Contextual Shaping of Student Design Practices: The Role of Constraint in First-Year Engineering Design

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ABSTRACT

Research on engineering design is a core area of concern within engineering education, and a fundamental understanding of how engineering students approach and undertake design is necessary in order to develop effective design models and pedagogies. This dissertation contributes to scholarship on engineering design by addressing a critical, but as yet underexplored, problem: how does the context in which students design shape their design practices? Using a qualitative study comprising of video data of design sessions, focus group interviews with students, and archives of their design work, this research explored how design decisions and actions are shaped by context, specifically the context of higher education. To develop a theoretical explanation for observed behavior, this study used the "nested structuration" framework proposed by Perlow, Gittell, & Katz (2004). This framework explicated how teamwork is shaped by mutually reinforcing relationships at the individual, organizational, and institutional levels. I appropriated this framework to look specifically at how engineering students working on a course-related design project *identify* constraints that guide their design and how these constraints *emerge* as students interact while working on the project. I first identified and characterized the parameters associated with the design project from the student perspective and then, through multi-case studies of four design teams, I looked at the role these parameters play in student design practices.

This qualitative investigation of first-year engineering student design teams revealed mutual and interconnected relationships between students and the organizations and institutions that they are a part of. In addition to contributing to research on engineering design, this work provides guidelines and practices to help design educators develop more effective design projects by incorporating constraints that enable effective design and learning. Moreover, I found that when appropriated in the context of higher education, multiple sublevels existed within nested structuration's organizational context and included course-level and project-level factors. The implications of this research can be used to improve the design of engineering course projects as well as the design of research efforts related to design in engineering education.

Dedication

To my grandmother, Mary Medvesky

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CHAPTER 1: INTRODUCTION & MOTIVATION

1.1 STATEMENT OF THE PROBLEM & MOTIVATION

The National Academy of Engineering (2004) defines engineering as “design under constraint” (p.7). Engineering design is creating and designing within the constraints of nature, cost, safety, reliability, environmental impact, manufacturability, maintainability, and many other factors (Wulf, 1998). Consequently, engineering education strongly emphasizes the design of systems, components, or processes as part of engineering experience (ABET, 2000). However, the realities of design are inherently complex, making design pedagogies difficult to model and teach, and consequently making it hard for students to learn how to design (Dym, Agogino, Eris, Frey, & Leifer., 2005). Designers often operate under a system of purpose, related contexts, and constraints (Gero, 1996) that transform as the designer explores the relationship among these elements in the search of the conceptual solution space. Highlighting the role of the purpose, context, and constraints in design research leverages how we understand the complexities of the design process. Furthermore, Bucciarelli’s (1994) ethnographic study of engineers illuminated engineering design as a situated and social process rather than an isolated and purely factually based process. Accordingly, the context surrounding constraints plays a distinguishing role in defining design and understanding design practices.

One aspect of constraint in design is its limiting and directing nature (Newell & Simon, 1972; Stokes, 2001). While the constraints surrounding the design problem limit and direct choice (Chua, 2008), designers presumably still face a myriad of choices when developing design solutions. When faced with too many choices, the evaluation and selection process become costly in terms of the resources used. March and Simon (1958) specifically consider time and attention scarce resources in decision-making. In order to reduce the costly nature of evaluation and selection when presented with many choices, we can utilize the limiting and directing nature of constraints to our advantage by limiting and directing the time and attention used in design practices. To effectively direct time and attention, however, we need to identify and understand the aspects of design that designers focus their time and attention on before we can limit and direct those resources.

Course-related design projects take place in the context of an educational setting that also requires time and attention. Time and attention must be allocated among projects, courses, assignments, and other obligations outside of the students' curriculum. Therefore, students must make decisions regarding how to allocate the available resources based on their context. Explaining how these overarching contexts of the educational setting affect students' decisions and actions will demonstrate the importance to context on course-related experiences. In this study I demonstrate the importance of the educational context as well as the context of the design project.

1.2 Research Purpose and Primary Research Questions

The purpose of this study is to understand how the context in which students design shapes their practices by investigating the constraints associated with the design project and educational setting. To accomplish this, I employ a qualitative study of first-year engineering students working on a course-related design project. In order to study how design decisions and actions are shaped by context, I apply the theory of nested structuration (Perlow, Gittell, & Katz, 2004) to examine the mutually reinforcing relationships among student actions and decisions at the individual, organizational, and institutional level. This context-based approach, i.e. taking into account the contexts of the educational setting, will enable me to investigate student engineering design teams under the theoretical lens of nested structuration.

Previous design studies have investigated problems, outputs, and activities related to design (Mehalik & Schunn, 2006). However, contextualizing and integrating these elements in an educational context has been limited and the review of previous work illustrates this disparity in chapter 2. In this study, I investigate the aspects of the design project that are salient to students, i.e. what they focus on or continue to revisit, in order to ultimately understand the relationship between the characteristics of the design project and student design practices. Two separate but related research questions in this study address these components of the design project and their effect on design practice; specifically these questions are:

RQ1: What aspects of the design project are salient to students? *(Normative)*

RQ2: How do these salient aspects affect their design practices? *(Procedural)*

1.3 Research Approach & Methodology

To answer these questions I studied first-year engineering students' design experiences with respect to the course-related design project. This project focused on the application of the design process to solve an engineering problem as well as the application of sustainability principles to the design of a product, system, or process. Participant teams were observed and video recorded during design sessions in which they researched renewable energies, brainstormed and sketched possible solutions, as well as built prototypes and finals models of their design solutions. In addition to the design session observations, I conducted semi-structured interviews with design teams regarding their experiences with the course and design project. The body of video observation data and interview data was analyzed first by team, then across teams. Analysis augmented by student design artifacts helps to illustrate the aspects that were important to students and subsequently how they affected their practices in design. Figure 1 illustrates a conceptual model of this work, including the relationships between the research questions and approach.

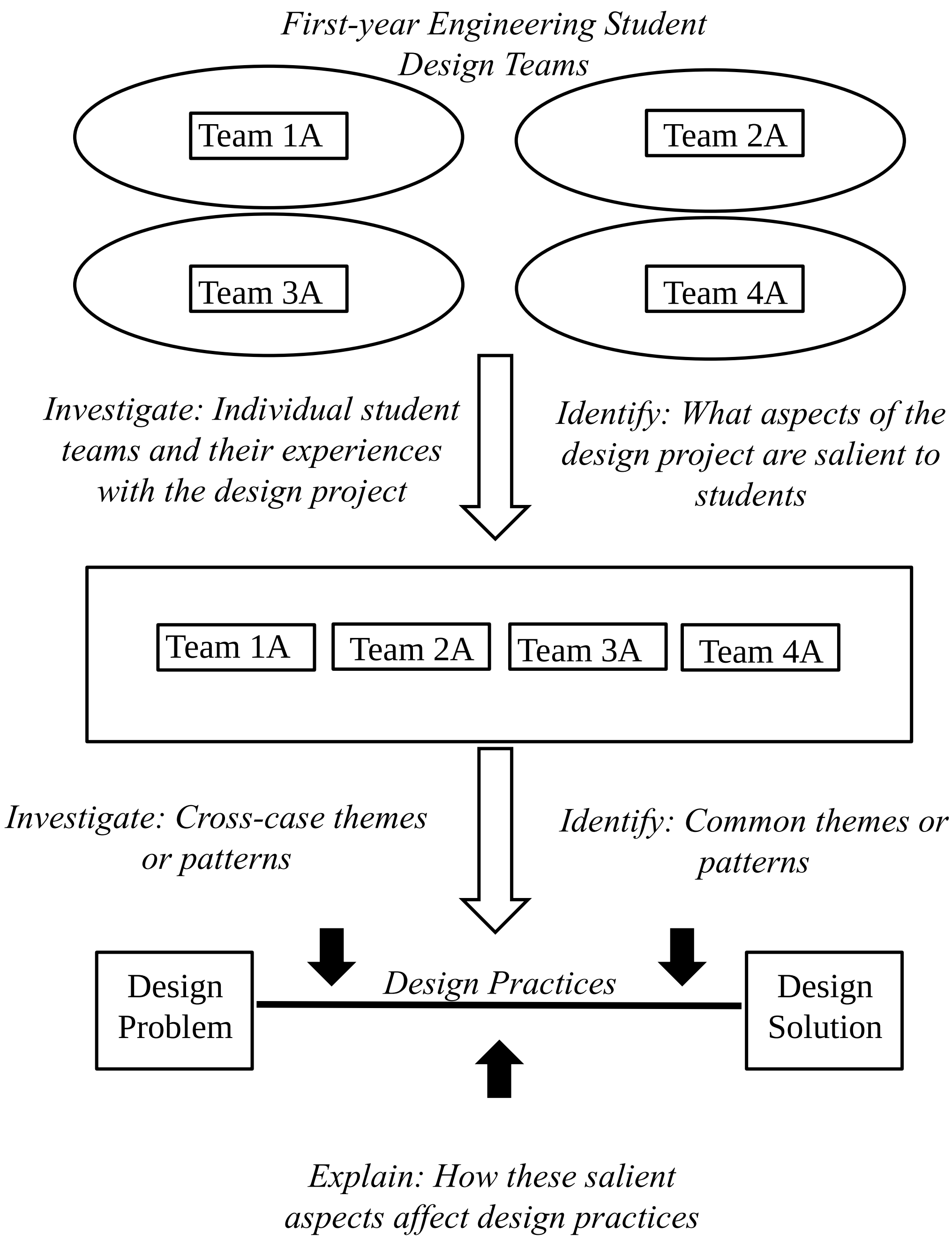

Figure 1. Conceptual Model of this Study

This work has two implications. First, it serves as a foundation for informing design curriculum and framing design projects in an educational setting, which is grounded on an understanding of what students perceive as important and their resulting practices. Second, this research provides further insight into teaching and evaluating design in an educational context.

1.4 Significance of the Dissertation

The theoretical contribution of this work to the engineering design and engineering education communities will highlight a new perspective on design education by emphasizing the importance of the design context coupled with the larger contexts of the educational setting that influence student design practices. These theoretical contributions will also augment possible practical contributions, which can include improved methods for designing course projects, grading projects, and design instruction within the context of an institution. Additionally, this work can contribute to the research practice and the context of research design. Understanding the effect of, or contribution to, the context in which students design will provide a more accurate framework for research practitioners studying design at various academic levels, e.g. freshman, senior, or institutions, e.g. universities, or other organizations, e.g. design firms or companies. Furthermore, the results from this work are also important to understanding the conclusions and implications of experimental studies that look at engineering design practices. An examination of student design outside of experimental conditions, and with respect to other contexts associated with an educational setting, illuminates aspects of design practice not captured or analyzed by experimental studies.

1.5 Summary of Remaining Chapters

In the remainder of the dissertation, I review previous work and literature around design constraints, as well as constraints as part of larger societal systems and contexts using the foundations of Structuration Theory (Giddens, 1984). Subsequently, I address how the broader context of design experiences (e.g. effects of the organizational and institutional context) can contribute to a better understanding of the effects on student design practice. Finally, I will discuss the within case and cross-case findings and how they relate to the Nested Structuration theoretical framework.

1.6 LIMITATIONS

I analyzed data from the design session observations and team focus group interviews using qualitative methods, which may be subject to other interpretations. Specifically, perceptual misrepresentations and researcher bias are potential limitations in qualitative studies (Yin, 2003). Participants volunteered to participate in the study rather than being selected based on specific criteria. Students who chose to participate in this study are possibly representative of students that would have agreed to meet regularly as a team and participate in similar practices as one another regardless of the study. These practices may also be qualitatively different from the practices of students who chose not to participate, thus one limitation of the data collected is that it did not capture the characteristics of student practices that did not necessarily fit with scheduled weekly design sessions. Additionally, one team opted to not participate in a focus group interview at the end of the design project, so data regarding their perceptions on the course and design project when asked directly is not included as part of the analysis for that team.

Possible methods to address limitations include conducting additional case studies using case selection criteria based on pre-interview or pre-survey data. Future research should examine possible disconfirming cases—e.g., what happens if teams do not share the same perceptions of the institutional and organizational contexts?

The nature of this study, like other qualitative studies, is to situate student design practices within a specific engineering education context in order to illuminate and exemplify the ways student practice design. This study is not intended to allow for broad generalizations but rather to instantiate of how students approach design when situated within an educational setting that encompasses multiple contexts.

CHAPTER 2: LITERATURE REVIEW & THEORETICAL DEVELOPMENT

2.1 Definition of Terms

The concept of "constraint in design" frames the discussion for the conceptualization of structure and agency as they relate to engineering design practices. In order to ease the discussion in this conceptualization, I start with a summary of the definition of terms integral to the theoretical underpinnings of this study. The terms "constraint", "structure", "agency", and "context" are discussed in this section for clarification.

