest that the middle school students in the Berta's Tower project developed understanding of center of mass through virtual engineering design challenges using a computer simulation. Moreover, these results suggest that in answer to our second research question, this learning took place through rapid iterations of the DBT cycle as students solved expressive design challenges in an autoexpressive microworld. In the discussion that follows, we argue that this process can be usefully characterized by the concept of *exploratoids*.

Exploratoids

As we saw in Rick and Carl's work, when students in Berta's Tower worked on design challenges, they engaged in rapid iterations of the design-build-test cycle on SodaConstructor—as many as 6 in just over a minute in the fourth video excerpt. These brief but repeated interactions allowed students to test and incrementally refine personally meaningful designs, and in the process helped develop both their understanding of the concept of the center of mass and their interest in designing complex structures in SodaConstructor.

In the video case, Rick and Carl went through multiple iterations of the DBT cycle for each design challenge, frequently and rapidly testing small ideas in the simulation in a manner similar to the rapid prototyping that marks the early stages of engineering design. As a result, they gained small and yet meaningful insights about physics from SodaConstructor's graphical feedback—that is, from the autoexpressive properties of the tool. These insights accrued over time as Rick and Carl reloaded previously saved designs and refined them for their next design idea. Their motivation to continue refining their images in this intensive process came from the way in which the tool and activities allowed them to build designs that reflected their personal interests—that is, from the expressiveness of the endeavor. Rick and Carl built their understanding of center of mass and their interest in using SodaConstructor cumulatively and incrementally through expressive activity in an autoexpressive tool.

As we described above, Crowley and Jacobs (2002) argue that young children often develop scientific understanding through explanatoids: short fragments of explanatory talk between a child and parent that accumulate over time into a stable base of interest in and understanding of a topic. We propose extending this idea to explain how students develop scientific understanding through expressive activities in an autoexpressive microworld. Just as conversations between parent and child function as explanatoids that create a motivating connection between interest and understanding, iterations of the DBT cycle function as *exploratoids*: short fragments of exploratory action between a student and microworld that over time accumulate to build interest and understanding.

The concept of exploratoid is a useful construct for understanding the experiences of students in the Berta's Tower workshops—and more broadly, for understanding how solving expressive design challenges in an autoexpressive microworld develops interest and understanding. In particular, it shows how and why the engineering practice of simulation-based rapid modeling may be a useful model for the design of learning environments where students learn scientific concepts through simulation-based design activity. Frequent, low-cost interactions between student and simulation provide meaningful and relevant feedback, engage the students in an area of interest, and allow students to develop understanding incrementally and cumulatively over time. Professional engineers rely on simulations to reduce the iteration cost of the DBT cycle during the preliminary design phase, allowing them to learn about a physical system through design iteration before committing to a design with which to move forward. In a similar way, the students of Berta's Tower were able to use a simulation for rapid, low-cost iteration of an engineering design challenge and thus increase their understanding of center of mass.

Limitations

There are a number of limitations to this clearly preliminary study. Much more work remains to be done on the nature of exploratoids and the potential role of professional practices in the context of computer-supported engineering design projects for science learning. The data presented in this paper do not address the role of workshop leaders in facilitating students' interactions with SodaConstructor—and thus, by extension, the role of mentors in mature engineering practice. This preliminary study does not look at the role of students' prior interests on their experience of the workshop. Nor does it examine the persistence and impact over time of the scientific understanding and interest students built, either on test scores or continuing curiosity in science. However, these limitations notwithstanding, this preliminary work does suggest that the theories of islands of expertise and pedagogical praxis may be useful tools in developing and examining computer-supported activities based on authentic engineering design—and that further study of these theories may lead to useful insights about the design of effective environments for science learning.

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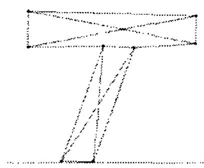
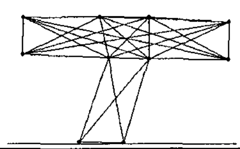
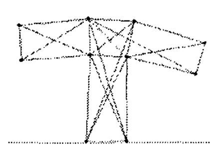
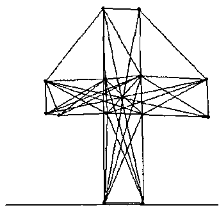
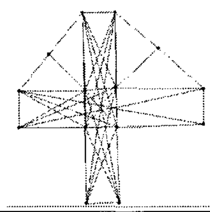
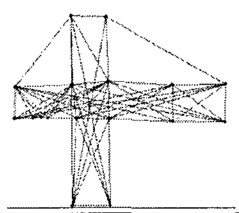
Appendix

Video Case, Excerpt 4: A moment during Rick's final design challenge experience.

Transcribed excerpt	SodaConstructor image and mode	Actions on SodaConstructor
(before speaking)	 CONSTRUCT	After simulating, the structure did not stand, falling to the right. Rick reloaded the design in CONSTRUCT mode and modified it.
With the extra supports it actually works; it bends over a little bit more than before...But I think it fell because the center of mass is a little more on this side when I was making it... yeah, now it's further out, so I think that was probably it.	CONSTRUCT 	After simulating, the structure did not stand, falling again to the right but more slowly than the previous iteration.
I was just looking at my other one – this one... this one was working really good...	 CONSTRUCT	Rick called up an older, saved model in CONSTRUCT mode, which had been *almost* stable when simulated but ultimately tipped to the right.

I'm thinking, I just would pull it up like this, I don't really want to connect these, because that would make a different shape	 CONSTRUCT	Rick began to refine his older model, adding an upper story to the structure. After simulating the design, it was more stable than previous iterations, but it fell back towards the left.
you know it doesn't look like it goes out very far... I don't know, I have to figure it out... Oh! I know what I can do...	SIMULATE 	Rick decided to extend the cantilever arms and add two members to the upper story as supports. When he simulated this design, it was stable.
(after speaking)	SIMULATE 	Rick extended the cantilever arm to the right and added more mass to the left side of the structure. When he simulated this design, it was stable.

Design meetings and design notebooks as tools for reflection

in the engineering design course

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Design meetings and design notebooks as tools for reflection in the engineering design course

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Abstract – **Engineering capstone and cornerstone courses have been rapidly incorporated as fundamental components of undergraduate engineering programs. Generally, students in these courses work in teams to solve realistic design problems in an "authentic" setting. However, do these adapted professional activities serve a more important pedagogical role than increasing authenticity? In this paper, we investigate this question by describing an ethnographic study of Biomedical Engineering (BME) 201, an engineering design course for sophomores at a large Midwestern university. The main goal of the study was to uncover the reflective learning processes experienced by the students in the course. In particular, we examined two activities for their pedagogical significance: the weekly design meeting and the student design notebook. Understanding how these participant structures facilitated student learning can influence the future design of capstone and cornerstone experiences as well as the broader landscape of engineering education.**

Index Terms – capstone courses, design, reflection

In many of today's undergraduate engineering programs, one- to two-semester capstone design courses are expected and anticipated, and cornerstone courses are also on the rise. Engineering professors and professionals realize that these experiences are critical to the complete development of new engineers. In order for students to understand the nuances of engineering – and to help them begin to think, act, and indeed *be* engineers – undergraduates must engage in the essential activity of the profession, engineering design, within a meaningful context. In an effort to provide students with an authentic "real world" experience, capstone and cornerstone courses often attempt to recreate aspects industry design for the undergraduates. However, do these adapted professional activities serve a more important pedagogical role than increasing authenticity?

In this paper, we investigate this question by describing an ethnographic study of Biomedical Engineering (BME) 201, an engineering design course for sophomores at a large Midwestern university. The main goal of the study was to uncover the learning processes experienced by the students in the course. In particular, we examined two activities – or *participant structures* [2] – for their pedagogical significance during BME 201: the weekly design meeting, and the student design notebook. Understanding how these participant structures facilitated student learning can influence the future design of capstone and cornerstone experiences as well as the broader landscape of engineering education.

THEORETICAL FRAMEWORK

The continual development of capstone and cornerstone courses over the past 20 years appears to have had the most influential impact on engineering education [5].Generally, students in these courses work in teams to solve realistic design problems, specific to their engineering discipline, under the guidance of a professor [6-9]. Students brainstorm ideas, identify constraints, research produces, build prototypes, and evaluate their designs in order to understand the nuances of the engineering design process. They write reports, give oral presentations, and participate in formal design reviews to develop the communication skills essential to success within industry. They keep a detailed design notebook to become familiar with the rigorous demands of engineering documentation for legal and patent purposes [9, 10]. These activities are commonly included within capstone design courses in order to provide undergraduate engineers with an *authentic*, "real world" experience as a way to develop the skill set – such as that outlined by ABET Criterion 3 required to be a successful practicing engineer.

BME 201

In this study, we focus on BME 201, a Biomedical Engineering course at a large Midwestern State University comprised mostly of sophomores. During the course, students engage in BME design projects posed by local clients, such as doctors, physical therapists, and professors. The two aspects of the course that are presented and analyzed in this paper are the weekly *design meeting* between the student teams and their design advisor (one of the professors of the course), and the *design notebook* kept by students throughout the semester. According to one of the course professors, the design meeting was meant to function as a "mini design review", in which the students reported their progress and any problems to their design advisor, and the design advisor provided insights, guidance, and at times, encouragement.

The design notebook used throughout the BME design sequenced is modeled after the professional documentation generated by practicing engineers. Course materials regarding the design notebook identify several reasons for students to keep such a record, such as: documenting individual effort on a project (for grading purposes), use in patent and legal evaluations, creating a resource for preparing reports, and providing a record of activity for projects that would be useful to future engineers working on the project. These reasons are all pragmatic, direct, and relevant, particularly because some of the projects produced in these courses are refined enough to actually be patented.

Beyond authenticity: The reflective practicum

BME 201 and other design-based courses rely on the authenticity of the activities and course components to help prepare undergraduate engineering students for industry. By participating in realistic adaptations of actual engineering practice, the students in these classes engage in a controlled environment that removes at least some of the commercial, physical, and social constraints of industry. In other words, the students engage in an authentic *simulation* of professional engineering practice.

The *reflective practicum* is another way to describe professional learning contexts that simulate authentic practice [11]. The work of Don Schon [12, 13] examines these learning environments, where novice professionals engage in authentic, messy, and ill-structured problems under the supervision of more experienced, often expert, mentors – or "coaches". The aim of the reflective practicum is to help novice professionals learn how to *reflect-in-action*, or the ability to engage in on-the-spot thought and action experiments which often consist of considering an action, asking "what if?", and thinking about the consequences – both intended and unintended – the move will have on the design. By listening to the situation's *back-talk* in this way, the designer engages in a *conversation with the materials*, which is the way Schon identifies professional artistry in design practice.

As the student grapples with authentic problems from the field in the practicum, she naturally encounters difficulty. A *coach* then consults with the student on her progress, often *reflecting on* the student's actions, helping her reframe the situation to point out misalignments with the norms of the profession. This *reflection-on-action* provides the student with insights into artistic professional practice. The coach can not only *reflect on* the student's past actions and help her understand why they might not have been the best choices; the coach can also *reflect-in-action* and discuss with the student ways of making forward progress on solving the problem: such as positing a set of potential moves, playing them out by considering their repercussions, or presenting different ways to reframe the problem so that the student may become "unstuck". This on-going dialogue between coach and student is essential for making the ways of thinking and knowing of a profession visible, understandable, and accessible to new members.

The ideas of "reflection" and "coaching" are not completely foreign to engineering education. Gorman et al [14] describes reflection as understanding problem solving strategies at the metacognitive level, which in turn enables practitioners to apply these strategies in novel contexts. Adams, Turns, and Atman [15] analyzed data from 4 separate studies to investigate how engineering students exhibit reflective practice when engaging in certain design tasks, such as iterating through ideas during the design process and problem setting. Khisty and Khisty [16] describe teaching practices employed within a particular capstone course in an effort to promote reflection-on-action and reflection-in-action, though no analysis was conducted on student learning outcomes or processes. Marin, Armstrong, and Kays [17] address the issue of coaching by providing three criterion for the successful "coaching and mentoring" of students within a capstone course. However, none of these studies address how students can develop reflection-in-action within the design practicum. In our study of BME 201,we sought to discover and understand the underlying opportunities for reflection embedded within the design meeting and the design notebook.

Reflection and the epistemic frame

Learning to reflect-in-action is more complex than mastering a list of abilities such as ABET's Criterion 3. Certainly, outlining a set of competencies is a valid and widely accepted way of characterizing the members of a particular profession. Another view – arguably a more complete one – of how to describe a profession's particular manner of acting and thinking is to use the idea of an *epistemic frame* [2, 18, 19]. An epistemic frame consists of the set of skills, knowledge, identities, values, and epistemology of a particular profession. For example, scientists act like scientists, know what scientists know, see themselves as scientists, are interested in what scientific discoveries, and perhaps most importantly, *think and reason* like scientists. Likewise, other professionals – such as lawyers, doctors, and urban planners – each have their own ways of doing, seeing, caring, and being, and thus each have a different epistemic frame.

Shaffer [2] argues that learning to reflect-in-action means developing the epistemic frame of a particular profession. In other words, as students work under the supervision of a coach in the practicum, they begin to learn the skills and knowledge required to practice as professionals. They begin to identify themselves as capable practitioners who understand the value system of the profession as they learn to see and act on the world in a new way. Here, we explore how BME 201 helps sophomore engineering students begin to develop the epistemic frame of engineering, focusing on the components of skill, knowledge, value, and epistemology. The identity component of the epistemic frame is beyond the scope of this paper and has been discussed elsewhere [20].

Participant structures: Occasions for reflection

Within a reflective practicum, the epistemic frame is developed through specific activities, or *participant structures,* in which reflective conversation occurs. Investigating these participant structures and understanding the types of reflection that occur, as well as the content of those reflections relative to the epistemic frame, is done through an ethnographic study called an *epistemography* [2]. For example, an epistemography conducted on a reflective journalism practicum revealed three participant structures – *news meetings, war stories, and copy editing* – as key contributors to the development of a journalistic epistemic frame. Although these participant structures may have been included in the course by the professor for other reasons, such as to create an authentic context for journalistic practice, it is their capacity for fostering reflection that made them pedagogically powerful.

The salient and reflective participant structures identified within the journalism practicum were all rooted in interactions between people, such as student-student and student-professor conversations. Here, we propose to extend the concept of a participant structure to include interactions between person and tool by applying the theory of *distributed mind* [21], which argues that person-tool interactions can be analyzed with the same lens as person-person interactions. In other words, in the analysis of the journalism practicum, person-person interactions cultivated reflection and thus helped students develop the epistemic frame of the profession. In our analysis of BME 201, we will not only analyze a person-person interaction (the design meeting) as a potential catalyst for reflection, but also a person-tool interaction (the student design notebook).