Constraint

In a general sense, a constraint is defined as any limit or restriction. In terms of engineering design, Dym & Little (2009) further characterize constraints as limits that shape the size of the design space but are not synonymous with design requirements or objectives. Objectives, however, are generally derived from requirements and constraints (Pahl & Beitz, 1996). Dym & Little's definition suggests constraints provide design with a conceptual space where ideas and solutions are formed. Other definitions describe constraints as limits to this space and agents that direct the search of this space (Stokes, 2006; Newell & Simon, 1972; Reitman, 1965). Goncher, Johri, Kothaneth, & Lohani (2009) note that design students used the limiting and directing nature of constraints associated with the design problem to exploit their prior knowledge while exploring solution space. Amabile (1979) and Amabile & Gitomer (1984) elucidate a social aspect of constraint, which places social control on the individual or situation. More specifically, Amabile and colleagues showed that external social constraints, specifically, expert evaluation, surveillance, competition, and restricted choice impact intrinsic motivation and creativity. Their studies further illustrate that constraints, external to the situation at hand, have an effect on practice and outcome.

For the purposes of this study, constraints are defined in terms of both the external social control constraints placed on student design practices as well as the limiting and directing nature of constraints. Constraints associated with solving design problems, e.g. economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (ABET, 2011), are qualitatively different from external social constraints. External social constraints, such as having choices made for you regarding choice of task materials, for example (Amabile & Gitomer, 1984)—versus making your own choices—and expecting evaluation from experts (Amabile, 1979), differ in how they relate to making decisions or choices in comparison to constraints associated with solving design problems. I hypothesize that these characteristics of constraints, e.g. characteristics of constraints related to solving design problems and external social constraints, affect student design practices. This research focuses on the limiting yet directing nature of both types of constraints in design practice.

Structure & Agency

From a sociological perspective, social structures are what influence the organization of society. This conceptualization of a structure suggests the existence of *shared* rules or norms among the members of society (Gidden, 1984). Bullock and Stallybrass (1977) go further to specify a social structure as the “discernable framework, form, shape, and pattern of interrelationships of men [sic] in a society” (p.789). Emphasis on the relationship between these norms and the individual leads to a focus on the role of the individual, or *agent*, who has the capability to exert some form of control over these relationships. The relationship between the agent and these frameworks, patterns, etc. is of particular interest for this study because I am interested in the relationship between students and the aspects of the design project that equate to the frameworks associated with social structures. This relationship leads to Giddens' work and perspective on structure and agency. He correlates the sociological concepts of framework, pattern, etc. to rules and resources, i.e. the properties of the social system (1984). Deriving from the previous definition, *agency* is then defined as the capacity of the individual or agent in the social system to exert control over the rules and resources through their actions (Giddens, 1984; Sewell, 1992).

Giddens further elaborates on these definitions and relationships in his theory of structuration. However, due to the abstract nature of these concepts in Giddens' theory, others have adapted these definitions to apply to more empirical settings. For example, Sewell (1992) defines these rules, or patterned interactions, as "schemas" (a term more ubiquitous in psychological and educational research (Barlett, 1932; Piaget, 1928)). Barley & Tolbert (1997) redefine structures as "institutions", even using these terms interchangeably, in their efforts to fuse institutional theory (Berger & Luckmann, 1967; Meyer & Rowan, 1977; Zucker, 1977) and structuration theory in a more empirical context. For the purposes of this study, I use the term *structure* in the foundational sense of Giddens, i.e. the shared rules and resources of a social system, but apply the empirical definition of Barley and Tolbert (1997) and what they define as an *institution*: "shared rules and typifications that identify categories of social actions and their appropriate activities or relationships" (p.96). The specific frameworks or patterns of behavior, organizational structures, and institutional structures will be discussed in more detail with respect to the theoretical framework used in this study, i.e. Nested Theory of Structuration (Section 2.5.2). Similar to Giddens' Theory of Structuration, Nested Theory of Structuration also examines the relationships between structure and agency, but in an empirical setting, which is more applicable to this study because the theory will be applied to data based on first-year engineering student design projects.

Context

Design includes context and people. Design, outside of experimental conditions, occurs in a naturalistic setting where designers shape their solutions based on the environment, the stakeholders, and the capabilities of the situation. Consequently, the context of design is complex, situated in real-world scenarios, with certain degrees of freedom, and limited input and feedback (Jonassen, 2000). However, the complexities of design are not limited to the constructs of design practices, but are also situated within larger societal contexts. In the larger societal sense, context is what characterizes the surroundings in which phenomena take place (Cappelli & Sherer, 1991). Johns (2001) and Rosseau and Fried (2001) argue for the importance of the contextualization of research findings in order to better understand the phenomena under investigation. The situativity perspective highlights the role of the physical and social contextual attributes with respect to learning and can provide a foundation to understanding engineering learning (Johri & Olds, 2011).

Furthermore, describing various contextual attributes helps explain the “constraints on” or “opportunities for” the situation under investigation (Johns, 2001). For example, I identify an aspect of the design project that involves students building a functional model of their design; one team used materials from Lowe’s (home improvement/hardware store), while another team ordered electronic materials online to build their final models. Under the context of the design project, teams were required to build a functioning model, but had different approaches that led to different types of functioning models. If I consider the larger societal contexts, e.g. institutional, these characteristics show that one team had means of transportation to the hardware store located within driving distance of the university's campus, and one team did not. In this case, not having access to a car placed a constraint on what types of materials were available to the students, e.g. lumber, nails, etc., but at the same time provided a different opportunity to approach how they constructed the functional model. Students who were "constrained" by their means of transportation in this situation had an opportunity to approach functionality differently. That "opportunity" was to buy materials online and use servomotors in their design.

Understanding the effect of societal contexts and their contextual attributes is pertinent to studying design in an educational setting. Students are never fully removed from the impacts of the classroom or institution during their educational experience. One purpose of this study is to understand how the contexts associated with the educational setting impact student design practices. Specifically, understanding the larger societal contexts is important to constructing a more holistic characterization of the surroundings that shape student design practices.

2.2 Nature of Design Problems

Design problems are complex, often ill-structured, and embedded within specific contexts (Jonassen, 2011; Jonassen, Strobel, & Lee, 2006). Consequently, the context in which design problems are solved influences the nature of those problems and can vary from well-structured to ill-structured (Brown & Chandrasekaran, 1989). The continuum from well-structured to ill-structured is classified by how well the problem or project defines the constraints and goals associated with it (Jonassen, 2011). Studying these constraints and their effect on design under the theoretical framework of nested structuration will illustrate how design practices are shaped, not only by the design context itself but also by larger contexts present in an educational setting. In order to understand how the Nested Theory of Structuration is an applicable framework for this study, I first discuss engineering design, Structuration Theory, and then components of the Nested Theory of Structuration. Figure 2 outlines the relevant concepts from the literature and their relationships.

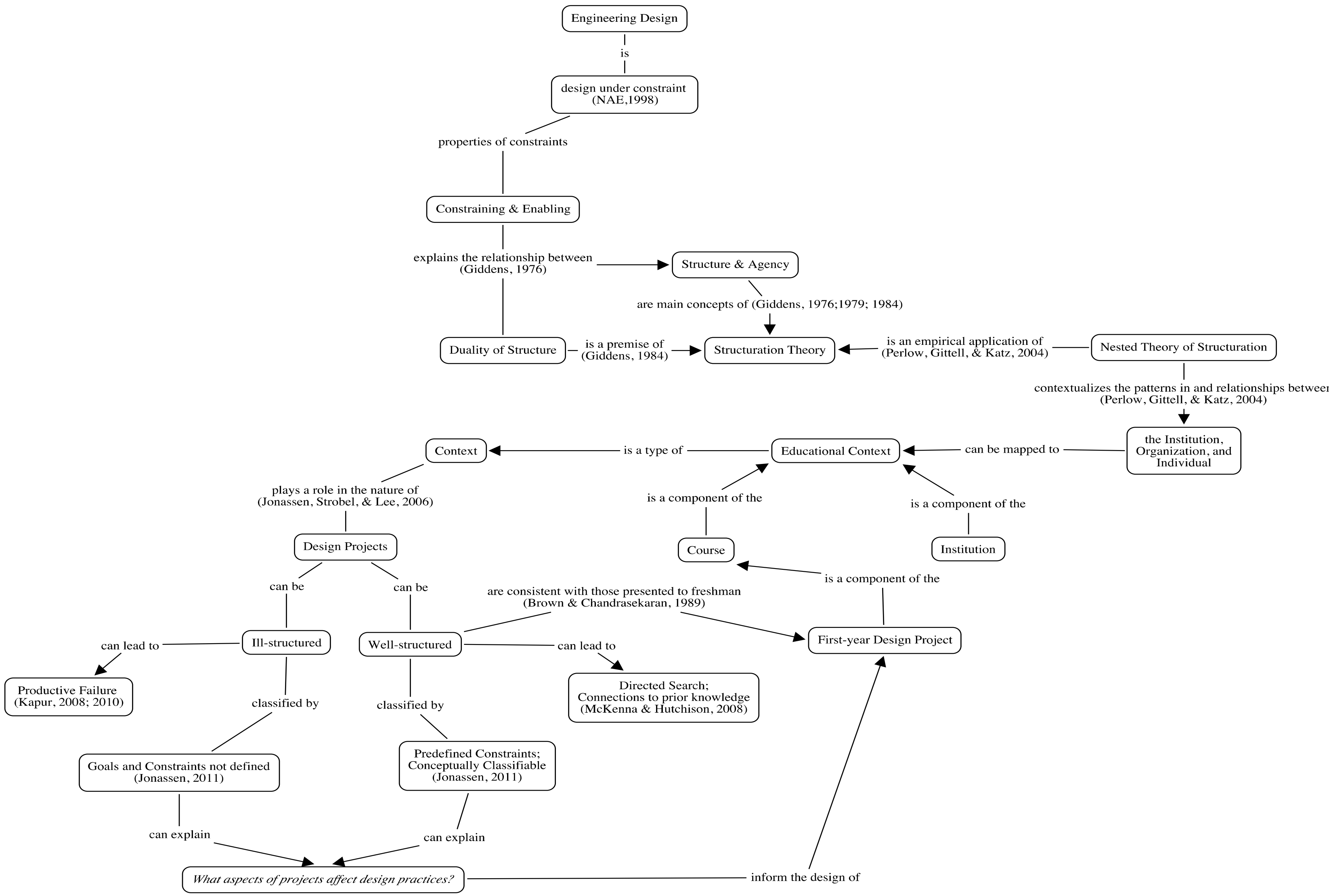

Figure 2. Overview of Relevant Concept

2.3 Engineering Design and Engineering Design Education

To understand the fundamental mechanisms of design, I first categorize various perspectives on design and how they are used to explain design practice. Perspectives regarding the definition of design suggest design is goal-oriented (Hirtz, Stone, & McAdams, Szykman, & Wood, 2002; Visser, 2006), process-based (Gero, 1993; Dym, et al., 2005; Schunn, Lovell, Wang, & Yang, 2010), or an aggregate of both perspectives (Shah, Vargas-Hernandez, & Smith, 2003; Nelson, Wilson, Rosen, & Yen, 2009). Although several perspectives highlight the goal-oriented aspect, the surrounding processes cannot be isolated from the overall nature of design. Engineering design specifically incorporates end goals, functionality, and a process-based approach. Other features underlying these descriptions include the involvement of the design contexts, requirements, and constraints. Previous research in engineering design education investigated design processes (Atman & Bursic, 1998; Atman Chimka, Bursic, Nachtmann, 1999; Cross, 2002; Atman, et al., 2007), but has mostly studied these in controlled settings or environments by giving designers hypothetical design challenges for the purposes of the study. For example, Atman et al. (1998; 2007) looked for similarities and differences between the expert/ student and freshman/ senior groups to identify and characterize design processes as they designed a playground for a fictional neighborhood (Dally & Zhang, 1993). Other empirical studies using hypothetical design problems isolated specific aspects of the design problem to study the effects on specific practices, for example, ideation (Viswanathan & Linsey, 2009; 2010; Shah et al., 2003). Viswanathan and Linsey (2010) looked at the effects of controlling various design practices, e.g. sketching, building, and testing, on ideation and goal attainment. While these types of studies uncover information on the nature of design processes, they take place in a controlled environment and do not address the context of the situation under investigation. Design challenges, or projects, are usually based on open-ended problems, authentic in nature, and performed in collaborative groups (Dym et al., 2005; Schunn, 2008); however, the structure of design problems can range from well-structured to ill-structured, depending on the context in which they are solved (Brown & Chandrasekaran, 1989).

Well- and ill- structured problems are discerned by the degree to which their goals and constraints are defined (Jonassen, 2011). Well-structured problems typically have predefined constraints that restrict the problem space and are considered conceptually classifiable, e.g. design solutions that need the use of heat transfer knowledge, further constraining the possible solutions. The aforementioned Viswanathan & Linsey (2010) study is an example of a well-structured design problem; the problem gave an explicit goal: design an object out of steel wire to bind ten pages of paper, and an explicit constraint: no damage to the paper. In this case, the problem constrained designers by the functionality of the solution and the type of material used. Ill-structured problems, on the other hand, do not have precise predefined goals or constraints. In McKenna and Hutchison's (2008) study of undergraduate engineering students solving well- and ill-structured problems, the ill-structured problem asked students for design assistance for the Government Health Organization (GHO) in order to combat mother-child HIV transmission. In this case, students essentially needed to design solutions for the GHO based on unstated or under specified criteria and relied on information surrounding the perceptions of breastfeeding and mother-child HIV transmission in the community. This problem did not specify criteria, so students' solutions were more affected by their approach to the problem. When McKenna and Hutchinson compared the design practices of the groups who were given either a well- or ill-structured problem, they found that engineering students had difficulties developing strategies to solve the problem. The students who were given the well-structured problem made better connections to prior knowledge and were more directed in their information search related to possible design solutions. Despite students' uncertainty in their approach to solve these types of problems, the implications of ill-structured problems are not without gain. Kapur (2008; 2010) compared the approaches of students who were given either ill-structured or well-structured physics problems and found that students who solved the ill-structured problem outperformed the students who were given the well-structured problem on knowledge transfer tests. This phenomenon, or "productive failure", is the result of students engaging in deeper learning throughout their unsuccessful trials. The differentiating factor between these types of problems and resulting effects is the degree of constraint associated with the problem. This limiting yet directing nature of constraints (Stokes, 2006; Newell & Simon, 1972; Reitman, 1965) is what leads to deeper learning, directed search, and better connections to prior knowledge. What has not been studied is the effect of the type of constraint or the specific aspects of design problems and projects that lead to the beneficial outcomes of well- or ill-structured problems. Is there an optimal range on the continuum of well-structured to ill-structured that directs effective search for information and facilitates better connections to prior knowledge? Constraints are an important feature of engineering design because of the constraining yet enabling nature. Furthermore, I posit that understanding the role of constraints in design projects will help to inform the design of design projects that ultimately facilitate deeper learning.

2.4 Constraints and their role in design and educational settings

The role of constraints is important to the study of engineering design because of their influence on decision-making and practices as designers work within the problem frame. Inherent to the nature of design, designers face limits within their search of the conceptual solution space. Subsequently, constraints, which are clearly defined limits, shape the size of the solution space

(Dym & Little, 2009). In well-structured design problems, constraints are well defined and restrict the range of applicable solutions. Furthermore, if these problems are also considered conceptually classifiable, they further constrain the possible solutions and methods used to arrive at these solutions. At the same time, it is an accepted expectation in formal classrooms that solutions can be evaluated on specific criteria (Jonassen, Strobel, & Lee, 2006). This concept further illustrates the role of context in the nature of design problems, specifically, the context of the classroom. In a mechanical engineering course that structured the material around problems rather than topics, Jonassen, Khanna, & Winholtz (2011), found that students perceived the course to lack structure and had difficulty adjusting from the methods they used to study for exams to the methods needed to solve the problems based on their expectations of an educational setting. The educational setting is structured in such a way that student work must be evaluated on some criteria and those assessments of the criteria are typically easier when it is well defined. Students have developed an expectation of the classroom that involves well-defined assignments so they know specifically what they will be evaluated on. In turn, student practice in an educational setting is structured by constraints and expectations of the school system.

The constraints of an educational setting also impose various tradeoffs that need to be considered when structuring activities for this type of context. For example, activities that promote student learning and engagement are often dependent resource commitment, especially in classrooms with large enrollments. Williams, McNair, Crede, Paretti, and Terpenny (2010) approached the development of a classroom activity that addressed the tradeoff between student learning and engagement and resource commitment by establishing the context then identifying the related objectives and constraints—similar to the approach of an engineering design problem.

In this case, the constraints of the educational setting played a role in structuring classroom activities that met certain objectives.

In Pope's book "Doing School" (2001), she identified the constraints of the school system that influenced the way students approached educational practices. She found that the emphasis on learning facts and techniques instead of problem solving was a result of the structure of the school system, e.g. fragmented school day, large class sizes, the tracking system of the institution (placing students into specific courses based on GPA, grade point average), and departmental organization (divided by subject area). Students often fell into the "grade trap" due to the structure of assessments that derived from outcome oriented teaching and learning. She points out that the factors that contributed to how students "did school" were consequences of the existing school structure and were further reinforced by the larger community and national culture, e.g. parents, colleges, and universities. While student practices were shaped by the structure of the school system –and at times compelled students to 'falsify' their behavior and manipulate the system in order to be successful— this structure also provided opportunities for participating in practices that they reportedly enjoyed. For example, students who participated in community service projects or extracurricular musical activities may have done so to improve their college applications, but also found enjoyment and reward in these activities. One student continued to participate in the community service projects even after it no longer impacted his college applications. This affect and importance of the contextual conditions can lead to implications for utilizing the structure of the school system to enable student practice, which has been demonstrated in an engineering design setting.

Similar to Pope's (2001) work, Dannels (2000) and Paretti (2008) demonstrated the prevailing influence of the academic context on student design practice, specifically communicative practices in design. While getting good grades drove many of the student design practices (rather than the professional context, e.g. designing for clients) students still learned design through the academic context. In other words, students adapted to the context and realities of the learning situation. Dannels (2000) suggests this adaptability will transfer to the professional context when these individuals are part of the workplace, or perceive the professional context as real. Furthermore, Paretti (2008) indicates that instructors can leverage the academic context in helping students to develop communication skills by being explicit about the needs, goals, and constraints associated with communicative design practices in specific contexts. For example, articulating and helping students understand why they must present a more detailed timeline, e.g. in order to make sure deadlines are realistic and determine if the instructor is able provide help, can also play a role in determining how well students transfer their experiences to the workplace. Instructors can also leverage the structure of assignments within the academic context to support student practice. By sequencing assignments associated with a design project, instructors can support student to stay on track and develop design documents over the progression of the project (Paretti & Burgoyne, 2005).

Dannels (2000) and Paretti (2008) illustrate that the context in which students design is never fully escapable and students are cognizant of the differences between the school and work contexts. Because students saw the academic and professional contexts regarding design as two distinct settings, their practices and objectives were tied to the context they perceived as real, i.e. the classroom. They further recommend that instructors who are part of the academic context need to realize its salience, use its prevailing power to impact how students learn, and develop assignments that promote the development of communicative design practice.

Other studies have looked at the effects of the classroom and coursework, including design curricula, on student design practice. Williams, Lee, Paretti, and Gero’s (2011) study of sophomore engineering students found that as students moved through design curricula they were more engaged in defining and scoping the problem, increased their efforts in reformulation the function, and engaged more frequently in design issues related to description, e.g. documentation. These types of behavior from the findings are more consistent with expert design behavior (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Morozov, Kilgore, & Atman, 2007) and illustrate an encouraging effect of design education on students’ design cognition. Similarly, Bailey and Szabo (2006) found that seniors at the end of a capstone design experience, i.e. students who are arguably more advanced through the design curricula, knew more about several engineering design issues than first-year students and were motivated to investigate where this knowledge was gained (in the time from their first year to senior year). Bailey (2007) found students’ “analysis-heavy” (p. 663) sophomore and junior level classes did not impact design process knowledge but students’ industry experience impacted their perception of design documentation and that it needed to occur throughout the design process. At the same time, students’ industry experience showed no effect on most aspects of the design process, which was possibly explained by the context of the industry experience, and students typically experienced only a small portion of the design process during their time in industry. In another study, Gruenther, Bailey, Wilson, Plucker, and Hashmi (2009) found that the capstone experience as part of the design curriculum increased several aspects of students’ understanding of the design process, including needs identification, how to spend their time on design activities, and the overall layout of the design process. From these studies we see that the context in which students practice design –either a classroom or a design experience outside of the classroom– can impact design cognition and design process knowledge. Depending on the structure of the course, e.g. design focused vs. analysis focused, or industry experience, e.g. exposure to a small part of the design process, students' understanding about design is impacted in various ways.

Even when the context of a course is designed to include a considerable amount of reflection and attention to learning it does not always necessitate that student practice will follow this model. For example, Newstetter (2008) observed and studied a student team in a mechanical engineering design class where the pedagogical views of the instructor and the classroom views of the students were often in conflict, resulting in the failed utilization of opportunities in learning and doing design. In other words, students' "institutional view" (p. 122) of the course, i.e. viewed design activities as assignments, took a divide and conquer approach to team activities, and in general were only motivated to get a good grade, impeded their utilization of design activities and tools that were intended to scaffold the process of learning and doing design. In this case, within the context of the mechanical engineering design course, students viewed the design activities as assignments or busy work and the instructor's learning view or pedagogical intentions were lost on the students whose attention was on performance and grades rather than understanding.

To make progress on how to utilize impact of the curricular efforts and the academic context on student practices and objectives, I suggest identifying the aspects of the academic context that students focus on and the effect they have, which presently is under-addressed in the literature.

The idea of context and constraints can lead to valuable insights into design practices. Theoretical frameworks for studying engineering design practices reflect a perspective that highlight how meaning is socially constructed in specific contexts. For example activity theory has been used to analyze communication practices in capstone design contexts (Dannels, 2003; Paretti, 2008). However the constraining yet enabling feature of constraints is mirrored in theoretical work on structuration and agency that outlines ways in which individuals interact as part of this context or social system. The next section of this chapter outlines and describes the theoretical frameworks associated with structure, agency, and constraint, and how they apply to design.

2.5 THEORETICAL FRAMEWORK

2.5.1 Structuration Theory

In order to explain organizational phenomena that address both the individual and institutional context and how they are related, Giddens' (1984; 1979) proposed a general theory of social organization that couples structure and agency in a mutually reinforcing duality. Giddens' framework aimed to resolve the disparate perspectives in the social sciences by uniting structure and agency rather than segregating social phenomena, as either products of external social structures or manifestations of human agents' actions within the world. The duality of structure and agency illustrates the transformative nature of social structures from human agency. In other words, social structures are produced and transformed based on the actions of humans in social contexts, and in turn, the actions of human agents are shaped by the social structures of the system. This dynamic nature of social structure is not only a constraining force but also an enabling force of human action. Structures, therefore, do not stand apart from human agency but are enacted by humans.

The nature of structuration is grounded in three characteristics (Jones & Karsten, 2003) to convey the ontology of human interaction and social structure. The first idea surrounding the duality of structure specifies key terms as *structures,* or rules/ resources that are organized as properties of social systems, while these *systems* are products of interaction between agents and subsequently organized as accepted social practice. To relate this to engineering design and design practices, consider a student engineering design team as part of a social system. As per the suggestion of the engineering course, students meet every week to progress toward a design solution for the course-related design project. While the course structured how students progressed, i.e. through team meetings, the students enacted those meetings. These enactments are situation- and team- specific and over time results in the establishment of norms. For example, if students come into a design meeting and open up a design document on their Tablet PCs, e.g. research report, it is now accepted social practice that during design meetings they will work on Tablet PCs to create the appropriate design documents. In other words, *structuration* is the reproduction and transformation of the social system where the transformation is governed by the actions and behaviors of the individuals within that social system. Social systems or contexts also can structure, define, and categorize how individual perceive their own abilities. Paretti and McNair's (2012) study demonstrated that the institutional structures engineers were part of shaped their identities.

The second characteristic of structuration focuses on the quality of a structure that is both constraining and enabling. Agency coupled with constraint introduces "possibility" in human agency, or the ability of agents to determine and choose their actions (Giddens, 1989). The power to make choices further connects structures with human actions. Agents rely on their existing knowledge and apply it to produce new knowledge that becomes rules or resources for future structures (Canary, 2010). For example, one type of constraint of the design project is the cost or a limit on how much students can spend toward their individual projects. In theory, students have the choice to either stay under budget or go over budget. What determines student action is the relationship the budget has to their overall project grade. Therefore, they have agency in terms of how to spend the budget but agency can be acted upon only within a specific set of structures. Points are deducted if they go over budget, and in this case, students use their existing knowledge of how to get the best grade possible and apply it to the design project. This can impact future structures for design choices; students now structure their actions based on the effect it will have on their project grade. In summary, the budget constrained the cost of the final project, but enabled them to incur points toward their grade.

The third characteristic, time/space distanciation, ties together the individual and institutional levels of social practice and their dynamic role in social life (Jones & Karsten, 2003). The relationship between the individual and institutional levels is a continuous practice, observable over time, and illustrates the capacity of social structures to continuously be produced and reproduced. In this study, I am interested in understanding specific phenomena in a particular place and time, but the findings of this study can encourage researchers to explore how design practices in an educational system develop over a longer time period. Giddens' work was fundamentally directed at establishing a general set of concepts with little intention of empirical application. However, the central idea, structure and agency, provides guidance in understanding student design practices. Figure 3 helps to illustrate the basic relationship between structure and agency as Giddens theorized it. While Giddens' structuration theory is capable of explaining phenomena at both individual and institutional levels, the theory is highly abstract and complex; therefore, it is limited in its empirical utilization.