The epistemography of BME 201

Thus, the aim of this study – the epistemography of BME 201 – is to uncover the learning processes within an undergraduate engineering design practicum. we examine two specific participant structures, the weekly design meetings and the student design notebook, for their capacity to foster and support reflection. We look at how these occasions for reflection address components of the engineering epistemic frame, focusing on the skills, knowledge, values, and epistemology of the profession. We then discuss how the results of this study may contribute to the field of engineering education, particularly with respect to designing reflective learning environments and experiences that promote the development of the next generation of reflective engineers.

METHODS

BME 201 was a one-credit course that officially met for two hours once a week 14 times during the semester. During the "formal" class time, student teams had design meetings with their design advisors. These meetings occurred regularly in the first half of the semester, when the students were in the conceptual design stage and generating design alternatives. After a mid-semester presentation, the students transitioned to building a prototype or model, so the design meetings were often shorter and more focused on the mechanics of the prototype instead of conceptual design. Outside of the scheduled course meeting, students met with clients, met with each other in their teams, and worked individually on various aspects of the project. As mentioned above, students were also required to keep a design notebook to individually document their design work.

Data collection and analysis

Data was collected in several ways throughout the semester. One researcher was present at 11 of the 14 classes as an observer. Within these 11 classes, she attended the first session where the students chose their

Code	Descriptin	Example
reflection-on-action	comments regarding past action; consequences of past action; ways to improve past action in the future	"Good work! It's always good to get information not only from the client, but from the people who work with the client and around the client."
		notes on earlier advisor suggestions (notebook)
reflection-in-action	comments regarding current and/or potential action; consequences of current and/or potential action	"[You need to] figure out what the clients wants, in the priority that he wants it. What is most important? What is non-negotiable?"
		list of questions and potential answers (notebook)
skills	abilities students need to develop to become engineers	"We're doing more research, trying to decide which company to go with. We are looking at different aspects of the software now."
		design diagrams (notebook)
knowledge	aspects of engineering domain knowledge	"We're working on PDS report."
		details of client setup (notebook)
values	things that are important to engineering practice	"You have a hands on client... you might want to set up a weekly meeting to get regular feedback."
		list of client needs (notebook)
epistemology	ways of thinking about or justifying activity within the engineering community	"You don't want to sit around waiting for information to come to you. You want to pick up the momentum of the design... keep the information coming in so you don't stall."
		written justification for design choice (notebook)

projects as well as both presentation days. The 8 remaining classes she observed consisted of the regular sessions involving design meetings between the student teams and design advisors. Five of these occurred before the mid-semester presentations, and 3 were after. During these observations, she generated field notes which provided a detailed description of the events, including direct quotations whenever possible. In the results section, our record of these actual utterances as recorded in the field notes are identified by quotation marks. After the third week of the semester, she began to closely follow one of the student teams. The week before the final presentations, three student teams – including the one she observed closely – participated in focus groups. In addition, she conducted individual interviews with the two professors who acted as design advisors in BME 201, as well as six other students who did not participate in the focus groups. All interviews and focus groups were tape-recorded.

All field notes and audio recordings were transcribed. Field notes from the design meetings of the team she observed more closely were segmented initially by date, and then by turn of speaker. Due to the change in focus of the course after the mid-semester presentations, only the data from the first 5 design meetings were included for analysis. The turn-by-turn segments were coded for instances of *reflection-on-action* and *reflection-in-action*, as well as the *skill, knowledge, values,* and *epistemology* components of the epistemic frame. She also took the design notebook of one student from the team, Erik, and segmented it first by date, then by entry. Here, we define a notebook "entry" at the level of a bulleted list, a sketch or design drawing with description, or a block of text such as a paragraph. These entry segments were also coded for instances of *reflection-on-action* and *reflection-in-action*, as well as the *skill, knowledge, values,* and *epistemology* components of the epistemic frame. For an example of these analytical codes, please see Table I.

After an initial coding of the data, the relationships between the two participant structures of the design meeting and the design notebook, the types of reflection that may have occurred within them, and the elements of the epistemic frame included in the reflective moments were analyzed within a *grounded theory framework* [22, 23]. Non-parametric statistical analyses were also conducted to further support the qualitative findings.

TABLE I. ANALYTIC CODES USED IN QUALITATIVE DATA ANALYSIS.

RESULTS

The results from this study of BME 201 are presented in three parts. The first section describes the design meeting and the design notebook as reflective participant structures within the course. The second section describes how these occasions for reflections were focused on the skill, knowledge, and value components of the engineering epistemic frame. The last section describes the relationship of these 3 components relative to the epistemology of engineering.

Reflective participant structures in BME 201

The analysis of the design meetings and design notebook indicated that both of these participant structures were occasions for reflection in BME 201.

Both of these structures involved reflection-on-action and reflection-in-action, though in different amounts.

Design Meetings. During the second class meeting of the semester, the design advisor, Mark asked the student design team – Erik, Ken, Nicholas, and Jack – what they had been working on over the past week. Erik replied that they were trying to "figure out the problem statement," and that the team had been doing a lot of "research online" while trying to think about a "list of questions for the client." Ken, the team communicator, chimed in, mentioning that they had not yet been able to meet with the client due to scheduling conflicts.

Mark indicated that this was normal and to keep trying to communicate with the client, mentioning that perhaps a phone call might be more effective than email for scheduling. Mark also suggested the team "should draw out" what they thought the system looked like based on the client description in order to "get an initial idea of what's really happening." Mark then asked if the students understood how "the main component of the system works - the mass flow controller?" Nicholas, the most mechanically savvy member of the team and the team leader, said that he thought he knew how the mass flow controller – or "MFC" – worked, though he did not provide any further information to demonstrate his understanding.

Mark then steered the conversation in a new direction by asking about the team's progress in researching the problem. Erik said they had "been looking up different parts of the system online" and that each of them were "looking at different types of MFCs for sure." He added that other members of the team were also "looking at the software for MFCs." Mark agreed with the students' actions but also advised the team to "check out how MFC's work, and look for information on the condition itself - on hypoxia." Mark then told the students that they "need to know about what the client works on," so they could more clearly understand the client's needs. The students nodded and a few jotted notes down in their design notebook. Mark opened the floor for any questions, and after pausing for a short while with no replies, he told the team they were doing well and that he would see them next week.

Types of reflection. In this design meeting, the design advisor, Mark, engaged in both reflection-on-action and reflection-in-action. For example, he reflected-on-action when he commented on how common it was to have difficulty scheduling meetings with the client during the design process, and provided the students with a suggestion on how to deal with this problem in the future (by placing a phone call to the client instead of emailing him). Mark also reflected-in-action when he told the team to also "look for information on the condition itself" during the online research the team was conducing that day in the computer lab.

There were significantly more occasions of reflection-on-action than reflection-in-action during the design meetings overall, as seen in Figure 1 (paired t-test, controlled for date of meeting, $p<0.05$). These reflections were made by both the design advisor and the students, with each making 14 reflective comments for a total of 28 reflective comments over the 5 meetings observed. For the design advisor, his comments were split evenly between reflection-on-action (50%, 7/7) and reflection-in-action (50%, 7/14). Of the 14 student comments, 86% (12/14) were reflection-on-action, and 14% (2/14) were reflection-in-action.

Design Notebook. Regardless of their thoughts on its effectiveness, students were required to record notes from brainstorming sessions, background research and literature searching, and all project meetings, as well as all sketches and calculations in their design notebooks. For example, following the design meeting described above, Erik sketched out his understanding of the client's system based on the client's description as seen in Figure 1:

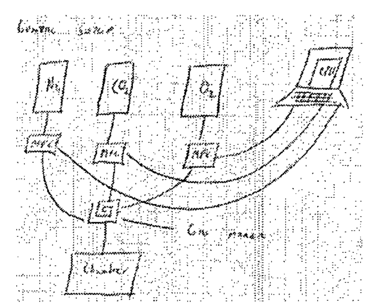

FIGURE 1. DESIGN DRAWING OF EXISTING CLIENT SYSTEM.

Here, Erik has each of the gas tanks (N_2, CO_2, and O_2) connected to a MFC, which is controlled by a computer, thus allowing for the regulation of gas allowed into the gas mixer and the experimental chamber. This diagram was followed by a written description the system, as seen in Figure 2.

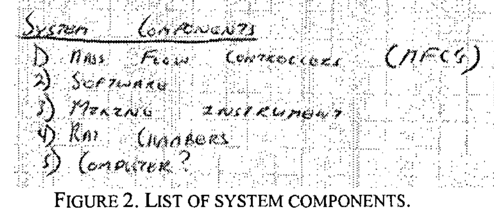

FIGURE 2. LIST OF SYSTEM COMPONENTS.

Here the actual gas tanks are not included while the software and computer are listed as separate elements. In Figure 1, these two elements were integrated into the image labeled "CPU". At the bottom of the page, Erik maintained a list of questions to be asked at the team's first meeting with the client, as seen in Figure 3. These questions stemmed from a desire to understand the parameters of the design problem, including the client's needs ("priority of components for project") as well as the physical and material constraints ("data acquisition card").

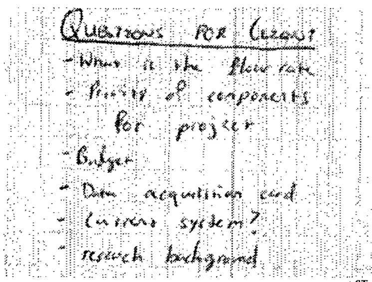

FIGURE 3. LIST OF QUESTIONS FOR THE CLIENT BEFORE 1ST MEETING.

After a few additional scheduling problems, the team was finally able to meet with their client during the third week of the semester. Two days passed, and then the team gathered to discuss how the client meeting went, the information the client was able to share with them, and what everyone's current understanding of the client's needs were. In his notebook, Erik recorded these suggestions by the team for client needs, as seen in Figure 4. The list of client needs includes design objectives ("better accuracy"), constraints ("21% – 11% oxygen"), and functions ("variable flow rate through chamber").

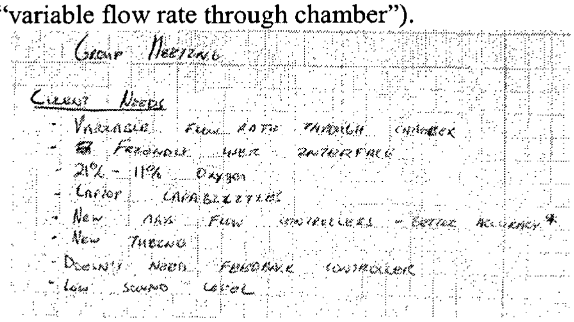

FIGURE 4. SUMMARY OF CLIENT NEEDS AFTER FIRST MEETING.

Types of reflection. These excerpts from Erik's notebook demonstrate the effectiveness of the design notebook as a tool for reflection. For example, he reflected-in-action when he listed the system components (Figure 2), wondering if the software and computer should be two separate components. If so, the implication would be that his team would have to research and identify both the software to control the MFCs as well as the computer to run the software. Erik again reflected-in-action when he generated the list of questions for client (Figure 3). Here, he was thinking about what information he needed from the client, as well as some potential components of the system to discuss with the client. In Figure 4, Erik reflected-on-action, when he – with his teammates – discussed the initial client meeting and identified an initial list of client needs.

Unlike the distribution of the students' reflective comments in the design meetings, there were significantly more occasions of reflection-in-action than reflection-on-action in Erik's design notebook (paired t-test, controlled for date of notebook entry, $p<0.01$). Of the 33 reflective entries, 85% (28/33) were reflections-in-action, while the remaining 15% (5/33) were reflections-on-action.

Reflection and engineering skills, knowledge, and values

Naturally, given the context of the course, the reflections described above were intended to assist the team of sophomore engineers in solving their design problem. However, a closer look at these conversations – both with the design advisor and with the design notebook – reveals that these participant structures were about developing engineering skills, knowledge, and values.

Design meetings. For example, in a design meeting a two weeks before the mid-semester presentations, Ken and Jack were talking with Mark about how the latest client meeting was "really very informative", and therefore the team had "a much better idea of what he really wants."

Mark replied enthusiastically, "That's good! Now you can restate the problem statement," allowing the students to reframe the problem and significantly trim the lengthy description initially provided by the client. Mark added that the students could now "zero in" on what they needed to do.

Mark then turned to another issue, asking the team, "Who else are you talking to besides the client?" Nicholas replied by saying he was talking to a software engineer on campus to "figure out more about MFC control networks." Mark nodded and said that this was a good idea, because "getting the perspectives of other people" who have other experience with the devices involved could provide the team with "another plan of attack". After a brief pause, Mark asked the team what they thought some of the main differences between their design alternatives might be, perhaps "different MFCs… or different software… or different hardware?"

Erik looked up from his notebook and indicated the team wasn't "sure yet" because they still had "to learn a little more about the system." Mark said that was fine, but he suggested the team should "get moving" on their other design ideas. "Remember", he cautioned, "you want to have at least 3 alternatives to present to the client."

During the reflective conversation in this design meeting, Mark referred to engineering skill, by telling the students to "restate the problem statement". He addressed engineering knowledge, by advising the students to get different "perspectives of other people" who might have additional and complimentary experiences with the devices involved in the design. Finally, he touched on engineering values, noting the importance of having "at least 3 alternatives" to present to the client.

Design notebook. The design notebook also demonstrated Erik's development of engineering skills, knowledge, and values. For example, in his notebook (Figure 5) there is a graph of the different concentrations of oxygen and nitrogen gas required for the experimental conditions. Here Erik demonstrated the engineering skill of design drawing.

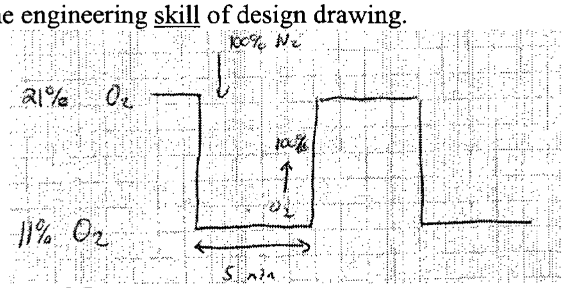

FIGURE 5. DESIGN SKETCH OF OSCILLATING GAS CONCENTRATIONS.

Instead of describing the necessary gas concentrations in words, he sketched out the pattern in his notebook, also including a partial time dimension by noting the 11% oxygen gas concentration must last five minutes long. Figure 5 also demonstrates Erik's engineering knowledge of understanding the chemical symbols and axial dimensions of the diagram.

In this next excerpt from the notebook, Erik identified the required "specs" for the rat chambers – meaning the required features that must be included in the design, as seen in Figure 6. This list was generated during a client meeting. By identifying the required specs of the chambers, Erik enacted the engineering value of interpreting client needs based on client description.