At its level of abstraction, structuration theory is not easily implemented through any methodological approach or research method (Pozzebon & Pinsonneault, 2005). However, various studies investigating public policy, organizational knowledge, and work-group interaction integrate and develop the broad level constructs of structuration with more contextual and concrete constructs to introduce frameworks that are both theoretical and practical. One example of this is Perlow, Gittell, and Katz's (2004) Nested Theory of Structuration that explicates the dynamic and mutually reinforcing relationships between the individual, organization, and institution.

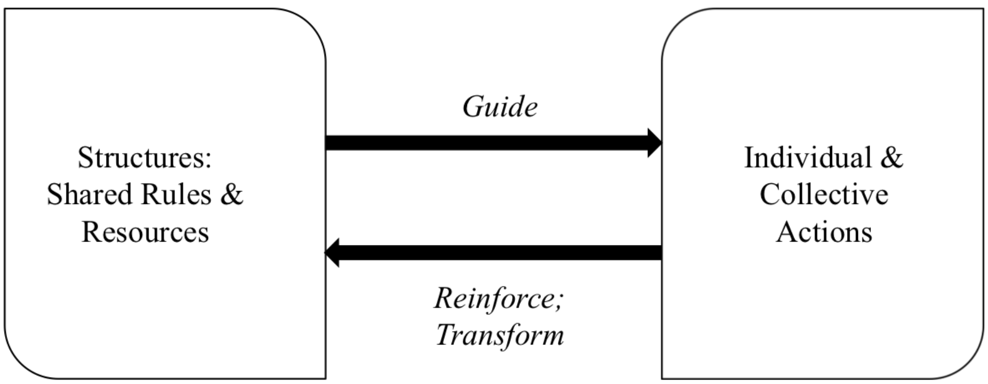

Figure 3. Basic Model of Structuration Theory

2.5.2 Nested Structuration

The focus of the study conducted by Perlow and colleagues (2004), which resulted in the development of the nested application, examined how groups accomplished work and why similar work could get done but in different locations. They studied this by examining patterns of interacting work groups, i.e. individual actions, and how the larger societal context, i.e. organization and institution, affected these patterns. Figure 4 below illustrates the nested concept and the mutually reinforcing relationship at each level. Their findings suggested that not only did the organizational context affect patterns of work group interaction between group members, but also the organizational system was further reinforced by the overarching institutional context.

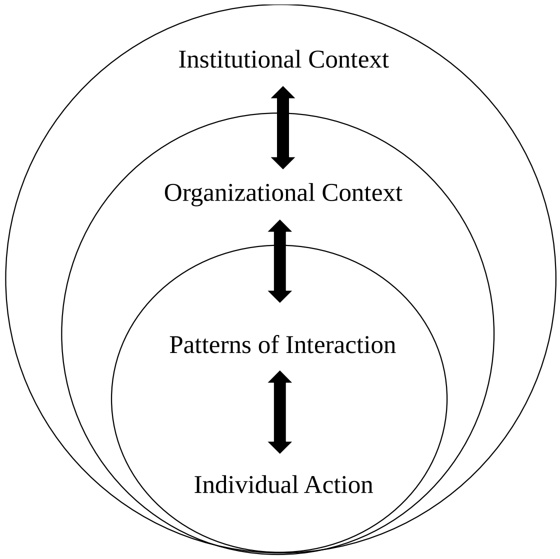

Figure 4. Nested Structuration (Reproduced from Perlow, Gittell, & Katz, 2004. p. 533)

Using this nested model to explain the relationship between the individual, the organization, and the institution in an educational context is applicable to this study because the original model was derived from an attempt to *contextualize* findings regarding group work interaction. In this study, I recognize the importance of context when working on engineering design projects in an educational setting and posit that this theoretical framework will help to explain how the organizational and institutional contexts associated with an educational setting affect design practice. Contextualizing the findings of this study under the Nested Theory of Structuration model will illustrate how the factors present in multiple levels of context impact design practice. This framework allows for further consideration of how these practices are shaped by the larger contexts and illustrates the value of unpacking the aggregate measures associated with them. For instance, if I were to only study design practice as part of a design process model, I would fail to uncover any overarching effects of the course or university. The treatment of design practice as a distinct organizational or institutional component ties together design practice and the overarching contexts associated with the project, course, and institution as well as the interconnections that exist between them. Perlow et al. (2004) further suggest that to sustain or change these patterns of interaction, an understanding of the institutional and organizational contexts must exist in addition to understanding how patterns are constrained or enabled. One purpose of this study is to understand the relationships between design practice, the larger contexts, and the patterns that stem from those relationships; the nested model of structuration provides methodological guidance and a framework for ultimately interpreting and understanding the relationships. In addition to using the Nested Structuration framework derived from Perlow et al.'s study to frame my analysis, I follow their methodological approach of studying engineering work teams in the context of their organizations and institution in order to investigate factors at multiple levels.

Based on the literature and previous work in engineering design, I also recognize the importance of constraint on engineering design practices and use that to frame my approach to identifying important aspects of the design project, how they affect design practices, and how that will ultimately inform the design of course-related projects. Table 1 summarizes the claims from this work and the related theoretical basis.

2.6 Summary of Theoretical Claims

Table 1. Claims of the Dissertation and Theoretical Bases

Claim	Theoretical Basis
In order to study the central features of engineering design, I must look at the role of constraints in design.	Engineering design is design under constraint. (NAE, 1998); Constraints are limiting and directing. (Stokes, 2006; Newell & Simon, 1972; Reitman, 1965); Constraints shape the size of the conceptual design space. (Dym & Little, 2009).
The structure of the design problem affects the way students approach design and their subsequent outcomes.	The degree to which constraints are defined determines whether design problems are well-structured or ill-structured (Jonassen, 2011); Well-structured problems can lead to more directed

	information search and better connections to prior knowledge in engineering students (McKenna & Hutchison, 2008); Ill-structured problems have also been shown to lead to better transfer of knowledge outcomes in comparison to well-structured problems in physics and math (Kapur, 2008; 2010).
The educational context also affects student design approaches.	Context plays an important role in specifying the nature of design problems (Jonassen, Strobel, & Lee, 2006); Students had difficulties in solving ill-structured problems in the classroom due to a disconnect in the methods used to study for exams and methods used to solve problems (Jonaassen, Khanna, & Winhold, 2011).
Understanding the constraining and enabling nature of constraints with respect to the design context and the educational context can inform the design of course-related projects.	The structures associated with social systems enable human agency (Giddens, 1976); Individual action, the organizational context, and the institutional context are not only related, but are also mutually reinforcing at each level (Perlow, et al. 2004).

Investigating the overarching contexts of the educational setting demonstrates the impact these contexts have on student practice and specifically the impact on design practice within the context of an engineering course. Similar to the fundamental tenants of engineering design, the constraints of these contexts enable and constrain design practices. Determining what factors limit and direct student design practices is important to the design of course-related projects. Ultimately, understanding these factors and how they affect design practice can help educators as well as designers to leverage these constraints in design. To accomplish this I studied engineering design teams within the context of their engineering course design project in order to understand their experiences.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Studying design team practices with respect to multiple contexts requires an approach that appropriately captures the complexities associated with design in an educational setting. Therefore, it is important to select a methodology that will ultimately help to describe and explain the phenomena under investigation. To explain my approach to studying student design team practices, I begin by discussing the benefits of a qualitative methodology and the rationale for applying the appropriate methods to this study. After examining the aspects of a specific qualitative methodology, i.e. case study, I present my approach: a qualitative field study of student design teams during their first-year design project experience. Specifically, I use a multi-case study approach (Miles & Huberman, 1994) to analyze individual cases as well as potential cross-case patterns regarding student design practices to ultimately describe, understand, and explain the phenomena surrounding design in educational settings. The multiple case study approach investigates several cases to identify patterns and understand the phenomena under investigation (Creswell, 2002; Stake, 2006; Yin, 2003). Table 2 summarizes the research questions, data collection and analysis, and the desired outcomes of this study. This chapter outlines the overall research approach and rationale employed in this study. In the remainder of the chapter, I further explain the research methodology and describe the data collection methods and analysis used to answer this study's research questions.

Table 2. Summary of Methods

Research Questions	Data Collection	Data Analysis	Outcomes
1. What aspects of the design project are salient to students? (RQ1)	• Video observations of student design teams • Semi-structured student interviews	• Reduction of data into categories (Miles & Huberman, 1994; Glaser & Strauss, 1967)	• Detailed descriptions of the design project aspects that students focused on and categorization of

		• Coding of individual cases, e.g. combination of inductive and a priori	those aspects
2. How do these salient aspects affect their design practices? (RQ2)	• Video observations of student design teams • Semi-structured student interviews	• Rich description of design practices; Two step analysis: 1. Analyze within-case data 2. Examine for cross-case patterns (Eisenhart, 1989)	• Detailed descriptions of each team's (case) design practices and their relationship to design project aspects • Overview of the patterns related to salient design project aspects and student design practices based on the cross-case comparison

3.2 Case Study Methodology

Case studies are one type of methodology that satisfies the three tenets of qualitative research, i.e. describing, understanding, and explaining, from their ability to examine the "how" and "why" aspects of an investigation (Yin, 1994). Using this type of methodology is beneficial in this study because I intend to describe the aspects of design that are important to students in order to characterize and understand what issues exist surrounding student design practices. In order to accomplish this, the cases I utilized as the object of the study represented a complex functioning unit and were investigated in a natural context using multiple sources of evidence (Feagin, Orum, & Sjoberf, 1991; Merriam, 1988; Miles & Huberman, 1994; Yin, 1994; Stake, 1995). For example, each student design team represented a unit of analysis within the study and I observed these teams during their design sessions in which they worked on their design project. In addition to the data or evidence collected from the observations, I interviewed the students at the completion of the project regarding their first-year design experience as another source of evidence.

Another benefit of this methodology is the potential for a better theoretical and empirical understanding of the interrelated activities within a case that is offered by the methodology's holistic approach to investigating phenomena (Feagin et al., 1991). One outcome of this investigation is the identification of design project aspects that are important to student design teams. An additional outcome is the explanation and understanding of the relationship between important aspects or parameters and design practices. Under the theoretical framework of Nested Theory of Structuration, I posit that these relationships are influenced by the surrounding contexts of design and the educational setting in which design takes place. To achieve these desired outcomes, I matched the underlying purpose of this study with the purpose of a Relationship/ Theory Building case study (Handfied & Melnyk, 1998; Voss, Tsikriktsis, & Frohlich, 2002). Table 3 matches the underlying research purposes with techniques related to theory building case studies as described by Handfied & Melnyk (1998) and Voss et al. (2002), and maps them to the purposes and techniques of this study.

Table 3. Theory Building Case Study: Matching Purpose and Methodology

	The scientific theory-building process: a primer using the case of TQM (Handfied & Melnyk, 1998); *Case Research in Operations Management* (Voss, Tsikriktsis, & Frohlich, 2002)	*The Identification and Emergence of Constraints in First Year Design Projects and the Effect on Practice in Engineering Students* (Goncher, 2012)
Purpose	• Identify and describe key variables • Identify linkages between variables • Identify why these relationships exist	• Identify and describe aspects of the design project that students focus on when they are working on the design project • Identify relationships between the salient design project aspects, i.e. what students

		focused on, and student design practices
Research Question(s)	• What are the key variables? • What are the patterns or linkages between variables? • Why should these relationships exist?	• What aspects of the design project are salient to students? • How do these salient aspects affect their design practices?
Research Structure	• Few, focused studies • In-depth field studies • Multi-site case studies • Best-in-class case studies	• In-depth field studies of 4 first-year design teams' experience working on the course design project

I discussed the potential benefits of a qualitative approach that utilizes a multi-case study methodology, but there are also several challenges in conducting case research. Observation and analysis of each case is time consuming and it is arguably difficult to draw generalizable conclusions from a limited set of cases. At the same time, using a limited set of cases makes it possible to misjudge an event or exaggerate the available data (Voss et al., 2002). I attempt to address these limitations by utilizing video data from several cases. Collecting and analyzing video from several cases is still time consuming but the other limitations are mitigated when events and data are compared across cases. The following section discusses the benefits of using video data of cases and how it can reduce some of the limiting factors associated with case studies.

3.3 Rationale for Video Case Studies

In order to exploit the events that took place during design sessions, I utilized digital video recordings of the design sessions and interviews. Several strengths of video data are that it can enhance the description of the phenomena under investigation, which is important in this study because one of the desired outcomes is a description of the important design project aspects and design practices. Specific strengths, including density and permanence of video data and opportunity for cross-case comparisons (Heath, Hindmarsh, & Luff, 2010), are needed in order to answer RQ2 in this study (refer to Table 2).