The design meeting and design notebook excerpts presented here involved reflection, and also demonstrated how these reflections were about engineering skills, knowledge,

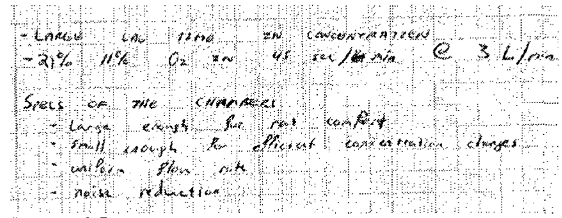

FIGURE 6. LIST OF REQUIRED SPECIFICATIONS FOR THE SYSTEM.

and values. Approximately 40% of the reflections in both the design meeting and design notebook were focused on engineering skills. The design meetings slightly more on engineering values (31%) than engineering knowledge (29%), while the design notebook focused more on engineering knowledge (42%) than engineering value (18%).

Engineering epistemology

Epistemic statements about engineering are statements that describe ways of thinking about or justifying activity within the engineering community. In BME 201, these statements did not occur in isolation; rather, epistemic statements were often bound together with references to other elements of the epistemic frame.

Design meetings. For example, at the end of the design meeting presented in the earlier section, Mark reminded the students that they should have 3 design alternatives to present to the client at the mid-semester meeting. To these cautionary words, Erik answered, "I think we have a good basic idea for the parts we're gonna need," as well as what the system "will look like when it gets set up."

However, Mark directed the conversation back to his previous point, saying "That's fine, but just be sure to really think about other design alternatives." He recognized that the team might "really like your first idea," but there are always other products or configurations that might "make a better design – less money, more efficient, that sort of thing."

In this brief excerpt at the conclusion of the design meeting, we see that Mark made an epistemic statement by justifying why a design or product might be better than another – "less money, more efficient, that sort of thing" – from the engineering world view. This explanation bound together his earlier comment about understanding other products and configurations (engineering knowledge) in order to create additional design alternatives (engineering skill) so as not to commit to a favorite or first design idea (engineering value).

Design notebook. Epistemic statements in the design notebook also bound the skill, knowledge, and value components of the engineering epistemic frame together. For example, in this excerpt from Erik's design notebook, he justified why he needs to replace the mass flow controller, as seen in Figure 7. With the second bullet point, Erik identified the need to replace the existing mass flow controllers, and he justified that decision by listing two reasons: the greater accuracy and greater response time that the new controllers will offer in the design. Particularly with the attention to accuracy, Erik was identifying the needs of the client (an engineering skill) while understanding components of the design (an engineering knowledge) while simultaneously satisfying the client's needs (an engineering value). Moreover, it was important for Erik to explicitly note these justifications of his design choices, so that when he presented the design alternatives to the client he could explicitly warrant the ways in which the new design is an improvement over the extant system.

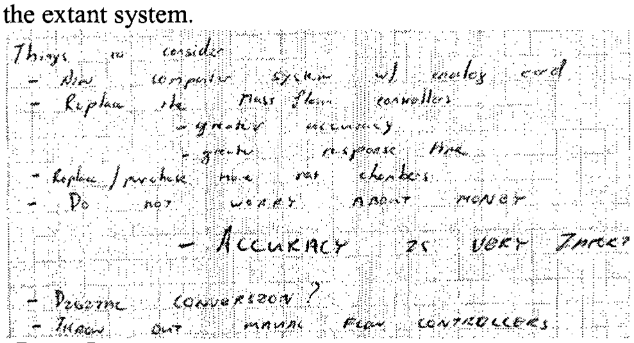

FIGURE 7. LIST OF CONSIDERATIONS DURING THE DESIGN PROCESS.

Across the design meetings and the design notebook, there were no epistemic statements made that referred only to a single frame component. Moreover, the co-occurrence of skills, knowledge, values with epistemic statements were highly correlated: R=.774 ($p<0.01$) for design meetings, and R=.749 ($p<0.01$) for design notebooks.

DISCUSSION

The analysis of BME 201 presented in this paper suggests that the design meetings and design notebook are, in fact, reflective participant structures. Moreover, these participant structures were occasions for the students and the design advisor to engage in conversation regarding engineering skills, values, and knowledge. References to these elements of the epistemic frame also tended to be bound together with a fourth component, epistemology, as represented in epistemic statements about the engineering profession.

Given Schon's work [12, 13] and Shaffer's [2] investigation of a journalism practicum, one might expect the design meetings in BME 201 to be a reflective participant structure. Similar to the other student-coach dialogues, the BME 201 design meeting is a thoughtful interaction organized around, and in, professional activity. Here, the design advisor and students engaged in more reflection-on-action rather than reflection-in-action, which might be explained by the original intent for the meetings to function as quick check-ins to make sure the student teams were moving forward with their work and provide suggestions if their progress had stalled. Also, the relatively short contact time between student and coach (as superficially compared to the contact time between student and coach in other accounts of reflective practica) may have prevented the conversation to move more towards the types of interactions Schon [12, 13] reported in the architecture studio, where the coach spins "a web of moves", asks "what if?", and considers the consequences. Nonetheless, the design meetings in BME 201 did in fact promote and support reflection within the practicum, thus serving in a powerful – and not necessarily intended – pedagogical role.

By applying the theory of *distributed mind* [21], the construct of the reflective participant structure with a practicum can be extended to include not only person-person, but also person-tool, interactions. Thus, we were able to explore a student's engineering design notebook as a tool for reflection by using the same lens we had applied to the design meetings. Documenting the design process from his own perspective in the design notebook required Erik to externalize his ideas, understanding, and justifications on paper. Although these representations were written and not spoken, the entries in the design notebook commonly demonstrated Erik's reflection-in-action – and thus demonstrated a gradual progression towards more mature engineering practice. As stated within the course materials, the design notebook is intended to be a document that can be used for patenting and legal purposes, serve as a resource for report-writing, and potentially be a guide for future teams taking on the project. Without doubt, the design notebook functioned in these authentic ways during BME 201. Perhaps more significantly, however, was the fact that the design notebook also helped Erik engage in reflection-in-action, which is a key facet of the undergraduate's professional development. Thus, the design notebook fulfilled an instrumental – and once again, not necessarily intended – pedagogical role as part of engineering practicum.

Though much of the focus of this paper has been about reflection and reflective participant structures, the content of these reflective moments should not be overlooked. Naturally, the reflections in the course were about "doing" engineering. For example, some of the reflections in BME 201 addressed how to find information, what that information means, how to use that information to solve the design problem, why engineers need certain types of information, and what counts as useful information. More generally, the reflections were about elements of the engineering epistemic frame, particularly the skills, knowledge, values, and epistemology of the profession. However, it is the binding of skills, knowledge, and value by epistemic statements that is interesting. In this study, epistemic statements tended to use a particular value to justify a particular skill that required particular knowledge. This finding suggests an underlying model for the epistemic frame of engineering and its development: in order for students to develop the engineering epistemology and begin to "think like engineers", they must be engaged in meaningful activity that involves the development of these 3 other frame components.

Of course, the study presented here has several limitations that should be considered. First and foremost, the scope of the analysis conducted here is quite narrow, consisting of the design meetings of a single student team and the design notebook of a single student. Second, this small cross-section of data was confined to one design course in a six-semester sequence, thus resulting in a detailed yet discrete snapshot undergraduate engineering development. However, this study does shed light on the reflective capabilities of two common participant structures within engineering practica, how these participant structures address elements of the engineering epistemic frame, and the nature of the engineering epistemic frame itself. These findings – and future studies investigating reflective engineering design practica and the development of the engineering epistemic frame – can shed light on how to better prepare undergraduates to transition smoothly and successfully from the classroom to the workplace.

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Engineering girls gone wild: Developing an engineering identity

in the Digital Zoo

Presented at the

International Conference of the Learning Sciences

Citation:

Svarovsky, G. N., & Shaffer, D. W. (2006). Engineering girls gone wild: Developing an engineering identity in Digital Zoo. Paper presented at the International Conference of the Learning Sciences (ICLS), Bloomington, IN.

The "incredible shrinking pipeline" (Camp, 1997) of women engineers – the decreasing number of women graduating with bachelors degrees in engineering – is attributed in part to girls being unable to envision themselves as successful engineering professionals. Initiatives such as "Introduce a Girl to Engineering Day" and the "Engineering Girl!" website (www.engineergirl.org) provide young women with information about the profession, but do little in the way of engineering identity development.

Here, we examine a different approach to helping girls see themselves as engineers. In the Digital Zoo *epistemic game* (Author, in press), middle school girls work as engineers by engaging in activities modeled after an undergraduate engineering design course. In this poster, we analyze how gameplay based on the profession of engineering can foster the development of engineering identity in young women.

Theoretical Framework

Becoming an engineer means developing the *epistemic frame* (Author, in press) of engineering – the particular combination of skills, knowledge, values, identity, and epistemology that characterizes the profession. Like most professionals, engineers develop this frame in a practicum: a structured learning environment in which new members of a profession work on authentic problems under the guidance of an experienced mentor. The theory of *epistemic games* (Author, in press) suggests that a game which simulates the conditions of a professional practicum – such as an engineering design course – can help young players develop the epistemic frame of a profession. Designing such a game requires a detailed understanding of how the curriculum, tools, and interactions contribute to the development of the epistemic frame in the professional practicum.

In this study, we look at a key element of an epistemic frame, professional identity, and how it is cultivated both within an epistemic game and in the professional practicum on which it is based. Specifically, we investigate how undergraduates in an engineering design course and the players in Digital Zoo come to see themselves as engineers. We ask: 1) whether conducting an ethnographic study of an engineering practicum uncovers salient processes through which an engineering identity is developed; 2) whether creating and implementing an epistemic game for girls based on these results help them develop an engineering identity, and 3) whether the process of professional identity development for the students in the practicum and girls in the epistemic game is similar.

Methods

Ethnographic study

An ethnographic study was conducted on Biomedical Engineering (BME) 201, a design course at a large Midwestern state university. During the semester, sophomore engineering students work in teams on actual design problems from external clients. Data was collected in observational field notes, individual interviews with professors, and three focus groups. Data was analyzed within a grounded theory framework (Strauss & Corbin, 1998).

Epistemic game

The design of Digital Zoo was based on the ethnographic study of BME 201. In the game, students develop wire-frame prototypes of ambulatory characters for an upcoming animated film within a computational spring-mass modeling environment. At the end of each week, formal design reviews are held with external engineering experts who provide players with input and feedback on their designs.

In the summer of 2005, seven middle school girls played Digital Zoo during a three-week summer program. Six of the players were students of color. Clinical pre- and post-interviews with the players were transcribed and analyzed within a grounded theory framework.

Results

BME 201 undergraduates developed an engineering identity

One emergent theme from the focus group data was the development of engineering identity throughout BME 201. Of the 12 focus group participants, 10 (83.3%) responded positively to the question "Do you feel like an engineer?", and 7 of 12 (58%) students linked their engineering identity to client interaction. In addition, there was a statistically significant correlation between student references to client interaction and receiving client feedback ($r = 0.85$, $p<0.01$). For example, in response to the "Do you feel like an engineer?" question, one student said:

> Yeah, I do, especially when talking to the client. Coming in [to their office] and asking them to see what to do is helpful. A lot of [engineering] comes down to communication with the client.

In other words, meeting with the external client and receiving feedback on their design work were essential to the process of engineering identity development for the undergraduates.

Digital Zoo players developed an engineering identity

The number of Digital Zoo players who indicated they had thought of themselves as engineers increased from pre- (2/7, 29%) to post-interview (7/7, 100%, $p<0.01$), with all players responding positively to the "Have you ever thought of yourself as an engineer?" question in the post-interview. Five players (71%) linked their engineering identity to external expert interactions. In addition, there was a statistically significant correlation between player references to expert interaction and receiving expert feedback ($r = 1.00$, $p<0.01$). For example, when asked whether she had ever thought of herself as an engineer in the post-interview, one student responded, "Yeah, during Digital Zoo." When asked when specifically she felt like an engineer, she replied:

> Like the [Friday] presentations and the presentation at the end. That was when I saw myself as an engineer…I liked presenting my things and showing everybody what I made… I learned that there were things I could change about [my designs] because they like they had certain things to say about it – like some things worked better than like another thing… so then I could like… make mine even better.

In other words, meeting with the external engineering experts and receiving feedback on their virtual creatures were essential to the process of engineering identity development for the Digital Zoo players.

Discussion

Both the undergraduates in BME 201 and the players in Digital Zoo developed an engineering identity, and interacting with clients or experts external to the learning environment contributed to that development. Moreover, the significantly high correlations between client/expert interaction and client/expert feedback suggest that it was not only the external interaction, but also the content of the interaction, that impacted both groups.

The close alignment between the engineering identity development experiences of the BME 201 undergraduates and the Digital Zoo players suggests that: 1) conducting an ethnography of an engineering design course is a useful way to uncover the salient activities and interactions that contribute to professional identity development, 2) designing and implementing an epistemic game based on this ethnographic study can help middle school girls develop and cultivate an engineering identity, and 3) the processes of identity development for epistemic game players and practicum students were, in fact, similar. Thus, by helping girls see themselves as engineers, epistemic games such as Digital Zoo are potentially powerful and transformative tools for addressing the lack of women in engineering.

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APPENDIX B: Game Guide Used During Digital Zoo

This appendix contains the first week of the game guide, or "playbook", used by the design advisors in Digital Zoo. Each design advisor was trained in how to use the playbook, which provided prompts and logistical information essential to the flow of the game. The second week of the game followed the structure of the first week, and therefore the structure of the playbook was quite similar to the playbook sample presented here.

Monday, June 19th
Design Briefing: Welcome and Intro

Welcome

- Role playing game – work as engineers
- Kids go around and introduce themselves
- Rationale for interviewing
    - in order to figure out what you learn in digital zoo
    - we would like to have a conversation with you
    - we'll ask you some questions about things like science and engineering
    - some stuff will sound really weird or you might not have ever heard of some of the things we ask – AND THAT IS OK!
    - because some of the questions are about stuff we'll do in the game.
    - we're just interested in how and what you're thinking
    - so it's totally ok to guess!
- Interviewers introduce themselves
- Logistics for interviewing
    - 7 to go now, 8 to follow
    - 8 staying back: work on Personal Posters

Monday, June 19th	
8:00	**welcome and intro**
8:10	pre-interviews (7)
8:55	pre-interviews (8)
10:00	break
10:15	present posters
10:30	design briefing
10:45	assign teams/ intro brainstorming
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

<u>Personal Posters</u> *Materials: large post-its, markers* Draw example sheet on board Divide sheet into 4 quadrants, and without words, describe: • hobbies/interests (top left) • other plans this summer (top right) • favorite movie or TV show (lower left) • favorite food (lower right) ** Take pictures (headshots) of these 8 kids for ID badges	

Monday, June 19th
Pre-Interviews

Seven players to interview with:
Gina
Aran
Ashley
Mike
Erik
Janelle
Heather

Michelle: stay back w/8 players

- facilitate w/posters
- take head shots of these 8 w/digital camera
- take head shots of players being interviewed as they return from interviews
- give returning players materials for posters
- send 1st done w/poster w/ returning interview.
- Continue as needed.