In addition to providing a more comprehensive recording of the setting and events, digital video preserves an original record to allow for various perspective analyses, i.e. the ability to revisit the data and uncover different phenomena. Also, because video data remains consistent for every viewing, it allows for a nonlinear approach to categorizing and segmenting the data. These qualities are beneficial to the analytical approach in this study because, as previously stated, the cases were analyzed individually and then across cases; however, before coding individual video recording of each design session, I had to first reduce and categorize the data. A consistent record of each design session supported a systematic selection strategy when working with the corpus of data. Multiple and consistent viewings helped to determine the unit of analysis and facilitated a multistage analytic approach (Derry, Pea, Barron, et al., 2010) in which I created intermediate representations in order to identify segments for analysis (Erickson, 2006; Derry, 2007). For example, I collected data (video recordings) on team design sessions over the course of the project duration, segmented the corpus of data by team, and then by the focus of the meeting or the design artifact teams discussed and/or constructed. The following section describes the unit of analysis in more detail and provides background on the study's research setting and participants.

3.4 Participants and Research Setting

All individual participants were first-year students who were enrolled in the first-year, first semester engineering course (this course consisted of a separate lecture and workshop), during the Spring 2010 semester. Sixteen students, 1 female, 15 male, participated in this study and were selected based on the students who volunteered. Participant selection was guided by an attempt to study the experiences of student design teams in a natural setting through the observation of design team sessions so the selected teams were formed the same way as the teams who did not participate in this study. The workshop instructor placed the students who volunteered into teams by assigning students a number from one through four and then grouping them by number, resulting in four design teams with four members per team.

Engineering students enrolled at a large technical university on the east coast, Tech University, typically take the previously described course, ENGR 1234, in their first semester as part of the required engineering program curriculum. The objectives of the course are founded in several engineering topics including problem solving, design, modeling and visual representations, algorithm development, programming, ethics, and professionalism. In addition to ENGR 1234, students are also required to take other math and science courses as part of the engineering curriculum. Table 4 displays a typical first-year engineering student's course load for the fall and spring semesters, and is based on the assumption that the student carries no transfer, advanced placement, or advanced standing credits. While Table 4 indicates that students typically enroll in ENGR 1234 the fall semester, the participants in this study were enrolled in ENGR 1234 during the spring semester, but were also enrolled in the other typical spring semester courses. Table 4 is mainly provided in this document to contextualize the course load of a typical first-year engineering student, which is important under this study's theoretical framework with respect to their relationship with the larger institutional context.

As part of ENGR 1234, students attend larger lecture sessions as well as smaller recitation/ lab sessions, referred to as workshops (I did not collect data regarding official participant attendance for the course lecture or workshop). The instructional material for both the lecture and workshop addressed the main objectives of the course, e.g. design, programming, ethics, etc., but the design project under investigation in this study was a main tenet of the workshop. The workshop leader (instructor) guided teams throughout their experience with class discussions and individual team/ workshop leader meetings. Additionally, the workshop leader was also responsible for grading design assignments, or artifacts that are discussed in the next section. A rubric accompanied each design assignment and the students were cognizant of the point allocation and grading audience for the assignments. Specifics of the design project are described in the next section in order to situate and frame the analysis discussed later.

Table 4. Course Summary for a Typical First-year Engineering Student

	Fall Semester	
Course	Title	Credits
CHEM 1234	General Chemistry	3
CHEM 1234a	General Chemistry Lab	1
ENGR 1234	Engineering Exploration	2
ENGL 1234	Freshman English	3
MATH 1234	Elementary Linear Algebra	2
MATH 1235	Calculus	3
	Curriculum for Liberal Education Course (CLE)	1-3
	Spring Semester	
Course	Title	Credits
ENGR 5678 or ENGE 5679	Exploration of the Digital Future or Exploration of Engineering Design	2
ENGL 5678	Freshman English	3
MATH 5678	Vector Geometry	3

MATH 5679	Calculus	3
PHYS 5678	Foundations of Physics I	4
	Major Requirement or CLE Course	1-3

3.5 The Design Project: Designing Sustainable Engineering Products (DSEP)

The DSEP is the design project/ design experience for first-year students enrolled in ENGR 1234 and helps students develop knowledge regarding the engineering design process, sustainability, and teamwork fundamentals. All students enrolled in the ENGR 1234 workshop (Spring 2010) received the assignment for an eight-week project that utilized a renewable energy source. While the nature of the assignment was ill structured, "Your assignment is to develop a "Promotional Innovation" that publicizes awareness of a renewable energy source." (Appendix C, p. 205) the goals and constraints associated with structure of the project were more explicit. The course structured the project assignments to facilitate students' progression through the design process. Figure 5 illustrates the engineering design process used in this course and the design assignments/ artifacts associated with each step. In addition, when reviewing the design process in class, students are also provided with an explanatory document of the design project that details all of the required components of the DSEP.

The DSEP Information Document given to the students (provided in Appendix C of this document) describes the objectives and requirements for each assignment and provides templates depending on the assignment. While the project design prompt is generally open-ended, the design document delineates more specific parameters of the project for students. In this study, discerning the specific parameters given to students in the DSEP document was important to analyzing and understanding how students approached the design process and how these given parameters affected their design practices. These parameters included design solution functionality, safety and innovation, use of one or more key components of a renewable energy source, and applications to education, entertainment, as well as an ability to generate inquiry in renewable energy sources (See Appendix C, Section "Assignment"). In addition to specific parameters, the design document placed a budget on the cost of materials students could use in their final design solution. This budget was restricted to $20.00 (USD) and carried a point deduction/ penalty in the final presentation rubric. The role of these parameters in student design practices was incorporated in the data analysis and is discussed later in this chapter, while the following section describes the data collection process.

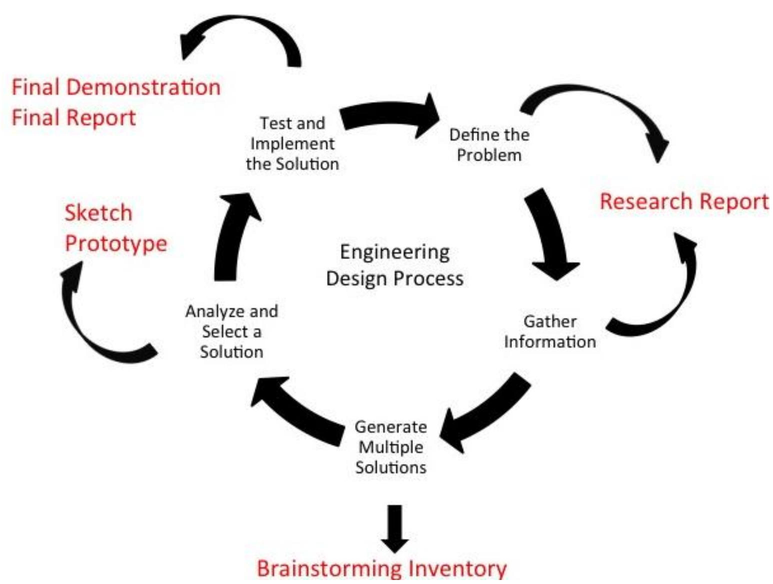

Figure 5. Engineering Design Process (adapted from Howell, *"Engineering Design: A Creative Process," ENGR 1234- Engineering Exploration Tech University*, Pearson Prentice Hall) **and Required Design Assignments**

3.6 Data Collection

In this study I collected data from a variety of sources: observations, interviews, and document review (used to confirm or clarify data obtained from observations and interviews) under the approval of the University's Review Board (IRB #08-421). I used this approach in order to fully describe the behavior of each design team with respect to the aspects of the design project, e.g. tasks, issues, parameters, constraints, and decisions encountered over the course of the design experience. This data is part of a larger corpus of video observations, interviews, and design documents collected under the NSF Award# ITR0757540 investigating creativity and creative practice in design and technology, as well as digital representations in creativity. The research team working under this award employed the same data collection methods, but used a different participant sampling and theoretical framework. The following sections describe the qualitative data collection methods and analysis applied to this study.

3.6.1 Observations

I conducted non-participant observations and video recorded the observations during team design sessions in a predetermined meeting room provided by the researcher. I intended to use data from the unobtrusive observations to gain knowledge regarding how teams interacted with the "structures", e.g. constraints, project parameters, etc., associated with the design project in their natural setting. While it is arguable how natural the design meeting room was with respect to student design practices, I acknowledge that design practices did take place outside of the observational meeting room, e.g. in student dorms or after class in the hallway, but students discussed and created the majority of their design project within the room and even referred to their outside meeting during the recorded design sessions.

The observer and camera position role were in relation to the participants, and design teams conducted their design activities in the same meeting room throughout the design process. The layout of the meeting room was mainly static across team meetings and members typically sat around one table/ large desk for each session. I collected video data using a fixed viewpoint camera position for each of the team meetings and I observed from a non-obtrusive position at a near proximity table. By positioning two fixed cameras in the meeting space, I intended to capture optimal front and back views of the participants in order to record each participant's workspace as best as possible, which usually included design materials and/or their Tablet PC. Heath, Hindmarsh, & Luff (2010) describe certain activities that are more appropriate for data collection under a fixed viewpoint camera position including activities that involve a small number of participants who remain in a relatively set position. Participating teams in this study were composed of 4 members and restricted their movement and interaction to the designated meeting space. Figure 6 diagrams the video data collection set up, illustrating the camera position and positioning of the participants.

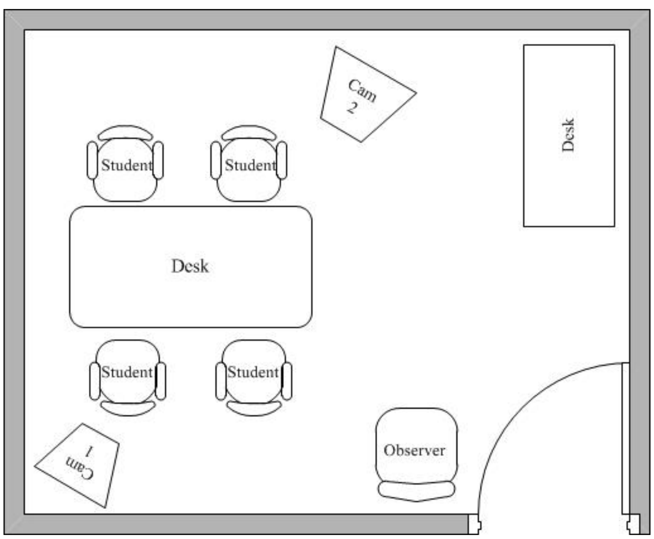

Figure 6. Video Data Collection Diagram

Heath, Hindmarsh, & Luff (2010) also highlight several advantages of the fixed camera position (in comparison to the roving camera method of data collection). One advantage is that the fixed camera records a consistent view of the setting and action while recording activities without having to anticipate future events and will be additionally advantageous during the analysis phase for revisiting data and comparing across cases. A second advantage of this method is that it is relatively unobtrusive and it does not distract or interrupt participant action with camera and observer movement. While the multiple camera viewpoint approach attempts to address some of the limited capabilities of a single viewpoint camera capturing every detail of the session, each camera still has a fixed range of what it is able to focus on for each session. The third advantage is that observers free of camera positioning during the data collection are capable of taking field notes of activities and events not explicit in the video recording. Watson's (1999) perspective on using video articulates that the use of the video ultimately depends on the setting, the questions informing the recording, and the conceptual approach to the analysis. Recording individual teams in a consistent meeting space across the duration of the project allows me to analyze each team and their respective design practices concurrently and consistently.

One of the advantages from Heath, Hindmarsh, & Luff (2010) highlights the added benefit of the observer's ability to record field notes when using a fixed camera position. The research team working under the NSF project helped to develop a detailed and more specific protocol for the observations (See Appendix A). We developed the protocol mainly for the design session related to brainstorming, but the protocol was also applied more generally to the other design sessions. Using this approach, the researcher focused on the following instances and took notes related to the:

- Main ideas that were discussed
- Points of agreement
- Points of disagreement
- Interactions between teams members
- Variability in discussed ideas
- Discussion if ideas were more creative than others
- Role of technologies
- Decision of final idea

The field notes aided in the initial stages of analysis by providing a reference to and overview of the factors I identified during observations. Subsequently, the video recordings were transcribed and coded for the type and path of constraints as well as the associated or underlying structures surrounding the team discussions.

3.6.2 Transcripts of Video Recordings

The author and an undergraduate research assistant transcribed the video data verbatim and edited the transcripts to include notes of when participants were using programs on their Tablet PC or doing tasks that did not involve a normal amount of speaking with one another, e.g. prototype building. We created and arranged the transcripts as a play script (Derry, 2007) with each participant listed in speaking order to follow the chronological progression of the design sessions as captured by the video recording. Sections of the transcripts that were inaudible were either due to participants speaking over one another (marked "crosstalk") or participants not speaking loudly enough to be captured by the microphone (marked "inaudible"). Video data accompanied by the transcripts provided a more holistic perspective on the design practices. This holistic perspective on student design practices is fundamentally important to understanding the salient aspects of the design project and design practices and is also needed to answer the research questions of this study.