Laura S will join us to do one interview.

- When she arrives, please give her an interview packet, pen, and recorder and send her out w/a kid.

When all interviews are done, take 15 min snack break.

Team: whoever's done w/2 interviews, set up snack outside or in lobby if weather is bad.

- Ashley: collect all protocols
- Mike and Erik: collect all recorders.

Monday, June 19th	
8:00	welcome and intro
8:10	**pre-interviews (7)**
8:55	**pre-interviews (8)**
10:00	**break**
10:15	present posters
10:30	design briefing
10:45	assign teams/ intro brainstorming
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

Monday, June 19th
Design briefing: Present posters

Poster presentations

- hang posters on the wall
- each player to present
- if lots of time, hang posters, use post-its on posters to place guesses from everyone on quadrants, then presentations

Monday, June 19th	
8:00	welcome and intro
8:10	pre-interviews (7)
8:55	pre-interviews (8)
10:00	break
10:15	**present posters**
10:30	design briefing
10:45	assign teams/ intro brainstorming
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

Monday, June 19th
Design briefing: Overview

Game overview
Video Camera ON!

Engineering – what is it?

Does anyone know an engineer? What does he/she do?

Overview of DZ:

- group of biomechanical engineers
- work on designing "character prototypes" for an upcoming animated film
- working w/DAs and engineering experts (will come in to critique work)

Clips of A Bug's Life

First thing: engineers work in teams and BRAINSTORM ideas

Monday, June 19th	
8:00	welcome and intro
8:10	pre-interviews (7)
8:55	pre-interviews (8)
10:10	break
10:15	present posters
10:30	**design briefing**
10:45	assign teams/ intro brainstorming
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

Monday, June 19th
Design briefing: Intro brainstorming

So what do you think brainstorming is?

Have you done it before?

Here we will do it as engineers do it

- engineers think of their own ideas first and write them down.
- then they share them within their teams
- then they narrow down the team's list of ideas
- and then make their final decision.

So, today we will practice brainstorming by coming up with a team name and logo.

does everyone know what a logo is?

what is an example of a logo?

what are some things that you should think about when making a team logo?

ok, so here is what we're doing today:

- everyone will take a few

Monday, June 19th	
9:00	welcome and intro
9:10	pre-interviews (7)
9:35	pre-interviews (8)
10:00	break
10:15	present posters
10:30	design challenge
10:45	**assign teams/ intro brainstorming**
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

minutes to think of ideas for the team name and logo, and write them down silently on the paper in our folders • then we will share them in our teams. we will write down everyone's ideas on our sheets. • and then we will decide on which ideas to keep • then we will talk about them a little more to decide which name and logo we will have for our team. Aran: Write steps on board: • Get together • Each person shares 1-2 ideas for name and logo • everyone records ideas on paper • Decide as team on name and logo	

Monday, June 19th Brainstorming session (in teams)

Break into teams
Hand out player folders
1 DA per team

DAs: check in w/team – no iPods today

- **What ideas have you come up with?**
- **Are you having trouble with anything?**
- **Please make sure you're writing down all of the team's ideas on the engineering paper in your folders.**

Points to emphasize:

- *provide suggestions for team names and logos if needed.*
- *make sure they write "brainstorming" on top of their sheet, and the date. (prepping them for notebooks tomorrow)*

Monday, June 19th	
9:00	welcome and intro
9:10	pre-interviews (7)
9:55	pre-interviews (8)
10:00	break
10:15	present posters
10:30	design briefing
10:45	assign teams/ intro brainstorming
11:00	**brainstorming**
11:10	team name, poster
11:30	team presentations
11:45	wrap up and preview

Monday, June 19th
Team Name and Logo Posters

Hand out 2 large post its and markers

One post-it is for the team name
The other is for the logo.

teams create team posters

Monday, June 19th	
8:00	welcome and intro
8:10	pre-interviews (7)
8:55	pre-interviews (8)
10:00	break
10:15	present posters
10:30	design briefing
10:45	assign teams intro brainstorming
11:00	brainstorming
11:10	**team name, poster**
11:30	team presentations
11:45	wrap up and preview

Monday, June 19th **Team Poster Presentations**	
How did you come up with your name? Your logo?	

Monday, June 19th	
8:00	welcome and intro
8:10	pre-interviews (7)
8:55	pre-interviews (8)
10:00	break
10:15	present posters
10:30	design briefing
10:45	assign teams/team brainstorming
11:00	brainstorming
11:10	team name & poster
11:30	**team presentations**
11:45	wrap up and preview

Monday, June 19th
Wrap up and preview tomorrow

Any questions about today?

Monday, June 19th	
8:00	welcome and intro
8:10	pre-interviews (7)
8:55	pre-interviews (8;
10:30	break
10:15	present posters
10:35	design briefing
10:45	assign teams for brainstorming
11:00	brainstorming
11:10	team name, poster
11:30	team presentations
11:45	**wrap up and preview**

Tuesday, June 20
Design Briefing: Welcome and Intro

Welcome back!

Tuesday, June 20	
8:00	**Design briefing, overview day**
8:15	Physical activity: marshmallows and straws
8:30	Design briefing: introduce SC
8:45	design problem 1
9:00	Design briefing: introduce notebook
9:15	Design time
9:30	Design meeting
9:45	Documentation time
10:00	Break
10:15	Design briefing: design problem, brainstorm design ideas
10:30	Design time
10:45	
11:00	Design meeting
11:15	Design briefing
11:30	(Documentation time)
11:45	Wrap-up and preview tomorrow

Tuesday, June 20
Physical Activity

Materials: 1 building kit per team jumbo marshmallows, straws, scissor, and newspaper to cover table

Design problem
Make a structure that can support a notebook placed on top of it.

Spread out, one DA per team.

Points of emphasis when assisting players

- cross-bracing
- additional supports
- small tests during design, etc.

Go to whole group – look at designs, test in front of whole group.

Emphasize during group discussion:

- cross-bracing
- additional supports
- small tests during design

Tuesday, June 20	
8:00	Design briefing: overview day
8:15	**Physical activity: marshmallows and straws**
8:30	Design briefing: introduce SC
8:45	design problem 1
9:00	Design briefing: introduce notebook
9:15	Design time
9:30	Design meeting
9:45	Documentation time
10:00	Break
10:15	Design briefing: design problem, brainstorm design ideas
10:30	Design time
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Tuesday, June 20
Design briefing: Introduce SC

Overview computer rules

- monitors off, hands off keyboards and mouse when not in use

Ground Rules for Interactions w/DAs

- can call over team DA if needed - anytime
- team DA might come talk to you just to see how it's going
- these conversations will be recorded, just to help us figure out how we (the DAs and project leaders) are doing
- we might also use them to help us understand how you learned something!

Go to SC website – Gina to talk through

MIKE TO DEMONSTRATE ON PODIUM COMPUTER

- log in
- go over different modes
- go over saving
- VERY IMPORTANT: save every design before "simulating"
- VERSIONING procedure: save as name1, name2, etc.

Tuesday, June 20	
8:00	Design briefing, overview day
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Tuesday, June 20
Design problem 1

Design problem 1

build anything that stands up when you simulate

DAs: check in w/players as needed

TURN IPODS ON AT BEGINNING OF SESSION

Points of emphasis when assisting players

- *provide suggestions – cross-bracing, additional supports*
- *remind of VERSIONING procedure*

TURN IPODS OFF AT END OF SESSION

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Tuesday, June 20
Design briefing: Introduce notebook

Share thoughts on design problem 1

- Can someone share with us what worked while you were working in SC?
- What were people having trouble with?
- What were you trying to do at the time

Introduce design notebook

- Why do you think engineers keep notebooks?
  - it helps us keep all of our ideas and all of our thinking in one place
  - it helps us remember what we were trying to do
  - it helps us remember what worked, and what didn't
  - if another engineer was going to start working on our project, it would help her/him understand what we've already done – so she/he wouldn't have to start from scratch.
- What do you think engineers put in their notebooks?
  - ideas
  - pictures/sketches
  - notes about what went wrong, and what went right
  - notes about stuff to think about
  - notes about what they're doing next.

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• Let's take a look at what our notebooks will look like. *again, gina to talk through, mike to demonstrate here on podium computer.* so, let's say mike wants to document his design process like a good engineer. • first, he opens his notebook. • he fills in his name • and then on the next page he writes down the description of the problem • what ideas the team came up with in brainstorming • and what ideas he is going to work on. then, when he starts working on SC, mike wants to talk about what he's doing in his design in his notebook. • first, he takes a screen shot – alt + PrintScreen. • then he pastes it into the notebook – control + v • then he writes down his thinking in the description • and writes down what his next step might be. then he goes back to SC and the cycle repeats. Now, you're going to try it! The design advisors will help you get started. Our second design problem is: Build a two-unit torso of different sizes	

Tuesday, June 20
Design Time 2

Design problem 2
Build a two-unit torso of different sizes

DAs:

- help kids open notebook and write name on first page.
- **TURN ON IPODS AT BEGINNING OF DESIGN TIME.**
- pull into quick brainstorming session (5 min)
- help players fill in notebooks.

Points of emphasis when assisting players

- cross bracing
- documenting in the notebook
- descriptions of work, and thinking during work in notebook
- next steps portion filled out in notebook

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Process measures – check in with individuals. **start about half way through time, or as appropriate.** 1. How's it going? What are you trying to do right now? 2. What are you having trouble with? 3. What have you done that seems to have worked? **Listen for:** • specifics! **TURN OFF IPODS AT END OF DESIGN TIME.**	

Tuesday, June 20
Design meeting 1

Project managers: announce Design Meeting, and explain procedures.

- discussion between teammates and DA
- time to share your ideas
- remember, you are working as a team to develop designs, so these meetings are really important to make sure you pool the hard work of your team!

Teams assemble, one DA talks with each team.

Process measures: IPODS ON!

1. Each of you talk about a design you're proud of, and why you are proud of it.
2. Each of you talk about what you had trouble with, and how you dealt with it.
3. How was the first time using the design notebook?

Listen for:

- specifics! ask clarifying questions if needed. or, "can you say more about that?"

IPODS OFF!

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10:00	Break
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Tuesday, June 20
Documentation time 1

Let's take a few minutes to catch up our notebooks…

Erik: get snack ready for transport.

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Tuesday, June 20
Break

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Tuesday, June 20
Design briefing

Share thoughts from team meeting

- best designs
- problems
- notebook

Present **Design Problem 3**: Design the tallest multi-unit torso possible, with at least three different units.

5-minute Brainstorm

Tuesday, June 20	
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Tuesday, June 20
Design time 3

Design Problem 3

Design the tallest multi-unit torso possible, with at least three different units.

IPODS ON!

Process measures – check in w/individuals

start about half way through time, or as appropriate.

1. Is your notebook helping you? how? How is it going? What are you doing right now?
2. What are you having trouble with?
3. Have you put that in your notebook? Can you show me your notebook? (do a quick spot check,
4. Is your notebook helping you? how?
5. If I were a new engineer working on your project, how would this notebook help me?

Listen for:

- specifics – how exactly was it helpful? when/where did you use it? etc.

Look for:

- descriptions of work, and thinking during work.
- next steps portion filled out

Tuesday, June 20	
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IPODS OFF!	

Tuesday, June 20
Design meeting 2

Teams assemble, one DA talks with each team.

Process measures: IPODS ON!

DAs:

1. What was the hardest part of doing this design?
2. Has our work today changed the way you think about being an engineer? How?

Listen for:

- Specifics
- opportunities to reinforce the importance of the notebook

IPODS OFF!

Tuesday, June 20	
8:00	Design briefing: overview day
8:15	Physical activity: marshmallows and straws
8:30	Design briefing: introduce SC
8:45	design problem [illegible]
9:00	Design briefing: introduce notebook
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Tuesday, June 20
Design briefing

Share thoughts from 2nd design time

Tuesday, June 20	
8:00	Design briefing: overview day
8:15	Physical activity: marshmallows and straws
8:30	Design briefing: introduce [illegible]
8:45	design problem 1
9:00	Design briefing: [illegible] to notebook
9:15	Design run
9:30	Design meeting
9:45	Documentation time
10:00	Break
10:15	Design briefing: design problem & brainstorm design ideas
10:30	Design time
10:45	
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Tuesday, June 20
Documentation time 2

Let's catch up our notebooks…

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Tuesday, June 20 Wrap up and preview			
		Tuesday, June 20	
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		11:45	**Wrap-up and preview tomorrow**

Wednesday, June 21
Design Briefing

Welcome back!

Head to computers – reminder to put snack away.

Before we get started on today, are there any questions from yesterday?

Today we're going to work with the concept of center of mass.

(Walk through agenda)

physical activity
design time
design meeting
documentation time
break
design time
design meeting
design evaluations
documentation time

Any questions?

Wednesday, June 21	
8:00	**design briefing**
8:15	physical activity: mobiles
8:30	design briefing: intro design problem 1 build a body that leans
8:45	brainstorm ideas
9:00	design time
9:30	design meeting
9:45	design briefing
10:00	documentation time and break
10:15	design briefing & brainstorming: problem 2 Design the tallest, multi-story body possible that leans
10:30	design time (individual check ins start at 10:45)
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Wednesday, June 21
Physical Activity
Mobiles

Materials: 1 mobile kit per team
long layer, 2 medium layers, 4 short layers
objects to hang

Design problem
Make a three-layered mobile using the materials provided. All layers should be horizontal and balanced by the end of the time allowed.

Spread out, one DA per team.

Points of emphasis when assisting players

-

Go to whole group

- how did you balance these layers?
- which side is heavier?
- how did you know where to move the "s" support?

balance point – that's what we call the "center of mass"

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Wednesday, June 21
Design Briefing
Intro design problem 1

So now, we're going to try to use the concept of CM in our designs.

First, how would we find the center of mass of an object, just by looking at it?

Janelle will help me demonstrate how to do this – through a technique called **graphical analysis**.

- *Janelle: Load CM1*
- *Open notebook*
- *cut and paste screen shot into notebook page.*

Ok, how do we figure out where the center of mass is?

Well, we're just going to estimate.

If you drew an imaginary, vertical line down the center, let's look at how many masses are to the left, and how many are to the right.