3.6.3 Semi-Structured Focus Group Interviews

In-depth focus group interviews were conducted in teams at the completion of the project and aim to gain an insight into the student perspective regarding their experience with the design project and course. The interviews were semi-structured and used open-ended questions as well as follow up / more specific questions related to the foundational ideas and parameters of the DSEP: design, sustainability, and teamwork. The interview protocol (See Appendix B) was originally designed to address the research questions associated with the larger NSF project, but covered very general topics related to the design project and the educational context, which is the focus of this study. I ultimately coded the interview transcripts under the theoretical framework and research questions related to this study.

The basic format of the interviews guided the students' descriptions of their experiences by asking open-ended and follow-up questions. A second interviewer and I asked the participants to reflect on their experience with the design project and the course by writing their thoughts down on a sheet of paper and then describing their experiences to the interviewer(s). The semi-structured interview format allowed for follow up questions related to participants' specific experiences and were adjusted based on the response. For example, we asked students to describe how they chose or arrived at the idea for their final design and in this instance the team members' responses were very focused on the budget parameter in the beginning of the interview. Specifically, the ideas they could design and construct for $20.00 or less. One team initially answered the question describing their experience with the budget parameter, but under the semi-structured format, the interviewer(s) were able to follow up and elicit a more elaborated response. An excerpt from the example interview transcript is provided below (pseudonyms are used to identify participants):

> Interviewer: "*You mentioned that cost was a big factor in choosing your final design, can you think of anything else that contributed to how your design materialized?*"
>
> Craig: "*We just thought it was an awesome idea. It was pretty fun, and the comedy about it just really made us want to do it. We wanted to do something that other people would think was cool, funny, you know…some of the other projects, like* the solar panel light up *book bag or something, it's just kind of generic. I wish ours, I mean ours was kind of*

generic in the sense that other students have done this in the past, but I really wish our stuff could have been more creative. Ours isn't even that creative, so I wish that we could have thought of something a little bit more creative. That would have gotten the idea out there. The idea to produce power would be the same, like any design, but implement it in something else."

From this additional response we were able to see that other factors such as creativity and peer opinion were part of their design selection, but the budget was the first parameter that came to mind when reflecting on their selection. Data from the observations and interviews can possibly support or contradict one another. Analyzing the cases holistically can help to explain if student interview responses are representative of what occurred in the observations.

The data from the interviews relies on descriptive information provided by different people and is based on recollections of past events. I did not utilize video segments to prompt student reflections and descriptions in the interview process; however, the interviews were conducted in teams and the team, as a whole, usually corroborated the recounts of the design experiences to overcome individual limitations of memory. Another limitation of the interview data was that participation in the focus group interviews was entirely voluntary so not every group member who participated in other data collection, e.g. design meetings, attended the interview. To compensate for the missing data, I augmented the interviews with individual team member evaluations (document review data) from each team member to resolve any evident missing data or corroborate it with the interview data. One of the largest limitations of the focus group interview data was that the interviews were not designed around the Nested Theory of Structuration; therefore, the students did not necessarily address concepts specific to structures and contexts.

In summary, the main forms of data I collected in this study were video recordings and field notes of student team design sessions, and video and audio recordings of semi-structured focus group interviews with the participating design teams. Table 5 recounts the data type and description of the collected data, and the following section (3.7.1) describes the analytic approach in using this data.

Table 5. Data Type and Description of Data Collected for this Study

Data Type	Description
Observations	Audio and video recording and field note documentation of in-class design activities, individual team design project meetings, team/ instructor design project meetings, and design presentations. The researchers also created transcriptions of the video observations for analytic purposes.
Semi-Structured Focus Group Interviews	Design project and course follow-up interviews with teams who agreed to meet outside of class for observations recorded with audio. Interview questions elicited student perspective on the role of previous experience and project requirements in their design process.
Document Review	A confirmatory data type, utilizing the design artifacts or assignments collected by the workshop leader as part of the project grade. For example, the brainstorming inventory or final design report was mainly created during the observed design sessions, so if the video data is unclear, the documents serve as a tangible artifact written by the students. Templates of these documents are provided in the DSEP Information Document (Appendix C).

Specifically, Table 6 illustrates the various design sessions collected for each team. Teams generally met based on the deadline for the upcoming design artifact and constructed their sessions or times together around generating these artifacts. Design artifacts were generally due the Friday of every week over the course of the design project; however, due to spring break and a Friday where classes were not held, artifacts were not due during these weeks. The weeks that artifacts were not due (essentially an “off week”) accounts for the variation in how teams met to complete certain design artifacts, e.g. taking two weeks or sessions to discuss brainstorming, which is evident in Team 4A’s design approach. At the same time, the absence of a design session does not necessarily indicate that a team did not participate in a required session, but that other teams decided to meet to discuss their design projects on certain weeks that other teams did not. For example, the project did not require teams to submit an artifact based on their "prototype discussion," but Team 1A met to discuss how they would construct a prototype of their design.

Table 6. Design Session Data Collected for Individual Teams

Design Session	Team 1A	Team 2A	Team 3A	Team 4A
Research Report	✓	✓	✓	✓
Brainstorming	✓	✓	✓	✓
Post Brainstorming				✓
Sketch	✓	✓	✓	✓
Prototype Discussion	✓			
Prototype Building	✓		✓	✓
Final Design Report	✓	✓	✓	✓
Final Design Building		✓	✓	
Final Design Presentation			✓	✓
Final Presentation (in-class)	✓	✓	✓	✓
Focus Group Interview	✓	✓	✓	✓

3.7 Data Analysis

3.7.1 Analytic Approach

Analysis focused on explanation building (Yin, 2009) and utilized within-case and cross-case analysis (Miles & Huberman, 1994), while the theoretical framework, Nested Theory of Structuration, drove my approach to examining the videos and transcripts. Prior to video and transcript analysis, I noticed that teams discussed issues seemingly external to their design project from my observations and I used these incidents to guide my general approach in examining the data. Eisenhart (1989) suggests a two-part analysis where in the first step the researcher analyzes the within-case data by listing events and critical incidents and/or creating taxonomies and networks of the data. Then, in the second step, he or she looks for explanation and causality. In this section of the proposal, I describe my analytical approach to investigating important design aspects and their affect on design practices within cases and then across cases by following the analytical guidelines of Miles & Huberman (1994) and Eisenhart (1989). However, Table 7 first provides taxonomy of the analytic phases. I then detail my approach to analyzing the corpus of video data.

Table 7. General Taxonomy of Analytic Phases

Taxonomy of Analytic Phases
1. Attentively view video data
2. Describe video data
3. Transcribe (methods of transcribing discussed in Section 3.6.2)
4. Identify important segments and critical events
5. Code
6. Construct storyline for individual cases
7. Compose narrative for cross-case comparisons

3.7.2 Analysis of Video Data

Recently, the CSCL and learning science communities have emphasized the importance of analysis and interpretation of video and audio data as part of the research process (Goldman, Dong, Lasiquot, 2009). A common perspective on video "data" is that it is not considered data until a well-document analytic process is applied (Goldman et al. 2007). While the analysis of new media, e.g. video recordings, allows for a multi-dimensional and non-linear approach (Spiro, 2006), another difficulty with video data is the complexity and immense cataloguing of data to archive and analyze (Ash, 2007). Heath, Hindmarsh, & Luff (2010) outline three stages for managing and manipulating the data: i) preliminary review; cataloguing the body of data, ii) substantive review; focus on fragment or segments of valuable data, and iii) analytic review; refined analysis.

In stage i), I began with data reduction by organizing the data to get a descriptive overview of the corpus of data. Followed by simple descriptions and classifications of the video and audio files, I named and described files based on the design session. These major categories included design sessions that focused on research, brainstorming, post-brainstorming, prototyping, testing and analyzing, final design construction, and final report/ presentation construction. Team, semester, and type of design project were more general categories used to identify and catalogue data. Teams generally met based on the design document or assignment, e.g. research report, brainstorming inventory, etc. that they planned to work on during the design session, so it was possible to also categorize the video files by what they created. Categorizing design sessions in these terms facilitated later analysis when coding for patterns in design practices across teams/ cases.

Stage ii) the substantive review of the data included transcription and initial analysis of phenomena, including team discussions around issues associated with the design project, the course (ENGR 1234), and other institutional issues, i.e. issues related to Tech University, the college of engineering, etc. Heath, Hinkmarsh, & Luff (2010) convey the importance of transcription to the research not only as a representation of talk and activity, but as a method of further developing observations and understanding the organization of activities. Multiple coders participated in the initial analysis to derive salient codes and increase the trustworthiness of the analysis.

In the third stage (iii), or the analytic review, I refined the analysis by developing and coding important segments of fragments of the video data for the constructs related to the Nested Theory of Structuration framework. These included structures relevant to the design project and the overall educational setting, e.g. course and institution. I used both inductive and a priori coding in this stage by assigning codes to the data as I watched the videos (inductive), and later coded the videos based on the important and reoccurring constructs and codes related to my theoretical framework (a priori) (Miles & Huberman, 1994). Using a coding scheme that was a result of stages i, ii, and parts of iii, two coders analyzed the video and applied the appropriate codes to each segment. The next section describes the codes and development of the codebook used in this study.

3.7.3 Codebook

The comprehensive codebook evolved to include three principle codes and several subcodes derived from each of the principle codes. This codebook was developed to address the research questions and phenomena associated with the larger study's corpus of data, while one of the principle codes was developed to address the research questions in this study. The three primary codes focused on design, technology, and (design) project themes. This study uses the "project" primary code in its analysis and was developed based on the constructs of the theoretical framework, Nested Structuration Theory. The comprehensive codebook is provided in Appendix D; however, I explain the development of principle code ("project") used in this study in the following paragraph.

I created the codebook following the guidelines of MacQueen, McLellan, and Milstein (1998) and included the sections: code, description, inclusion criteria, exclusion criteria, and example. MacQueen et al. developed this structure to facilitate team-based qualitative analysis, so utilizing this type of codebook was appropriate in stage iii) where two coders analyzed the video segments. The second coder participated in a group viewing of the video data in order to become familiar with the qualitative analysis. This involved viewing the video data from the design sessions (in this instance the design sessions were categorized as “brainstorming”) with researchers that were involved with the larger study and discussing how to code the appropriate video segments. To answer the research questions posed in this study, we decided to develop and employ the principle code, “project”, in the analysis.

The principle code, “project”, had seven subcodes and addressed ideas related to the DSEP as well as the course and institutional contexts. This study’s theoretical framework guided the identification of the subcodes and I developed them inductively as common themes emerged, and refined them at each stage of analysis. Table 8 expounds on the configuration of the main constructs used for developing the project code. Based on the Nested Theory Structuration theoretical framework, I identified the main constructs, i.e. Institutional, Organizational, and Individual, and used those to ascertain the sub-constructs related to the data. Sub-constructs ascertained from the Organizational constructed included, “Course” (Level 1) and “Project” (Level 2). Additional sub-constructs developed from the “Project” construct delineated the sub-constructs, “Project Structure” (Level 2a) from “Project Parameter” (Level 2b). Again, Table 8 indicates the constructs, sub-constructs, and instances of these constructs.

Table 8. Coding Scheme Framework

Construct	Sub-constructs		Instances
Institutional			Curriculum, Course load/ Workload, Infrastructure
Organizational	Course (Level 1)		Course tests, Grades, Homework, Instructor/

			Workshop leader
	Project (Level 2)	Structure (Level 2a)	DSEP Requirements, Objectives, Grading, Cost, Timing/Deadlines
		Parameter (Level 2b)	Functional, Safe, Interesting/ Innovative, Renewable energy source, Possible/ Applicable
Individual	Interaction Patterns		Decision, Discussion, Division of labor

Based on the identified constructs from the Nested Theory of Structuration and instances from the data, I developed the codes used in the analysis of this study. An excerpt from the codebook, including codes and formalized definitions, is given in Table 9 along with instances of when to use each type of code, i.e. inclusion criteria. Once the codes were formalized, the second coder and I coded on the video segments using this convention. After the formalization of the codebook, I trained the second coder to code and create video cases for each code and each team.

Table 9. Codebook Excerpt

Codes based on the theoretical framework, Nested Theory of Structuration		
Code	Description	Inclusion Criteria
Institutional	Related to the institution, including the engineering curriculum, workload associated with courses other than ENGR 1234, and the infrastructure of the institution.	*Instances, circumstances, or existing conditions related to the institution (University). Can be related to the infrastructure and resources, the structure of the curriculum, or the requirements of the institution and/or college of engineering).*
Organizational; Course	Related to the course (ENGR 1234), including course tests, course	*Instances, circumstances, or existing conditions related to the context of*

	grades, course homework, and the instructor/ workshop leader.	*the engineering course (ENGR 1234). Can be related to resources, content material, and requirements for the class/workshop/ project/homework. Also includes student perceptions of these parameters.*
Organizational; Project; Structure	References to or issues related to project components. Specifically related to the given requirements, objectives, and other details stated in DSEP document.	*References to or issues related to project components. Specifically, discussions or decisions based on the DSEP requirements and objectives for each of the design artifacts.*
Organizational; Project; Structure; *(Cost)*	$20 Overall Project Budget	*References and decisions related to the cost constraint/ budget given in the project requirements (DSEP document). Suggestions on use of project budget.*
Organizational; Project; Structure *(Timing/ Deadlines)*	Decisions or discussions based on timing and project deadlines.	*Project deadlines, scheduling, and other time constraints.*
Organizational; Project; Structure *(Grading)*	Related to grading of the project and/or course.	*References to how assignments are graded or student perceptions of how assignments are graded or weighted and the resulting practices.*
Organizational; Project; Parameter	Project Parameters (as defined by DSEP document): Functional, Safe, Interesting/ Innovative, Renewable Energy Source, Possible & Applicable.	*Instances, circumstances, or existing conditions related to the design project (DSEP). Specifically, the functionality, safety, innovativeness, use of energy, and applicability of the design solution and its relationship to or effect on student practices.*

While the analysis (based on the Nested Theory of Structuration framework and constructs) of team design sessions and focus group interviews can identify the mutually reinforcing relationships at several levels, there are some important limitations to this data. While I have no direct evidence of the existence of a reinforcing relationship between organizational and institutional levels, secondary data exists illustrating how the course has changed over semesters.