- *(Janelle, pls draw this line.)*

Ok, there's kind of an equal amount on either side. So from left to right, we know the CM is about halfway.

But how about from the top to bottom? How would we figure that out?

- *Draw a horizontal line, look at density above and below*

Wednesday June 21	
8:00	design briefing
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So where is the CM? • *Put marker on CM in notebook.* ok, this one was easy – since it was pretty much in the middle. But how about one like this? • *load CM2* • Go through graphical analysis here. Ok, now you are going to try to think about center of mass while you're working on our first design problem: design a body with at least three units that leans We'll start with a team brainstorm then go to our computers to work!	

Wednesday, June 21
Design Time 1

IPODS ON FOR DESIGN TIME

BEGIN WITH BRAINSTORM

Design problem:
design a body with at least three units that leans.

Points of emphasis when assisting players
SAY NAMES!

- locating center of mass
- where is center of mass relative to base

Process measures as appropriate
SAY NAMES
START NEW IPOD CHAPTER IF POSSIBLE

1. How's it going? What is the name of the design you're working on now?
2. What are you having trouble with? (can you say more about that? what in particular about that?)
3. What ideas have you already tried to deal w/the problem? (can you tell in what specifically you did? how is this one different than the one before?)
4. How did you get that idea?

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Did we do an activity that helped you come up with that idea? **Listen for** • specific things they're having trouble with • specific strategies they've used to try to deal w/it	

Wednesday, June 21
Design Meeting 1

Logistics:
Have players email you a design they are/were having trouble with about 3 min before starting the meeting. Open your email on a computer and open the message.

Talking points:

Ok, in this meeting we will help each other out. Here is P1's design (pull up on machine).

1. P1, can you talk about what you were trying to do with this design? What part of it is giving you trouble?
2. What ideas have you tried to deal with it?
3. (to rest of team) each of you think of one way P1 might improve her design. Please tell us your idea, and talk about why you think it will work or how you think it will help.

Repeat w/each player showing design.

Listen for:
- specific things they're having trouble with
- specific strategies they've used to try to deal w/it
- trying to get other players to offer suggestions and

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justify their ideas • trying to get other players to come up w/different ideas – try going around in different orders.	

Wednesday, June 21
Design briefing

Erik – camcorder on

share designs – email one design per team to Janelle

Janelle to pull up on screen and we'll talk about them.

8:00	design briefing
8:15	physical activity: mobiles
[illegible]	design briefing: intro design problem 1 build a body that leans
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[illegible]	design time
[illegible]	design meeting
9:45	**design briefing**
10:00	documentation time and break
10:15	design briefing & brainstorming: problem 2 Design the tallest, multi-story body possible that leans
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Wednesday, June 21
Documentation time and break

finish up your documentation
please leave your SC windows open for break

Gina will load something in there.

load overturn on each machine if not already in acct

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Wednesday, June 21 **Design briefing:** **Introduce design alternatives**	
now for a different challenge – "floating arm" Design a body for this arm. The body can only attach to two points of the arm. The narrower the portion of the body touching the floor, the better! start w/brainstorm then go to computers	

8:00	design briefing
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Wednesday, June 21
Design time 2

IPODS ON DURING DESIGN TIME

BEGIN W/BRAINSTORM

Design problem:
Design a body for this arm. The body can only attach to two points of the arm. The narrower the portion of the body touching the floor, the better!

Points of emphasis when assisting players
SAY NAMES!

- locating center of mass
- where is center of mass relative to base

Process measures
SAY NAMES!
IPODS ON

1. How is it going? What are you doing right now?
2. Can you tell me about your design alternatives? How are they different from each other?
3. If I were a client, how would you convince me which design alternative was better?

Listen for

- specifics – shocking, I know

8:00	design briefing
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10:00	documentation time and break
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Wednesday, June 21
Design meeting 2

Logistics:
Have players email you two design alternatives if possible (or 1, if they only have 1) about 3 min before starting the meeting. Open your email on a computer and open the first message.

Talking points:

1. P1, can you talk about what you were trying to do with these designs? In what ways are they different? Why did you choose to make them different in those ways?

2. How did you feel about coming up with design alternatives? Can you say more about that?

3. Did coming up with design alternatives change the way you think about engineering? How?

Repeat w/each player showing designs.

Listen for:
- specific ways designs are different
- specific descriptions of how they felt about developing alternatives

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• specifics about how their feelings about engineering have changed	

Wednesday, June 21
Design briefing:
Introduce evaluations

share thoughts from team meetings

- how designs were different
- how it felt to come up with different design alternatives
- new ways of thinking about engineering?

ok, now we have 2 design alternatives. how do we figure out which one is better?

we test them through design evaluations!

today we will just do one evaluation on both designs:
the gravity test.

the way the gravity test works is this:

- your team will gather with your engineering paper around 1 computer with the DA.
- The DA will ask you what you think will happen in the design evaluation with each of your designs.
- the DA will measure how tall your design is (probably in cm or mm).

8:00	design briefing
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8:30	design briefing: intro design problem 1 [illegible]
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9:45	design briefing
10:00	documentation time and break
10:15	design briefing & brainstorming problem 2 Design the tallest, [illegible] teams
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• he or she will then raise the gravity to full strength, and remeasure your design. • the DA will then divide these numbers to get a percentage – and based on that, will give each design alternative a score. • everyone on the team will record everyone else's progress. remember, **we're working together!!** The scale works like this: 85%-100% = 5 70%-84% = 4 55%-69% = 3 40%-54% = 2 39% and below = 1 When the entire team is done, the DA will ask you a few questions, and then we'll write about what happened in our notebooks.	

Wednesday, June 21
Design evaluations with Design meeting

Logitstics:

Use designs sent to you for previous meeting.

IPODS ON!

(before evaluation)

1. Each of you talk about what you think will happen during the design evaluation for each of your design alternatives.

Run through Gravity Test with each player. make sure whole team records on their paper what's happening.

(after evaluation)

2. So, tell us about what happened. Was it what you expected, or not? Why do you think that happened?
3. What are some ideas you have to improve your designs?

IPODS OFF!

8:00	design briefing
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Wednesday, June 21
Documentation time

8:00	design briefing
8:15	physical activity: mobiles
8:30	design briefing: intro design problem 1 build a body that leans
8:45	brainstorm ideas
9:00	design time
9:30	design meeting
9:45	design briefing
10:00	documentation time and break
10:15	design briefing & brainstorming: problem 2 Design the tallest, multi-story body possible that leans
10:30	design time (individual check ins start at 10:45)
11:00	design meeting (team check in)
11:15	design briefing: intro evaluations
11:30	**design evaluations and documentation**
11:45	wrap up and preview tomorrow

Wednesday, June 21
Wrap up and preview tomorrow

Great work today!

Tomorrow we will work on our first problem from "the client".

This is in preparation for Friday, when we will present to engineering experts who will play the part of "the client".

8:00	design briefing
8:15	physical activity: mobiles
8:30	design briefing: intro design problem 1: build a body that leans
8:45	brainstorm ideas
9:00	design time
9:30	design meeting
9:45	design briefing
10:00	documentation time and break
10:15	design briefing & brainstorming: problem 2 Design the tallest multi-story body possible that leans
10:30	design time (individual check ins start at 10:45)
11:00	design meeting (team check in)
11:15	design briefing: intro evaluations
11:30	design evaluations and documentation
11:45	**wrap up and preview tomorrow**

Thursday, June 22
Design Briefing: recap

Welcome back!

Let's pick up where we left off yesterday – we kind of had to finish in a rush.

center of mass: review

balance point of an object

let's look at the floating arm.

where is the cm of the floating arm?

let's do our graphical analysis. – ***OPEN gina 6-22.ppt***

but let's make sure we all know the steps.

1. look at the arm from left to right. place a vertical line about half way from the left and halfway to the right.

2. more mass on the left or right? ok, the left. so we know the center of mass will be to the left of this line.

3. ok, now, look at the arm from top to bottom. place a horizontal line about half way from the left and halfway to the right.

4. is there more mass above or below the line?, ok, above. so we know the center of mass will be above this line.

5. and we know it will be to the left of

8:00	**Design briefing**
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

this line. 6. so now we can kind of estimate where it is – i think it'll be right around here. so now we had to build a body for this arm. the purpose of the body was to keep this part off the ground, and at the same height if possible. what were some ways that you did that? build below? build next to? build around? now, what I'd like you to do this morning is to take a short bit of time to finish up your designs alternatives from yesterday. but in your design notebooks, I want to you to do 2 things on every screen shot: • find the center of mass of your design • draw a box around the part of your design that is touching the "ground" – the bottom of the screen. • and what I want you to think about is what happens when the CM is somewhere above the base, and what happens when the CM is off to one side of the base area.	

Thursday, June 22
Design time 1 – finish up

Finish up designs from yesterday

Points of emphasis when assisting players:

- find the center of mass of your design
- draw a box around the part of your design that is touching the "ground" – the bottom of the screen.
- and what I want you to think about is what happens when the CM is somewhere above the base, and what happens when the CM is off to one side of the base area.

**If players are already done with several design alternatives, emphasize the importance of the notebook and documentation, and point out ways they could improve their notebooks.

Process measures – check in with each player individually
IPODS ON!

1. How's it going? What are you stuck on?
2. Are you thinking any differently about center of mass today? How? (ok to give some clarification on CM here.)
3. Are you noticing anything about the center of mass how it relates to the base?

8:00	Design briefing
8:15	**Design time 1 – finish up our design alternatives from yesterday.**
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Design meeting 1

Logistics:
Have players email you the design alternative that was/is the most difficult to balance about 3 min before starting the meeting. Open your email on a computer and open the first message.

Questions:
IPODS ON!

4. P1, can you talk about how you tried to balance this design?

5. Did you think about center of mass at all when you were trying to balance it out? If so, how?

6. To team – what are some different ways P1 could have balanced this design, or made her design work better?

7. Did coming up with design alternatives change the way you think about engineering? How?

Repeat w/each player showing designs.

Listen for:
- specific ways designs are different
- specific descriptions of how they felt about developing alternatives
- specifics about how their feelings about engineering have changed

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday
8:30	**Design meeting 1**
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Design briefing

share ideas from design meeting

So what did you learn in your design meetings with your team?

What are some ways you can balance your SodaConstructions?

Did anyone figure out where the CM has to be in relation to the base?

Good work finishing up from yesterday!

OK, so now we're going to switch gears and look at what's coming up the rest of the day.

In a few minutes we'll look at a "problem statement" from a client. This will tell us what the client is looking for in particular, with respect to specific characters for a specific scene.

Then we'll work on each designing 2 design alternatives to the problem. We'll have a couple of meetings in there to check in.

At the end of the day, we will share our work with each other in a team presentation. Here's how those will work:

You will go up to the front with your team, and each of you will show your 2 design alternatives.

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	**Design briefing – share ideas from design meeting**
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

I would like each of you to say 2 things when it's your turn: • How you tried to make the 2 alternatives different from each other, and • which one you think the client will like better, and why. REMEMBER, IT'S OK TO GUESS!! We haven't really talked to clients yet so it's hard to imagine what they might say. But just try to put yourselves in their shoes and think about what they would like to see. Those presentations will start around 11:15, just so you can budget your time.	

Thursday, June 22
Design briefing: introduce client problem statement

So here is the problem statement from the client.

hand out client statement

give time to read through

what do the clients want?

character prototypes like P.T. Flea

body w/several arms extended

maybe movement – but start w/static (non-moving) body prototypes.

Client expectations

- each engineer will produce at least 2 design alternatives
- those designs will be evaluated to determine which one is better
- each team will present their work to the "clients" – who are really engineering experts – tomorrow.
- in these presentations, you will want to show your client how you developed your design ideas, and in the end you want to be able to recommend ONE design alternative to them.

We'll start with a team brainstorm session… and then get to work.

Before you meet as a team, you'll want to come up with at least 2 ideas of your own first!

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	**Design briefing: Introduce client problem statement**
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Design Time 2

IPODS on!

brainstorming:

Each player should come up with 2 design ideas on their own to develop – then team brainstorm.

Points of emphasis when assisting players:

- start with short, simple arms first! always easier to build out.
- Is this what the client wants?
- think about where the center of mass is of your character. where is it in relation to the base?

Process measures
SAY NAMES!!!

1. How's it going? Are you getting stuck anywhere? Can you tell me what you're having trouble with?
2. Are you sticking with your original design ideas, or have they changed? If so, how? What made you change your ideas?
3. How do you think this design will satisfy what the client wants? How do you know?

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	**brainstorm ideas**
9:30	**design time 2**
9:45	
10:00	
10:15	design meeting
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Design meeting 2

Logistics:
Have players email you one design alternative they would like help or feedback on about 3 min before starting the meeting.

At this point, we hope that they have at least completed one and have started the 2nd.

Open your email on a computer and open the messages from P1 one at a time..

Questions:
IPODS ON!

1. Ok, here is a design from P1. P1, can you tell us about what you are trying to do with this design?
2. What specifically would you like help with?
3. (go around to each player) What would you suggest here? What ideas can you give P1? How did you come up with that idea?

Repeat w/each player showing designs.

Listen for:
- specific ways designs are different
- specific descriptions of how they felt about developing alternatives
- specifics about how their feelings about engineering have changed

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	**design meeting 2**
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Documentation time and break

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: Introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting 2
10:30	**documentation time and break**
10:45	design time 3
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
design time 3

coming back from break
let's quickly check in with each other
what seems to be working?

can someone tell us about a problem they were having, and how they were able to fix it?

ok, so now we're going to head back to our computers…

**Remember, we will show our designs to each other beginning at 11:15.

You will go up to the front with your team, and each of you will show your 2 design alternatives.

I would like each of you to say 2 things when it's your turn:

- How you tried to make the 2 alternatives different from each other, and
- which one you think the client will like better, and why.

REMEMBER, IT'S OK TO GUESS!! We haven't really talked to clients yet so it's hard to imagine what they might say. But just try to put yourselves in their shoes and think about what they would like to see.

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting 2
10:30	documentation time and break
10:45	**design time 3**
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Team presentations

ERIK: WE MUST VIDEO RECORD THIS!!

Logistics:
About 3 min before we start, each team should fill out the Presentation Grid – which has 3 columns for name, SC login, and name of design.

Ashley will start SodaConstructor Local, which is to the right and slightly below where you hit "click here to play". In this application you can view designs w/login and design name. Ashley will stay up at the computer to help transition the kids.

We'll go team by team, and person by person. Each person will show their 2 designs, and talk about:

- How you tried to make the 2 alternatives different from each other, and
- which one you think the client will like better, and why.

8:00	Design briefing
8:15	Design time 1 – finish up your design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting 2
10:30	presentation time and break
10:45	design time 3
11:00	
11:15	**team presentations**
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 22
Design meeting 3

Gather in teams and debrief about the presentations.

IPODS ON!

1. How did the presentations go? How did you feel about doing them?

2. How did it feel to show your work to the rest of the engineers?

3. Did you learn anything today? If so, what? Did we do something in particular that helped you learn that?

IPODS OFF!

8:00	Design briefing
8:15	Design time 1 – finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing – share ideas from design meeting
9:00	Design briefing: introduce [illegible] problem [illegible]
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting 2
10:30	documentation time and break
10:45	design time 3
11:00	
11:15	
11:30	**design meeting**
11:45	wrap-up and preview

Thursday, June 22 wrap up and preview	
go over schedule for tomorrow design evaluations prepare presentations practice give presentations	

8:00	Design briefing
8:15	Design time 1 -- finish up our design alternatives from yesterday.
8:30	Design meeting 1
8:45	Design briefing - share ideas from design meeting
9:00	Design briefing: introduce client problem statement
9:15	brainstorm ideas
9:30	design time 2
9:45	
10:00	
10:15	design meeting 2
10:30	documentation time and break
10:45	design time.
11:00	
11:15	
11:30	design meeting
11:45	**wrap-up and preview**

Friday, June 23
Time to finish work

- finish up your design alternatives
- if you need to, you can focus on 1 and make it good
- but at 8:45 we will 'evaluate' our designs, so you have to be ready at that point.

IPODS ON!

At 8:45, have your engineers send you their design alternatives. We can't extend the time!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Design briefing

Today we will two design evaluations on our design alternatives:
the stability test, and the reliability test.

We'll do both of these in our teams.

In the **Stability Test**, we will open each of your designs. Then,

- the DA will measure how tall your design is (probably in cm or mm).
- he or she will then increase the gravity to 50% strength (halfway up the "g" scale), and remeasure your design.
- the DA will then divide these numbers to get a percentage – and based on that, will give each design alternative a score.
- You should write down your scores and cheer on your other teammates' designs!

The scale works like this:

85%-100% = 5
70%-84% = 4
55%-69% = 3
40%-54% = 2
39% and below = 1

For the Reliability Test, we will reopen all of your designs. Then,

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	**Design briefing – introduce design evaluations**
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

• the DA will delete 1 spring at a time, up to 5 springs total. • once the structure collapses to below half its height, the DA will stop. Scoring for this evaluation will be: 5 springs deleted = 5 4 springs deleted = 4 3 springs deleted = 3 2 springs deleted = 2 1 springs deleted = 1 • You should write down your scores and cheer on your other teammates' designs! So we'll gather in our teams • bring your paper and pencil to write down your scores • the DA will ask you what you think will happen with your designs • they will run the evaluations • you and your team will talk about what happened, and brainstorm ways to improve your designs • and then we'll switch!	

Friday, June 23
Design evaluations and meeting

IPODS ON!

Logistics:
gather team
open first design from P1

(before evaluation)

4. What do you think will happen to this alternative during these design evaluations?

*Run through **Stability Test** and **Reliability Test** with P1, design alternative 1.*

(after evaluation)

5. So, why do you think that happened?

6. Does anyone have any suggestions to improve P1's design? (How/why would that make it better?)

Repeat w/ P1's design alternative 2, and then with rest of team.

When you're done running your team's evaluations, have the engineers go back to their computers and make a notebook page with their results.

IPODS OFF!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	**design evaluations and design meeting**
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Finish documentation/design matrix

Ok, now that we're done with that, how would we compare our two designs?

Engineers sometimes use this thing called a design matrix!

Post up **designmatrix 2006.ppt** on projector

we can:

- record our scores
- add across the row
- compare the totals – whichever design scores higher, that's the better design!

Here's your matrix. (pass them out)

Make sure you put the names of your designs in the boxes on the left. Put in your scores and see which one of the alternatives that you developed might be better for the client!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	**finish documentation/matrix**
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Prepare presentations

ok, it's time to prepare our presentations - the DAs will help you.

DAs:

- FIND AN UNUSED COMPUTER TO WORK ON if at all possible.
- you start sitting at the computer
- open your email
- download "designpresentation1 2006.ppt"
- open it
- and walk through the template with your team.

(while you are doing this, Gina and Aran will copy notebooks to flash drives for transport to team computer)

Once your notebooks are all on the computer you're working on, then you can begin putting your presentation together. The DA will help as needed.

DAs: please have your team fill out the presentation grid as we did yesterday – and check if what they've written is correct during the practice presentations!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	**prepare presentations**
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Practice presentations

practice going through slides

help kids write down talking points as they walk through slides

use index cards if needed!

CLIENTS MIGHT ASK ABOUT:

- How did you come up with those ideas?
- How do you know this one is better?
- Did your ideas change over time? How/why?
- Can you tell me about what happened during the design evaluations?
- Based on your design evaluations, is there anything you'd like to change about these designs?

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	**practice presentations**
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23 **Break** before going on break DAs – make sure to save presentation Gina and Aran will go to your machines w/the flash drives and pull them off during break and load them onto the podium computer.	

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	**break**
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Client Presentations

ERIK – WE MUST RECORD THIS!

We'll go team by team

all of you go up there and talk about your work

(Ashley, please run SodaConstructor local again)

then clients will comment

and then we'll switch teams!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	**clients arrive/presentations begin**
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 23
Design meeting

Gather team and go through presentation debrief.

IPODS ON!

1. So, how did that go?
2. How did you feel before the presentation?
3. How do you feel now?
4. Did doing the presentation change the way you think about engineering?
5. Did doing the presentation change the way you feel about yourself?

IPODS OFF!

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	**design meeting**
11:45	wrap up

Friday, June 23
wrap up

8:00	time to finish work from Thursday
8:15	
8:30	
8:45	Design briefing – introduce design evaluations
9:00	design evaluations and design meeting
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

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Monday, June 26
Design Briefing

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8:00	**Design briefing: overview day**
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC – example creatures, w/pairs of legs
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: explore w/pair of legs on fixed masses
10:45	
11:00	Design meeting – share ideas
11:15	Document
11:30	Design briefing – bring up folks to show
11:45	Wrap up and preview next day

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Welcome back! You girls did great on Friday.

This week, we will learn about how to make walking characters on SodaConstructor.

Today, tomorrow, and Wednesday, we will explore concepts having to do with "gait".

Then Thursday, we'll get another client problem statement.

And on Friday, we'll have another presentation for the clients.

So let's get the week started!

Does anyone know what the word "gait" means?

- the way someone/something is walking.

So today, we will start off with some "gait analysis" – we're going analyze how we're walking.

- lots of things are going on when you're walking
- stuff that you never think about because walking comes pretty naturally
- what I'd like each of you to do right now is think about all the things you have to do to walk.

- imagine you are standing still and walk to walk forward.
- **on your engineering paper,** take a minute to write out all the actions you have to take in

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</table>

order to take 6 steps – left, right, left, right, left, right. What did you come up with? Ok, first thing today we are going to focus on when one leg is touching the ground, and when it's in the air. In order to do that, we're going to get in our teams and watch each other walk. We have a "walking area" for each team set up out in the hallway, complete with a "start" and "stop" line. One person will be a "walker", and the other two engineers will be a "timer". • Walkers will start walking before the start line and past the stop line of the walking area, with a red bandana tied around Right ankle, and a blue bandana tied around left ankle. • one teammate will watch the **right leg (red bandana).** o Using the stopwatch, you start time when the walker crosses start. o you hit "split when the right leg next touches the ground. o you hit split when the right leg leaves the ground. o you hit split when the right leg touches the ground o you hit split when the right left leaves the ground o continue until the walker crosses the "stop" line. • the other teammate will watch the **left leg (blue bandana)**	

- Using the stopwatch, you start time when the walker crosses start. - you hit "split" when the left leg next touches the ground. - you hit split when the left leg leaves the ground. - you hit split when the left leg touches the ground - you hit split when the left left leaves the ground - continue until the walker crosses the "stop" line. When you're done, your DA will help you put your readings on a data sheet. Then we'll switch roles. The first walker will walk slow, the 2nd walker will walk normally, and the 3rd walker will walk kind of fast (but not too fast). *Any questions? your DA will be there to help you – oh yeah, and we're switching DAs this week.*	

Monday, June 26
Physical Activity: gait analysis

Materials: stopwatches (1 per person), masking tape (to mark begin and end of walking track), worksheets to record data.

Player roles:
- Walker: team member walking across the analysis area. wears red bandana on right leg, blue bandana on left leg.
- Timers: operate the stopwatches. one watches the right leg, the other watches the left leg.

Data collection:

- Walkers will start walking before the start line and past the stop line of the walking area, with a red bandana tied around Right ankle, and a blue bandana tied around left ankle.
- one teammate will watch the **right leg (red bandana).**
    - Using the stopwatch, you start time when the walker crosses start.
    - you hit "split when the right leg next touches the ground.
    - you hit split when the right leg leaves the ground.
    - you hit split when the right leg touches the ground
    - you hit split when the right left leaves the ground
    - continue until the walker crosses the "stop" line.
- the other teammate will watch the **left leg (blue bandana)**
    - Using the stopwatch, you start time when the walker crosses start.
    - you hit "split" when the left leg next touches the ground.
    - you hit split when the left leg leaves the ground.
    - you hit split when the left leg

8:00	Design briefing: overview day
8:15	**Physical activity: gait analysis**
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC – example creatures, w/pairs of legs
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: explore w/pair of legs on fixed masses
10:45	
11:00	Design meeting – share ideas
11:15	Document
11:30	Design briefing – bring up folks to show
11:45	Wrap up and preview next day

touches the ground o you hit split when the left left leaves the ground o continue until the walker crosses the "stop" line. DAs: • Help players understand roles. Assist with data collection as needed. • record splits onto worksheet. have girls read times off to you. • When finished collecting data, go to computer and enter numbers into "DZ gait analysis.xls". • Go to graphs. Show right leg, left leg, and then 2 together per player. Talk about how upwards lines are when foot is off floor, downward lines are when foot is on the floor.	

Monday, June 26
Design briefing: discuss different gaits

Gina – IPOD this, Aran – please record w/video camera.

- ok, how was that?
- Did you look at the graphs?
- Did you notice any patterns? (up/down lines)
- What did you notice about the graphs when you compared one person's walk to another? (skinnier peaks)
- How did things repeat?

Ok, so when you watch someone or something walking, the repeating pattern of movement is called a "gait cycle".

- consists of 2 parts – or phases:
- the "stance" phase, when a particular leg is in contact with the ground, and
- the "swing phase" – when that particular leg is in the air.

So on the graphs that you guys made, can someone tell me when the stance phase is happening? (downward lines)

How about the swing phase? (upward lines)

8:00	Design briefing: overview day
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Monday, June 26
Design briefing: intro gait analysis on SC

Ok, so now in our teams we are going to do some gait analysis on the dainty walker, trying to figure out its swing phase and stance phase.

You'll all sit around the DA's computer. Then, you'll open Sodaconstructor.

You'll see the daintywalker.

Go to construct mode, and then load the "daintywalker" in construct mode. (hit file, and you'll see it in the list.)

It should be frozen in time. Hand out "daintywalker key".

Each team will have a speaker, a timer, and a recorder.

- Using the key, the speaker will identify a "leg of interest" of the daintywalker in construct mode.
- when you go to simulate, the dainty walker will move to the left first. pay attention to the leg you're watching!
- once it hits the left wall, the timer will start your watch.
- when the leg of interest hits the ground, the speaker will say ON! – and the timer will hit the split button.
- when the leg of interest leaves the ground, the speaker will say OFF – and the timer will hit the split button.
- continue until the dainty walker hits the wall on the right side.
- timer should then read the split times off to the recorder.
- then, switch jobs, reload the daintywalker in construct mode, and observe a different leg.

8:00	Design briefing: preview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	**Design briefing: introduce gait analysis on SC**
9:15	Conduct gait analysis on SC – example creatures, w/pairs of legs
9:30	
9:45	
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: explore w/pair of legs on fixed masses
10:45	
11:00	Design meeting – share ideas
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11:45	Wrap up and preview next day

▪ When you're all done, your DA will help you put your stuff into an excel spreadsheet so you can see the graphs. We'll demonstrate here. Erik will be the timer I will be the speaker. Load dainty in construct watch leg 1	

Monday, June 26
Gait analysis on SC exemplars

DAs:

Help teams do gait analysis on 4 legs of dainty walker. Assist with roles as needed.

When done collecting data, compile into daintywalkergait.xls.

Show graphs – back legs, front legs, all legs

IPODS on!

Meet in team setting and discuss:

1. So let's look at the back legs here. Where do you think the swing phase and stance phase of each leg are?
2. And the front legs – where do you think the swing and stance phases are for each leg?
3. Do you notice anything when we look at all four legs together?
4. Do you think the daintywalker has a broken, uneven gait or a smooth, even gait? Why?

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	**Conduct gait analysis on SC – example creatures, w/pairs of legs**
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: explore w/pair of legs on fixed masses
10:45	
11:00	Design meeting – share ideas
11:15	Document
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11:45	Wrap up and preview next day

Monday, June 26
Documentation time and break

Ok, we've done a lot this morning!

Let's take some time to write about it in our design notebooks.

You won't fill out the "design ideas" page, but you'll want to

- have a page that talks about what you learned with the physical activity, and
- at least 1 page that talks about your gait analysis with the dainty walker.

Go to break

Janelle, stay back and help Gina import "legpair" to girls' sodaconstructor accts.

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
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9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC - example creatures, w/ pairs of legs
9:30	
9:45	Design meetings
10:00	**Documentation time and break**
10:15	Design briefing
10:30	Design time: explore w/pair of legs on fixed masses
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11:45	Wrap up and preview next day

Monday, June 26
Design briefing

ok, so now we are going to look at the first step in making a walking creature – trying to figure out how to make a pair of legs work.

when you go back to your computers, you will find a sodaconstructor design called "legpair" in your account. you'll want to load it.

It's two legs hanging from midair. We want you to try and play around with them to see how to make a pair of legs work.

(Show on podium computer)

So here is the muscle wave on SC.

To get things to move, you click on a spring, and drag it's marker up into the muscle wave. Like this.

START WITH ONE LEG FIRST, then work on both legs.

What we want you to think about as you explore is this:

1. where should you put the spring markers for one leg in order to get a smooth stride?
2. where should you put the spring markers for a pair of legs in order to get a smooth, even gait?
3. What does this bar on the side do?
4. What does the little dot on the marker do?

These are the questions that you should outline in your notebook, and then take screenshots of your attempts. Make sure to point out what you changed and how it affects the legs you are designing.