3.7.4 Within-Case Analysis

In order to understand the dynamics of each case, I analyzed the observation and interview data by individual team. This was possible following stage (i) where I categorized the video data by team and the focus of each design session. The video cases created by the second coder and myself facilitated analysis of individual cases and in-depth descriptions of what aspects of the design project students focused on for each team. This type of analysis is consistent with Miles and Huberman's (1994) guidelines and the analytic approach of this study aimed at answering RQ1, i.e. *what aspects of the design project are salient to students*? Results obtained from this part of the analysis were used to compare across the cases and is discussed in Chapter 5.

3.7.5 Cross-Case Analysis

Based on results from individual cases, I conducted a cross-case analysis to identify common themes or patterns that existed across design teams. Identifying salient aspects of the design project within individual cases helped to inform the identification and discussion on what aspects affect student design practices across teams. Guided by the constructs of the theoretical framework, I discuss how these common themes affect practice at the institutional, organizational, and individual levels. Overall, the cross-case analysis facilitated an understanding of design practices within an educational context, effectively answering RQ2: *how do these salient aspects affect their design practices?*

3.8 SUMMARY OF METHODS

This study utilized qualitative case study methods in order to answer research questions related to salient design project aspects and student design practices. I collected observational and interview data and used document review for any needed clarification of the main forms of data.

The observational data was mainly in the form of video recording of student team design sessions and I followed guidelines from the literature on video research to effectively manage and code the large corpus of video data. Multiple stages and iterations of analysis led to the development of a coding structure informed by inductive and a priori coding. Subsequently, each case was analyzed individually to identify the aspects of the design project that were important to students. Finally, I used the results from the individual analysis to identify patterns or themes that are common across cases in order to understand how those aspects affected design practices. Overall, collecting multiple sources of evidence, building a case study database, employing multiple coders, and several stages of analysis, ensured research quality for this study.

CHAPTER 4: RESULTS: WITHIN-CASE

This chapter reports the findings from the within-case analysis as described in section 3.7.4 and was constructed to answer RQ1: *What aspects of the design project are salient to students*? Sections in this chapter are organized by team (1A, 2A, 3A, and 4A) and guided by the constructs of the theoretical framework used in this study. I discuss the salient aspects of the design project in terms of how often these aspects came up, i.e. discussion, and if they had an impact on design decisions or practices. Quotations and excerpts from team design sessions are provided to support the findings.

4.1 TEAM 1A

Team 1A chose to utilize solar energy as their source of renewable energy ultimately producing a solar-powered canopy for charging electrical devices as their final design solution. Three males, Eddie, Jason, Cory, and one female, Kelly comprised Team 1A; again, all names used are pseudonyms for this team and the following teams. The team members did not know each other prior to working together on the DSEP, but were all in the same lecture and workshop section.

This team had a fairly concrete vision of their design prior to working on the DSEP design activities, e.g. research, brainstorming, and sketching. In fact, they discussed the idea used for their final design within the first four minutes of the first design session and even prior to reintroducing themselves to one another.

Research Report Session:

Kelly: "So, you do want to start now? I was thinking, like, not that I thought about it a lot, but with solar energy we can do something with, obviously outside. So, like, I know *when I'm lying out or something because I lay out a lot. You want outlets and you want some kind of energy, so some kind of thing when you're in an open space like the beach or the pool…"*

Eddie: "You know, like those canopies?"

Although they went through the motions of researching and brainstorming, the team's constraints were based on personal experience and did not significantly evolve with the experience of employing the design process. While they relied heavily on the DSEP document to frame how they approached and completed DSEP design activities, their design practices were also affected by the institutional context as illustrated from their frequent discussions surrounding other courses, interactions with the software assistance team (SWAT), as well as interactions with other students. The following paragraphs expand on their constraints related to the institution, the organization, and their effect on Team 1A's design practices.

4.1.1 Institutional

4.1.1.1 What do you have due and when?

Team 1A was cooperative with one another, and their tasks related to the DSEP were well coordinated among team members. The team members were always cognizant of the assignments due in ENGR 1234 and their other courses, constantly questioning or confirming with one another about the amount of work and when it was due.

Research Report Session:

Kelly: "I have an English research paper due on Thursday, though."

Jason: "Yeah, I got one due, too."

Cory: "I got one due, too, but we're working on ours the rest of the semester."

Kelly: "What the heck? I got it assigned last week. 6 pages."

Jason: "Yeah, we have 4 pages due tomorrow."

The discussions around assignments for the DSEP or other courses were usually focused on the assignment's requirements, how much work/ how long it would take to complete each assignment, and when it was due in comparison to other assignments. These comparisons also evolved into comparisons of course instructors and how they structured the course or tests. Comparing test scores was another salient area of discussion, including how the instructor planned to curve the test scores or determine their final grade.

Research Report Session:

Jason: "But I heard Chang curves at the end."

Cory: "I haven't heard that."

Jason: "Because my friend's in that class and she said that guy who helped her study had it the past semester and he had a 33 on his first test and still got an A in the class."

Eddie: "Oh no, because he takes...he doesn't completely curve; he just takes your lowest grade and replaces it by taking 5 points off."

Cory: "Even though I got a 20 I can still get up to a 96. Because 5% is like 5 points off your final grade."

Jason: "I'm just trying to pass my class."

Kelly: "Yeah, the same."

Cory: "I'll be happy if I get a B or a C."

Jason: "I'm looking for a C-."

This comparison and evaluation of their performances in other courses as well as the ENGR 1234 course continued throughout the team's design sessions, but was mainly a discussion to inform one another about how other courses were structured and about methods or tactics that would affect their performance in ENGR 1234. For example, Team 1A members would discuss assignments and tests related to ENGR 1234 that led to discussing existing practice tests as a study tool that other members were not aware of.

Prototype Building Session:

Eddie: "Did you guys study yet?"

Cory: "I feel like this stuff is common sense, like you know it or you don't."

Kelly: "I feel like you might…yeah it's like chance."

Eddie: "Yeah, I took the little practice test thing."

Jason: "I didn't study at all. We have a practice test?"

Eddie: "It's the one from last semester."

Cory: "I took my roommate's test from like last semester."

The discussions around other courses and assignments (not directly related to the DSEP) were typically a method to learn about each other's work and gauge their own. At times, this type of discussion dominated the time spent in the design session, but in some cases they used team member workload outside of the project to decide on how to divide the individual assignments for DSEP artifacts they needed to submit. The team first divided the research report by sections (as designated by the requirements in the DSEP document, e.g. historical benchmarks) and then assigned or chose to write about those sections based on how much writing they perceived each section would need to be included in that section.

Research Report Session:

Eddie: "Is anyone like really busy this week? Cause I would just say, if you're not that busy this week, then you would take the longer one. That makes more sense."

Eddie: "I'll do historical benchmarks, just because my How Stuff Works project is due this week too."

Kelly: "Oh yeah, definitely. I'll definitely do the longer one."

Using the amount of work due outside of the DSEP not only affected their decisions regarding how they approached writing the research report, but also led to later practices that affected the research report itself. Eddie mentioned the amount of work he had due during the time when they were working on their individual sections (outside of the research report design session); the time consumed by other assignments affected how he approached writing his section of the research report.

Brainstorming Session:

Jason: "What happened?"

Eddie: "I did my research thing and I wasn't even really thinking about it, I was just writing down what the website said. And it was word for word what it was and I mean..."

Kelly: "Well, I just didn't want anyone to get in trouble and I didn't know how she would handle it. She seems cool, but..."

Eddie: "No, she just emailed me right now to see her sometime this week."

Kelly: "She was cool about it though. I was just like, I don't want this to happen again."

Eddie: "No, it's completely my fault. My bad. I just had 17 things to do so I was just like, maybe I can get away with this. Clearly I didn't, though."

In this instance, the amount of time consumed by other assignments led Eddie to plagiarize his section of the research report, subsequently causing Kelly to spend additional time revising his sections because she was in charge of compiling individual member's sections. Additionally, how individual members approached their time management of writing the research also varied, but was similarly impacted by the amount of work required by other assignments.

Research Report Session:

Kelly: "Are you writing yours now?"

Jason: "Yeah! I got to get this thing done; I got a lot to do."

Cory: "It shouldn't take that long."

Eddie: "I have too much work to do."

Kelly: "I have that paper due tomorrow."

Team 1A never explicitly questioned the requirements for the DSEP artifacts, but did closely follow the requirements explicated in the DSEP document. They also reassured themselves and one another that "it shouldn't take that long" or "it shouldn't be that bad." Similarly, they attempted to manage their overall workload by addressing a given assignment during designated times or when they completed other assignments or classes, "Well, I have class until 2, so I'll do it after 2."

4.1.1.2 Well, what my roommate did was…

Other institutional aspects played a role in how team members evaluated the amount of work and requirements associated with the design artifacts. The next section highlights the impact of team members' interactions with other students as part of the institutional context and its impact on their design practices. Cory specifically referenced and used his roommate's experiences with the DSEP to help conceptualize how they approached different design practices. From how they considered different components for their design to how they perceived the DSEP requirements, he referenced these prior experiences to help inform Team 1A's design decisions and practices. Prior to brainstorming ideas, Cory used his roommate's DSEP project idea to reinforce Team 1A's initial design concept by providing methods in which they could help their own design concept to materialize.

Research Report:

Cory: "My roommate did solar power last semester and he did, like, a solar fan and put a plant box behind it and put the solar panel mounted on top of the box. And he hooked it *up with rechargeable batteries. He put a desk lamp over it before he went to class to charge it… and it'll work."*

Making the design "work" was also influenced by Cory's roommate's experience with the design project. This influence included if the final design had to "work" as well as how they approached building the prototype and what requirements were associated with a completed prototype.

Prototype Discussion:

Eddie: "It doesn't have to work either, right?"

Cory: "My roommate's worked. But I think they want you to try to make it work, but I don't think...."

Later in the Prototype Discussion:

Cory: "My roommate used the same one for both. For the little..."

Kelly: "Maybe we could buy all the parts but not put it together."

Cory: "Yeah and just explain what it's going to be. 'Cause that's what he did. He didn't have it finished so they just took what they had and told what the finished thing would be."

The previous excerpt illustrates how the team was also generally unsure of what was required for the prototype or the final design, so they used a combination of referencing the DSEP document and relying on their interpretation from other students' design experiences. Being unclear about exactly what they had to do for the design artifact requirements, e.g.

requirements for the prototype or final design included in the DSEP document, led the team to reduce the design requirements of their initial concept as they worked through the design phases. For example, Team 1A had a rechargeable battery component (based on the roommate's previous project) in their design to improve the functionality, but ultimately abandoned this idea as the team progressed through the design process and began eliminating design requirements. As the team reduced requirements needed to make their design "work," they eliminated the battery component from their final design. When hashing out what they needed to include in the DSEP final design report, Cory referenced the rechargeable battery pack, but realized that while the inclusion of a battery would assist in making the final design "work," it was not needed to meet what they perceived as the requirements for the final design and final design report.

Final Design Report Session:

Cory: "I feel like it has to be in this [Final Design Report]. Like, either it didn't work or it did haha."

Jason: "Yeah, that's probably true."

Cory: "We could just say, we found that it puts out really low voltage."

Eddie: "Yeah, I mean it does, so."

Cory: "And it wouldn't be ideal unless you charge a battery."

Team 1A's constraints were initially based on interactions with other students within the institutional context, specifically students who previously worked on the DSEP, and they used this to constrain what they perceived they could produce in terms of a final design. Cory referenced components of his roommate's DSEP to reinforce the team's initial idea to use a rechargeable battery pack, but ultimately eliminated this component when they were not able to borrow a solar panel or the rechargeable battery pack from his roommate. After the team was not able to obtain the solar panel and rechargeable battery pack used in the roommate's previous design project, they purchased the solar panel on their own and reduced the design requirements to lighting an LED directly from the solar panel.