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC example creatures w/pair of legs
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	**Design briefing: developing a pair of legs on SC**
10:30	explore w/pair of legs on fixed masses
10:45	
11:00	Design meeting – share ideas
11:15	Document
11:30	Design briefing – bring up folks to show
11:45	Wrap up and preview next day

Monday, June 26
Design time: explore muscle wave

DAs:
Emphasize the exploration of these questions:

1. where should you put the spring markers for one leg in order to get a smooth stride?
2. where should you put the spring markers for a pair of legs in order to get a smooth, even gait?
3. What does this bar on the side do?
4. What does the little dot on the marker do?

Make sure players are documenting what they are doing – one change per notebook page!

Process measures: check in with each player individually
IPODS ON!

1. How's it going? Are you having trouble with anything? How have you tried to fix that?
2. How have you been trying to answer the questions that we're working on? Can you tell me about your process using Sodaconstructor to figure out how to do that?
3. Can you tell me about the swing phase and stance phase of one of these legs? How are these phases related to those of the other leg?

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC – examples [illegible] pairs of legs
9:30	
9:45	Design meeting
10:00	Demonstration time and break
10:15	Design briefing
10:30	**Design time: explore w/pair of legs on fixed masses**
10:45	
11:00	Design meeting – share ideas
11:15	Document
11:30	Design briefing – bring up folks to show
11:45	Wrap up and preview next day

Monday, June 26
Design meeting

Logistics:
Gina will have the players email you the pair of legs they have been designing about 2 minutes in.

Open P1's design.

1. P1, what do you like about these legs? What did you try with the muscle wave?
2. Is there anything you'd like to change about them? Or anything you need help with? (Ask other players for input/suggestions)
3. (if nothing to change/improve) Other players, how could you change the gait of these legs?

Repeat with other players.

When finished, return to computers and documentation. They will rely on these notes for the rest of the program – they need to make sure they are thorough!

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on [illegible]
9:15	Conduct gait analysis on [illegible] – example creatures, w/pairs of legs
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: experiment w/pair of legs on fixed masses
10:45	
11:00	**Design meeting – share ideas**
11:15	**Document**
11:30	Design briefing – bring up folks to show
11:45	Wrap up and preview next day

Monday, June 26
Design briefing

ok, so in our last meeting of the day – I'd like to take some volunteers to share some of their knowledge with the group.

first, who thinks they can answer the first question? come on up and show us!

go through a few options here.

second question?
please show us

third question?
please show us.

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
8:30	
8:45	Design briefing: discuss different gaits
9:00	Design briefing: introduce gait analysis on SC
9:15	Conduct gait analysis on SC - example on [illegible], a pair of legs
9:30	
9:45	Design meetings
10:00	Documentation time and break
10:15	Design briefing
10:30	Design time: explore a pair of legs on fixed machines
10:45	
11:00	Design meeting - share ideas
11:15	Document
11:30	**Design briefing – bring up folks to show**
11:45	Wrap up and preview next day

Monday, June 26
Wrap up and preview

8:00	Design briefing: overview day
8:15	Physical activity: gait analysis
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10:45	
11:00	Design meeting – share ideas
11:15	Document
11:30	Design briefing – bring up falls to show
11:45	**Wrap up and preview next day**

Tuesday, June 27
Design Briefing

Welcome back girls!

Great work yesterday on the gait analysis.

Yesterday, we did a bunch of "**research**" – figuring out what gait was, what the swing and stance phases were, how to make stuff work on SodaConstructor.

Today we are going to put our knowledge to good use – designing our first set of walking characters.

Can someone remind us what these terms mean?

- gait
- swing phase
- stance phase

For each triangle leg (2-spring leg), how far apart should you place the spring markers?

- ¼ of the wave apart

How do we change these things in Sodaconstructor?

- amplitude
- speed

Our first design problem is:

- design a 4-legged character that walks.
- the body should be only 1 unit – 1 shape.
- the character should demonstrate a smooth and even gait.
- the character should incorporate "repeating elements"

What do you think that means? ***repeating elements?***

8:00	**Design briefing: overview day**
8:15	**Introduce design problem 1: create a walker**
8:30	Brainstorm design ideas
8:45	Design time
9:00	
9:15	Design meeting
9:30	
9:45	Design briefing: highlight work
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Right – we use something we developed before and we know works well, and repeat it throughout the design. So, when we create our walkers, it ***might be helpful*** to start with yesterday's "legpair" design – and then building another suspended pair next to it. The design advisors can help you w/the fixed masses if you need it. This will help you get the timing down for a 4-legged thing. You should document this in your notebook. Then you can try to build a body with 4 legs and apply the timing you figured out with the suspended legs. So, just to recap: • we'll start with a brainstorm about our 4-legged characters. • when we start working, we should try to get the timing down with 4 suspended legs by building on what we did and learned yesterday. • then once we've got that part under control, we can work on making our 1-unit body w/4 legs.	

Tuesday, June 27 brainstorming

DAs

emphasize:

- SIMPLE bodies to start with – *simple shapes.*

As you break up your brainstorming session, **emphasize:**

- start with getting 2 suspended legs working, then add another pair of suspended legs
- get the timing down for the 4 legs, and make sure it's documented.
- then, move on to making a body w/4 legs
- and trying to get that to work.

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	**Brainstorm design ideas**
8:45	Design time
9:00	
9:15	Design meeting
9:30	
9:45	Design briefing: highlight work
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design time 1

Design problem 1:

- design a 4-legged character that walks.
- the body should be only 1 unit – 1 shape.
- the character should demonstrate a smooth and even gait.
- the character should incorporate "repeating elements"

Points of emphasis when helping players:

- start with getting 2 suspended legs working, then add another pair of suspended legs
- get the timing down for the 4 legs, and make sure it's documented.
- then, move on to making a body w/4 legs
- and trying to get that to work.

Process measures – check in with individuals.
IPODS ON!

4. How's it going? What are you trying to do right now?
5. What are you having trouble with?
6. What have you done that seems to have worked?
7. Have we done anything in particular (an activity or discussion) that has helped you think about how to solve your problem?

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	**Design time 1**
9:00	
9:15	Design meeting
9:30	
9:45	Design briefing: highlight work
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design meeting 1

Logistics:
Have players email you a design they are/were having trouble with about 3 min before starting the meeting. Open your email on a computer and open the message.

Talking points:

Ok, in this meeting we will help each other out. Here is P1's design (pull up on machine).

4. P1, can you talk about what you were trying to do with this design? What part of it is giving you trouble?

5. What ideas have you tried to deal with it?

6. Where have you used repeating elements in your design?

7. (to rest of team) each of you think of one way P1 might improve her design. Please tell us your idea, and talk about why you think it will work or how you think it will help.

Repeat w/each player showing design.

Listen for:
- specific things they're having trouble with
- specific strategies they've used to try to deal w/it
- trying to get other players to offer suggestions and justify their ideas
- trying to get other players to come up w/different ideas – try going around in different orders.

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time
9:00	
9:15	**Design meeting 1**
9:30	
9:45	Design briefing: highlight work
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design briefing

highlight work

talk about where repeating units can be helpful.

talk about suspending character from a fixed mass to get a look at the gait

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	**Design briefing: highlight work**
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Documentation time and break

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	Design briefing: [illegible] work
10:00	**Documentation time and break**
10:15	
10:30	Design briefing: design problem 2: create a cost-efficient walker, brainstorm ideas
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design briefing: design problem 2

our next design problems – finish one before moving on to the next one:

- 4-legged walker w/multi-unit body
- 6-legged walker w/3-unit body
- 8-legged walker w/4-unit body
- ***all with smooth, even gaits.***

(if these are already completed, then move on to making designs cost-effective and deleting unnecessary springs)

HIGHLIGHT THAT WE WILL HAVE TEAM PRESENTATIONS AT 11:30 – SHOWING THE DESIGN THEY ARE MOST PROUD OF AND TALKING ABOUT WHY.

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	Design briefing: highlight work
10:00	Demonstration time and break
10:15	
10:30	**Design briefing: design problem 2**
10:45	Design time
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design time 2

Next design problems – finish one before moving on to the next one:

- 4-legged walker w/multi-unit body
- 6-legged walker w/3-unit body
- 8-legged walker w/4-unit body
- ***all with smooth, even gaits.***

Points of emphasis when helping players:

- start simply!
- get the timing down for the 4/6/8 legs, and make sure it's documented.
- then, move on to making a body w/6/8 legs
- and trying to get that to work.

Process measures – check in w/individuals

IPODS ON!

6. How is it going? What are you doing right now?
7. Are you stuck on anything? What's been challenging or frustrating?
8. Is your notebook helping you today? how?
9. If I were a new engineer working on your project, how would this notebook help me?

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	Design briefing: highlight work
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2
10:45	**Design time 2**
11:00	
11:15	Design meeting
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27
Design meeting

Logistics:
Have players email you the design they are ***most proud of*** *with about 3 min before starting the meeting. Open your email on a computer and open the message.*

Process measures: IPODS ON!

DAs:
Open P1's design.

3. P1, why are you most proud of this design?

4. What was the hardest part of doing this design?

5. P2, what do you like best about P1's design? (repeat with each of the other players)

6. P1, is there anything you need help with on this design? (if so, ask team for suggestions.)

7. Has our work over the past 2 days changed the way you think about being an engineer? How?

Repeat with other players.

When finished with meeting, have girls fill out Presentation Grid for team presentations. They should show the design they are most proud of, and talk about why they like it.

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a walker
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	Design briefing: highlights [illegible]
10:00	Documentation time and break
10:15	
10:30	Design briefing: design problem 2
10:45	Design time 2
11:00	
11:15	**Design meeting**
11:30	Team presentations
11:45	Wrap up and preview next day

Tuesday, June 27 **Team presentations**	
Janelle to run SodaConstructor local Show the design you are most proud of – and tell us why you are proud of it. If you had a tough time with something, please share with us what you were having trouble with and how you were able to address the problem. As each one is shown: What do you girls like about this design?	<table><tr><td>8:00</td><td>Design briefing: overview day</td></tr><tr><td>8:15</td><td>Design briefing: design problem 1: create a walker</td></tr><tr><td>8:30</td><td>Brainstorm design ideas</td></tr><tr><td>8:45</td><td>Design time 1</td></tr><tr><td>9:00</td><td></td></tr><tr><td>9:15</td><td>Design meeting 1</td></tr><tr><td>9:30</td><td></td></tr><tr><td>9:45</td><td>Design briefing: highlight work</td></tr><tr><td>10:00</td><td>[illegible] on line and [illegible]</td></tr><tr><td>10:15</td><td></td></tr><tr><td>10:30</td><td>Design briefing: design problem 2</td></tr><tr><td>10:45</td><td>Design time 2</td></tr><tr><td>11:00</td><td></td></tr><tr><td>11:15</td><td>Design meeting</td></tr><tr><td>11:30</td><td>Team presentations</td></tr><tr><td>11:45</td><td>Wrap up and preview next day</td></tr></table>

Tuesday, June 27
Wrap up and preview

8:00	Design briefing: overview day
8:15	Design briefing: design problem 1: create a trailer
8:30	Brainstorm design ideas
8:45	Design time 1
9:00	
9:15	Design meeting 1
9:30	
9:45	Design briefing: highlight work
10:00	Documentation: notes and break
10:15	
10:30	Design briefing: design problem 2
10:45	Design time 2
11:00	
11:15	Design meeting
11:30	Design briefing: highlight work
11:45	**Wrap up and preview next day**

Wednesday, June 28
Design Briefing

Great work on the walkers yesterday!

Today we are going to start off with a little more gait analysis – like the first thing we did Monday.

Just to recap:

We have a "walking area" for each team set up out in the hallway, complete with a "start" and "stop" line. One person will be a "walker", and the other two engineers will be a "timer".

- Walkers will start walking before the start line and past the stop line of the walking area, with a red bandana tied around Right ankle, and a blue bandana tied around left ankle.
- one teammate will watch the **right leg (red bandana).**
  - Using the stopwatch, you start time when the walker crosses start.
  - you hit "split when the right leg next touches the ground.
  - you hit split when the right leg leaves the ground.
  - you hit split when the right leg touches the ground
  - you hit split when the right left leaves the ground
  - continue until the walker crosses the "stop" line.
- the other teammate will watch the **left leg (blue bandana)**
  - Using the stopwatch, you start

8:00	**design briefing**
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

time when the walker crosses start. o you hit "split" when the left leg next touches the ground. o you hit split when the left leg leaves the ground. o you hit split when the left leg touches the ground o you hit split when the left left leaves the ground o continue until the walker crosses the "stop" line. When you're done, your DA will help you put your readings on a data sheet, just like on Monday. Today, we're all going to walk like we have a bad leg injury – and we're limping. Choose which leg is hurt, tell your team, and record some data!	

Wednesday, June 28
Physical Activity

do the antalgic gait analysis

DAs:

- when you are finished collecting data, put numbers into "antalgic gait analysis.xls"
- look at the graphs

IPODS ON!
Questions:

1. Where are the swing and stance phases on each of these graphs?
2. How do these graphs similar or different from the graphs we did on Monday?

IPODS OFF!

When finished with questions and discussion, please have engineers go back to their computers and put a page in their notebook about the antalgic gait analysis.

8:00	design briefing
8:15	**physical activity: antalgic gait - limping**
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28 **Design briefing**	
debrief about antalgic gait – describe design problem 1: • design 2 design alternatives for a 4-legged walker with antalgic gait • each alternative should be demonstrate an antalgic gait in a different way. (i.e. you can't just remove one spring marker from the muscle wave for both of your designs.) Start with brainstorm – individual ideas then team.	

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	**design briefing: design problem 1**
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Brainstorming & Design Time 1

Individual then team brainstorming

IPODS ON!

Design problem:

- design 2 design alternatives for a 4-legged walker with antalgic gait
- each alternative should be demonstrate an antalgic gait in a different way. (i.e. you can't just remove one spring marker from the muscle wave for both of your designs.)

Points of emphasis when assisting players

- start simply! go with simple body shapes first

Process measures as appropriate
SAY NAMES and WRITE DOWN TIMES
START NEW IPOD CHAPTER IF POSSIBLE

5. How's it going? What is the name of the design you're working on now?

6. What are you having trouble with? (can you say more about that? what in particular about that?)

7. What ideas have you already tried to deal w/the problem? (can you tell in what specifically you did? how is this one different than the one before?)

8. How did you get that idea? Did we do an activity that helped you come up with that idea?

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	**Brainstorm design ideas**
9:00	**design time**
9:15	
9:30	design meeting
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design meeting 1

Logistics:
Have players email you a design they are/were having trouble with about 3 min before starting the meeting. Open your email on a computer and open the message.

Talking points:

Ok, in this meeting we will help each other out. Here is P1's design (pull up on machine).

8. P1, can you talk about what you were trying to do with this design? What part of it is giving you trouble?

9. What ideas have you tried to deal with it?

10. (to rest of team) each of you think of one way P1 might improve her design. Please tell us your idea, and talk about why you think it will work or how you think it will help.

Repeat w/each player showing design.

Listen for:
- specific things they're having trouble with
- specific strategies they've used to try to deal w/it
- trying to get other players to offer suggestions and justify their ideas
- trying to get other players to

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	**design meeting 1**
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

come up w/different ideas – try going around in different orders.	

Wednesday, June 28 Documentation time and break	

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
10:00	**documentation time and break**
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design briefing & brainstorm

additional design problems when first 2 design alternatives are finished:

- try to make another walker with a broken, uneven gait – without limping. what are other ways that you could have uneven gait?
- try to make a 6-legged walker with antalgic gait that has at least 3 units in its body.
- design an 8-legged walker with antalgic gait that has at least 4 units in its body.

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
9:45	design briefing: highlight work
10:00	documentation time and break
10:15	**design briefing: design problem 2, brainstorm design ideas**
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design time 2

IPODS ON DURING DESIGN TIME

BEGIN W/BRAINSTORM

Design problems: listed above

Points of emphasis when assisting players
SAY NAMES!

- repeating elements of design
- different ways to make antalgic gaits

Process measures
SAY NAMES!
IPODS ON

4. How is it going? What are you doing right now?

5. Can you tell me about your design alternatives (that you started to develop during design time 1)? How are they different from each other?

6. If I were a client, how would you convince me which design alternative was better?

Listen for

- specifics – shocking, I know

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
9:45	design briefing: highlight work
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	**design time 2**
10:45	
11:00	design meeting
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design meeting 2

Logistics:
Have players email you two design alternatives if possible (or 1, if they only have 1) about 3 min before starting the meeting. Open your email on a computer and open the first message.

Talking points:

8. P1, can you talk about what you were trying to do with these designs? In what ways are they different? Why did you choose to make them different in those ways?
9. P2, if you were a client, which of these would you choose, and why? (repeat with other players)

Repeat w/each player showing designs.

Listen for:

- specific ways designs are different
- justification by other players for why they would choose one over the other.

When finished, back to computers for documentation.

8:00	design briefing
8:15	physical activity: antalgic gait - limping
8:30	design briefing: design problem 1
8:45	Brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
9:45	design briefing: highlight work
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	**design meeting 2**
11:15	design evaluations
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design evaluations

Now we are going to do a cost analysis on our design alternatives.

In our teams, the design advisor will pull up each of your designs.

They will count how many springs and how many masses you have. (by deleting springs first then masses.)

Each spring will cost $100.

Each mass will cost $200.

They will calculate how much your design costs.

You should record the costs on your engineering paper.

Process measures:
After you run the cost analyses, ask each player:

1. Did you learn anything from the cost analysis?
2. Do you have any ideas on how to make your design less expensive?
3. (to others) do either of you have any suggestions for P1?

8:00	design briefing
8:15	physical activity: analogic gait - limping
8:30	design briefing: design problem 1
8:45	brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
9:45	design briefing: highlight work
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	**design evaluations**
11:30	design briefing: results and evaluations
11:45	wrap up and preview tomorrow

Wednesday, June 28
Design briefing/redesign time

put results of cost analysis in design notebook

identify ways to make designs less expensive

work on it as time allows.

8:00	design briefing
8:15	physical activity: analgic gait - limping
8:30	design briefing: design problem 1
8:45	brainstorm design ideas
9:00	design time
9:15	
9:30	design meeting
9:45	design briefing: highlight work
10:00	documentation time and break
10:15	design briefing: design problem 2, brainstorm design ideas
10:30	design time
10:45	
11:00	design meeting
11:15	design evaluations
11:30	**design briefing/redesign time**
11:45	wrap up and preview tomorrow

Wednesday, June 28 **Wrap up and preview**		
	8:00	design briefing
	8:15	physical activity: antalgic gait - limping
	8:30	design briefing: design problem 1
	8:45	Brainstorm design ideas
	9:00	design time
	9:15	
	9:30	design meeting
	9:45	design briefing: highlight work
	10:00	documentation time and break
	10:15	design briefing: design problem 2, brainstorm design ideas
	10:30	design time
	10:45	
	11:00	design meeting
	11:15	design evaluations
	11:30	design briefing: results and evaluations
	11:45	**wrap up and preview tomorrow**

Thursday, June 29
Design Briefing

Today we are going to start working on a new problem for the client – and we'll present our work to them tomorrow.

Each of you will

- choose one character of the 3 to work on
- develop 2 design alternatives for that character
- document your process in the design notebook

Team presentations at the end of the day – everyone has to show 2 design alternatives.

I would like each of you to say 2 things when it's your turn:

- How you tried to make the 2 alternatives different from each other, and
- which one you think the client will like better, and why.

Those will start at 11:15! Budget your time!

8:00	**Design briefing**
8:15	**Introduce client problem statement**
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Brainstorming

IPODS on!

Let's start with a brainstorming activity:

Hand out client problem statement – **get in teams.**

What do the clients want?

- three characters, each demonstrating a different gait
- a potential fourth character
- cost limit
- "ambulatory"

In teams:

- Come up with game plan – who's doing what.
- take a few minutes to come up with ideas for your character.
- P1 – what are your ideas?
- other players: please think of 1 idea to help P1 with her character.

8:00	Design briefing
8:15	Introduce client problem statement
8:30	**brainstorm ideas**
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Design time 1

IPODS on!

Points of emphasis when assisting players:

- start with short, simple bodies and legs! always easier to build out.
- *Is this what the client wants?*
- repeating elements

Process measures
SAY NAMES!!!

4. How's it going? Are you getting stuck anywhere? Can you tell me what you're having trouble with?

5. Are you sticking with your original design ideas, or have they changed? If so, how? What made you change your ideas?

6. How do you think this design will satisfy what the client wants? How do you know?

7. Have you thought about repeating elements while working on your design? How has/might that help you?

8:00	Design briefing
8:15	Introduce client, problem statement
8:30	brainstorm ideas
8:45	**design time 1**
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Design meeting 1

Logistics:
Have players email you the design alternative they are working on, having trouble with, or would like help or feedback on about 3 min before starting the meeting. They can send up to 2 design alternatives to get feedback from the group.

Open your email on a computer and open the messages from P1 one at a time..

Questions:
IPODS ON!

4. Ok, here is a design from P1. P1, can you tell us about what you are trying to do with this design?

5. What specifically would you like help with? What have you already tried?

6. (go around to each player) What would you suggest here? What ideas can you give P1? How did you come up with that idea?

Repeat w/each player showing designs.

Listen for:

- asking for help on specific parts – not just “it doesn’t work”

8:00	Design briefing
8:15	Introduce client problem statement
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	**design meeting**
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29 **Documentation time and break**		
	8:00	Design briefing
	8:15	Introduce client problem statement
	8:30	brainstorm ideas
	8:45	design time 1
	9:00	
	9:15	
	9:30	design meeting
	9:45	
	10:00	**documentation time and break**
	10:15	design briefing
	10:30	design time 2
	10:45	
	11:00	
	11:15	team presentations
	11:30	design meeting
	11:45	wrap-up and preview

Thursday, June 29
Design briefing

coming back from break
let's quickly check in with each other
what seems to be working?

can someone tell us about a problem they were having, and how they were able to fix it?

ok, so now we're going to head back to our computers…

**Remember, we will show our designs to each other beginning at 11:25.

You will go up to the front with your team, and each of you will show your 2 design alternatives.

I would like each of you to say 2 things when it's your turn:

- How you tried to make the 2 alternatives different from each other, and
- which one you think the client will like better, and why.

8:00	Design briefing
8:15	Introduce client problem statement
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	**design briefing**
10:30	
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Design Time 2

continue to give feedback and assistance as needed.

IPODS ON!
Process measures
SAY NAMES!!!

1. How's it going? Are you getting stuck anywhere? Can you tell me what you're having trouble with?
2. How do you think this design will satisfy what the client wants? How do you know?
3. Do you think you are approaching your design work for the client differently this week than last week?
   a. How so?
   b. Did we do anything in particular that made you change the way you do something?

8:00	Design briefing
8:15	Introduce client problem statement
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Team presentations

ERIK: WE MUST VIDEO RECORD THIS!!

Logistics:
About 3 min before we start, each team should fill out the Presentation Grid – which has 3 columns for name, SC login, and name of design.

Ashley will start SodaConstructor Local, which is to the right and slightly below where you hit "click here to play". In this application you can view designs w/login and design name. Ashley will stay up at the computer to help transition the kids.

1. P1, can you talk about what you were trying to do with these designs? In what ways are they different? Why did you choose to make them different in those ways?

2. How did you feel about coming up with design alternatives? Can you say more about that?

Repeat w/each player showing designs.

Listen for:
- specific ways designs are different
- specific descriptions of how they felt about developing alternatives
- specifics about how their feelings about engineering have changed

8:00	Design briefing
8:15	Introduce client problem statement
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
Design meeting 3

Gather in teams and debrief about the presentations.

IPODS ON!

4. How did the presentations go? How did you feel about doing them?

5. How did it feel to show your work to the rest of the engineers?

6. Did you learn anything today? If so, what? Did we do something in particular that helped you learn that?

IPODS OFF!

8:00	Design briefing
8:15	Introduce client problem statement
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Thursday, June 29
wrap up and preview

8:00	Design briefing
8:15	Introduce client problem *statement*
8:30	brainstorm ideas
8:45	design time 1
9:00	
9:15	
9:30	design meeting
9:45	
10:00	documentation time and break
10:15	design briefing
10:30	design time 2
10:45	
11:00	
11:15	team presentations
11:30	design meeting
11:45	wrap-up and preview

Friday, June 30
Design briefing: introduce design evaluations

3 design evaluations today

sloped terrain test scoring

- 5 – all the way across 3rd sloped terrain
- 4 – on the 3rd sloped terrain
- 3 - all the way across 2nd sloped terrain
- 2 – on the 2nd sloped terrain
- 1 – walks on 1st terrain

sodaconstructor local info for terrain:
login: gsvarovs
modelname: slopedterrain1

cost analysis scoring

- 5 – $2,000 or less
- 4 – $2,001- $4,000
- 3 - $4,001 - $6,000
- 2 – $6,001 - $8,000
- 1 – over $8,000

Reliability test

For the Reliability Test, we will reopen all of your designs. Then,

8:00	**Design briefing – introduce design evaluations**
8:15	design evaluations and design meeting
8:30	
8:45	*redesign time*
9:00	
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

• the DA will delete 1 spring at a time, up to 5 springs total. • once the structure collapses to below half its height, the DA will stop. Scoring for this evaluation will be: 5 springs deleted = 5 4 springs deleted = 4 3 springs deleted = 3 2 springs deleted = 2 1 springs deleted = 1 So we'll gather in our teams • We'll hand out the design matrix for today. • they will run the evaluations • you and your team will talk about what happened, and brainstorm ways to improve your designs	

Friday, June 30
Design evaluations and meeting

IPODS ON!

Logistics:
gather team

Run through cost analysis

Run through sloped terrain test

Run through reliability test

Process measures – iPods ON!
Ask each engineer after all the evaluations are done:

1. Did you learn anything from doing these design evaluations? If so, what?
2. Did the evaluations give you any ideas on how to improve your design? If so, what are your plans?
3. Does anyone else have any suggestions for P1?

When you're done running your team's evaluations, have the engineers go back to their computers and make a notebook page with their results.

IPODS OFF!

8:00	Design briefing – introduce design evaluations
8:15	**design evaluations and design meeting**
8:30	
8:45	redesign time
9:00	
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30 redesign time	
emphasize: engineers should use the results of their evaluations to inform their redesign of their alternatives. **process measures** **IPODS on!** 1. What are you working on? Are you trying to make your design better? How? 2. How are you trying to balance keeping the cost low and having a reliable design?	

8:00	Design briefing – introduce design evaluations
8:15	design evaluations and design meeting
8:30	
8:45	**redesign time/documentation**
9:00	
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Finish documentation

8:00	Design briefing - introduce design evaluations
8:15	design evaluations and design meeting
8:30	
8:45	redesign time
9:00	
9:15	**finish documentation**
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Prepare presentations

ok, it's time to prepare our presentations - the DAs will help you.

DAs:

- download "**designpresentation2 2006.ppt**"
- open it
- and walk through the template with your team.
- *There is a new slide for a redesign notebook page and/or post evaluation comments.*

(while you are doing this, Gina and Aran will copy notebooks to flash drives for transport to team computer)

Once your notebooks are all on the computer you're working on, then you can begin putting your presentation together. The DA will help as needed.

DAs: please have your team fill out the presentation grid as we did yesterday – and check if what they've written is correct during the practice presentations!

8:00	Design briefing – introduce design evaluations
8:15	design evaluations and design meeting
8:30	
8:45	redesign time
9:00	
9:15	finish documentation
9:30	**prepare presentations**
9:45	
10:00	practice presentations
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Practice presentations

practice going through slides

help kids write down talking points as they walk through slides

use index cards if needed!

CLIENTS MIGHT ASK ABOUT:

- How did you come up with those ideas?
- How do you know this one is better?
- Did your ideas change over time? How/why?
- Can you tell me about what happened during the design evaluations?
- Based on your design evaluations, is there anything you'd like to change about these designs?

8:00	Design briefing – introduce design evaluations
8:15	design evaluations and design meeting
8:30	
8:45	redesign time
9:00	
9:15	final documentation
9:30	prepare presentations
9:45	
10:00	**practice presentations**
10:15	break
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Break

before going on break

DAs – make sure to save presentation

Gina and Aran will go to your machines w/the flash drives and pull them off during break and load them onto the podium computer.

8:00	Design briefing – introduce design evaluations
8:15	design evaluations and design meeting
8:30	
8:45	redesign time
9:00	
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	**break**
10:30	clients arrive/presentations begin
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Client Presentations

ERIK – WE MUST RECORD THIS!

We'll go team by team

all of you go up there and talk about your work

(Ashley, please run SodaConstructor local again)

then clients will comment

and then we'll switch teams!

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8:45	redesign time
9:00	
9:15	finish documentation
9:30	prepare presentations
9:45	
10:00	practice presentations
10:15	break
10:30	**clients arrive/presentations begin**
10:45	
11:00	
11:15	
11:30	design meeting
11:45	wrap up

Friday, June 30
Design meeting

Gather team and go through presentation debrief.

IPODS ON!

6. So, how did you think that went?
7. How was this week's client presentation compared to last week?
8. Based on these presentations, are you thinking about engineering any differently?

IPODS OFF!

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11:00	
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Friday, June 30 wrap up		
	8:00	Design briefing – introduce design evaluations
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