4.1.1.3 Ok, when do I have a couple of hours to sit here?

In addition to the workload outside of the DSEP and the influence of previous student experiences, another institutional factor that impacted student practice was related to an ENGR 1234 course requirement that relied on the institutional infrastructure to implement and use. The next section related to institutional factors and student practice illustrates one of Team 1A's member's experiences trying to install and work with LabVIEW as required by ENGR 1234.

Installing and working with LabVIEW was a problem for Kelly throughout the course and ultimately affected her homework grades associated with ENGR 1234; problems related to LabVIEW were also salient in terms of how often it came up throughout design sessions. The team used the time in design sessions to discuss problems they encountered involving LabVIEW and offered suggestions to overcome these problems based on their own experiences installing LabVIEW.

Sketch Session:

Kelly: "So I couldn't do my engineering homework."

Eddie: "Why?"

Kelly: "I've been at the SWAT team like 8 times and they could not get..."

Cory: "The Labview one?"

Kelly: "9.0 and I only have 8.6."

Cory: "See, that's what mine was, but I just reinstalled it."

Kelly: "They did that and I was like, what can I do? And he was like, 'you can come back next week.'"

Kelly attempted to download the required version of LabVIEW and sought assistance to resolve this issue through SWAT (Software Assistance Team), however due to the time required by SWAT to solve this problem, she was unsuccessful. The LabVIEW installation issue continued to arise in other design session discussions. Kelly reflected on her experience with SWAT, LabVIEW, and the impact these issues had on her course practices related to homework during the focus group interview.

Focus Group Interview:

Kelly: "My LabVIEW 2009 did not work; I went to SWAT like 3 times and he was like, it's not going on your computer. The only thing I can do is, you can come in here when you have a couple of hours on hand. And I'm like, ok when do I have a couple of hours to sit here? And I can uninstall everything on your computer and completely erase your hard drive. So I didn't do my homework."

Eddie: "Why didn't you do that?"

Kelly: "Why didn't I do that? So I didn't do some homework and I wrote that reason and got all of the points taken off. So then I just really..."

Jason: "You should've just had a friend send you a screen shot of theirs. And you're good to go."

Cory: "I feel like there were more people that encountered the same problem. I heard about people having a lot of problems."

Eddie: "Did you learn about ethics, haha?"

Jason: "Well, if it doesn't work that's not my fault…this class is all about learning how to pass."

Kelly: "So then I couldn't download LabVIEW vision so I got a 0 on that homework, too. It was really good ha. Just great. And it's not my fault, its technical problems."

The LabVIEW installation issue represents a couple of factors related to the institutional context and the resulting student practice. First, the amount of time required to resolve the issue was not feasible based on the time required by other assignments, so not having "a couple of hours" to devote to LabVIEW reinstallation resulted in Kelly not doing the homework required by the ENGR 1234 course. Second, Jason suggesting that Kelly use a screen shot of a friend's homework and Cory referencing other students' similar problems reveals how student practice related to the course, or organizational context, is impacted by student interactions with one another within the larger institutional context. The team members often relied on the experiences of other students and each other's experiences to develop practices that would assist them in satisfying the requirements associated with the project or course; this perception is also reinforced by Jason's comment, "This class is all about learning how to pass."

While one team member viewed the course as an exercise in learning how to pass, the data suggests that the impact of the course, as related to the organizational context, was not salient in terms of how it impacted team design decisions, or how often it came up in design sessions other than when it related to homework or assignments. The next section discusses practices related to the organizational context and the relationship to student design practices.

4.1.2 Organizational

4.1.2.1 That course is pointless half of the time; ***Course (Level 1)***

Team 1A members did not see the course in relation to the DSEP. They rarely referenced concepts or practices related to the lecture or workshop components of the course and when they did, it was usually in passing and not salient in terms of effects on design practice. For example, one team member referenced a brainstorming technique provided in the course textbook, but the group quickly overlooked this suggestion and relied on the requirements stated in the DSEP document.

Brainstorming Session:

Eddie: "Remember that thing in that book? If you really want to do it, it's just 5 or 2 minutes where we just think of ideas and say them. Then you write down stuff you think of. Just keep going that way. You don't have to, I'm just saying you could work at it that way and it might be easier.

Kelly: "That's the thing...her example was...a wind powered elevator. ...And that's one. So we just have to think of 20 and they can be from any. Like, it doesn't have to be solar; it can be any source."

If requirements or other methods related to the design process were not explicitly provided in the DSEP document, the team quickly overlooked them. They usually went through the motions of satisfying the requirements associated with the design artifacts and did not attempt to incorporate concepts related to the course as part of their design process, i.e. use the previous phase to inform the next. Instead of constraining their search during the brainstorming session by the research they completed in the previous design phase, they chose to use the unconstrained requirements of brainstorming the use of any renewable energy source in order to fulfill the 20-idea minimum for the brainstorming inventory. Similarly, they saw the brainstorming inventory as an exercise to generate ideas, but not necessarily feasible ideas.

Brainstorming Session:

Kelly: "I think we just need ideas. I remember her saying that it didn't matter if things were stupid; do you remember her saying that?"

Eddie: "Yeah."

Cory: "I mean those examples were stupid too, so..."

Again, this team had a fairly concrete idea of what their final design would be early on in the design process so they viewed the design activities, e.g. the brainstorming session, as other assignments or tasks to complete as part of the course. While the team generated ideas that they perceived as "stupid," they ultimately justified their final design by eliminating "things that weren't reasonable." This view of the course as more of a requirement than anything else was also illustrated through their discussions during the design sessions. For example, in the brainstorming session, they discussed whether they attended the weekly lecture.

Brainstorming Session:

Kelly: "That course is pointless half of the time."

Jason: "I just get a milkshake and go there and eat that...the whole time I'm there, just go and hang out."

Cory: "All we did last week was watch that movie."

Jason: "That movie was retarded, I watched a little of it, but I was playing solitaire for a very long time."

While the data illustrates that students are consumed by assignments and other coursework (section 4.1.1.1), they still attended the course lectures and workshops regardless of their practices during the lectures or workshops. Other team members also reiterated how they engaged in practices outside of the organizational context, e.g. looking at emails or doing homework.

Focus Group Interview:

Kelly: "That was like the time when I'd go in and look at my emails."

Cory: "So if you didn't pay attention, you had the notes in front of you. Haha."

Jason: "If you're on DyKnow you could just scroll all the way down and save."

Cory: "Half of the time I did the homework during class."

What they perceived as salient to the organizational context, i.e. attending lectures and workshops and completing assignments, impacted how they viewed design activities related to the DSEP. Specifically, the design artifacts were viewed as assignments rather than artifacts associated with phases of design process. This was further illustrated by their perceptions of the DSEP structure; the next section discusses how Team 1A used the constraints of the DSEP structure to shape their design practices.

4.1.2.2. A step-by-step process; ***Project Structure (Level 2a)***

Team 1A used the constraints of the project structure to frame how they approached the design project. The team met weekly in order to accomplish the tasks associated with each phase of the design process by the given deadlines. The team members were aware of deadlines (determined by the course), but typically were not aware of specifics regarding what design artifact they would be working on when they first attended the design sessions, or before consulting the DSEP document. One member would typically confirm with the group, "So we have the sketch this week?" or "And our prototypes are due next week?" This practice of working on design artifacts in terms of weekly assignments was also apparent as the team members reflected on what they liked about the design project during the focus group interview.

> *Focus Group Interview:*
>
> *Kelly: "I like how it was a step-by-step process and something was due each week rather than all at one time because it helped us not fall behind."*
>
> *Eddie: "The whole idea behind it, I think it was better you had steps to complete each time because it made it less stressful. It was more like, 'I have to complete that by tonight' and just do that. As opposed to being like, the entire week, 'I gotta finish this, I gotta finish that'."*

The constraints related to project deadlines enabled the team to focus on the design artifacts, e.g. research report, brainstorming inventory, etc., individually and complete individual design artifacts before moving on to the next phase of the design process. However, the constraint of a weekly deadline also hindered the team from perceiving the design process as phases that related to one another. While they tried to satisfy the requirements stated in the DSEP document associated with each artifact, completing these tasks rarely impacted any subsequent decisions related to their final design solution. Additionally, team members relied on initial assumptions regarding their design concept, overlooked any data gathered from their research, and did not use the data to inform subsequent phases of the design process. One assumption the team worked under in the early stages of the design process was the physical representation of a solar panel. The rigidness of a conventional solar led the team to consider a canopy structure over the folding umbrella.

Brainstorming Session:

Eddie: "The problem would be…how would you close it?"

Cory: "The research that I did, they have them...they're printing solar panels on sheets like newspapers now." "Yeah, they are really flexible because they're made out of silicone. And they can make them paper thin, so that wouldn't be a problem."

Kelly: "I guess we don't have to do all of this tonight at our meeting."

Cory: "Is this one due this week?"

This assumption remained unchallenged after Cory shared his findings from the research phase as the team moved forward with concerns about project deadlines. Even when prompted by requirements stated in the DSEP document for subsequent design artifacts, i.e. sketch, team members did not express how artifacts associated with early phases of the design process, i.e. research report, were connected to design idea selection in the later phases.

Sketch Session:

Eddie: "We could say, we decided it was the first thing we thought of."

Jason: "I mean the brainstorming stuff..."

Eddie: "It says pay special attention to the role your research played and why you ended up with your selected design, and also put a description of the function of your team's design."

Kelly: "We could, kind of say we narrowed it down."

And later in the Sketch Session:

Eddie: "Can you send me the list of ideas so I can just make up some random...how we narrowed it down."

Kelly: "Yeah. I'll send it to everyone."

While this team generally worked in compartmentalized phases of the design process, they were able to use the requirements of the sketch to inform later decisions regarding their final design solution. Specifically, the DSEP document required each team member to produce an individual sketch for his or her final design solution. One team member stated that the point of the sketch was to "get different ideas" and then they could compare the sketches in order to consider which design solution sketch was more "cost efficient." In this instance, each team member sketched a design they perceived met their design requirements of using solar energy to power electrical devices outdoors. However, the different design ideas represented in individual team member sketches were ultimately overlooked in terms of cost efficiency for “sturdiness.” The functionality parameter associated with the design played an important role in Team 1A’s design practices as they progressed and built a working model for their conceptual design.

4.1.2.3. Something more useful; ***Project Parameter (Level 2b)***

Team 1A committed to a specific direction upfront, i.e. using solar energy and applying it to an outdoor canopy, and used the constraints related to the project parameters to shape their design practices as they progressed through the design process. While the project structure didn’t greatly impact practice related to their initial design concept, the project parameters associated with the DSEP, i.e. functionality (“functional”) and applicability (“possible/ applicable”), were salient in terms of how it impacted the team’s design practices.

The functional and possible/applicable parameters were constraints throughout the design process and team members would typically revert to questioning whether or not a suggested idea would “work.” This came up throughout the brainstorming session when they discussed possible ideas to use as their final design. By constraining their search using the parameters related to functionality and applicability, the team did not seriously consider ideas outside of their initial design concept. The following excerpt illustrates how team members perceived geothermal as a renewable energy source for their final design; they ultimately chose solar energy based on their assumptions of how solar energy could be applied to their design.

Brainstorming Session:

Eddie: "If they're [geothermal Christmas or street lights] connected to the ground. I mean they have a long...instead of just having an outlet it would just go into the ground."

Cory: "I'm not sure how that would work."

Kelly: "Neither do I. I think we just need ideas."

The team's requirements for the final design, e.g. lighting an LED, and being "sturdy," also evolved based on the application of the functionality parameter and led them to develop a canopy with a four-post structure rather than the two-post structure, or the umbrella. The "sturdiness" of their design was a factor as they discussed how to build their design and even outweighed cost when determining their approach to materializing a design solution.

Sketch Session:

Eddie: "Well, yeah, but we'll see the actual construction elements. If you have two posts compared to four posts as compared to one post or 2 posts it's going to be.... and we'll look at if it's more sturdy."

Kelly: "Yeah, sturdiness would be a big thing I think. That's why I thought a canopy would be better."

Eddie: "Like, how windy will it be to stand up? Cause umbrellas, they always shake."

Kelly: "And they blow over."

Cory: "Yeah or flip inside out. We need something more stationary."

It was also interesting that the cost constraint was not mentioned in design sessions until the end of the sketch session. While they briefly considered choosing a design that was "more cost efficient," they continued to build their design regardless of what they actually spent on purchases and manipulated the cost constraint later in the project.

> *Prototype Building Session:*
>
> *Cory: "We just got to make sure we keep it under $20, which I don't think will be a problem."; "My roommate said too for stuff they...they bought stuff and theirs ended up being $21, or something. They just went on eBay and found the price and printed out a receipt."*
>
> *Kelly: "That's a good idea. Go on eBay."*

They implemented this technique of manipulating actual costs when the DSEP requirements for the final design called for an appendix showcasing the receipts for all the project's purchases.

> *Final Design Report:*
>
> *Jason: "This was 15[$]...the panel was 15 [$]. This [wood used to make the model]… I'll write up a statement from my dad's business that it was $3 haha. And that gives us $2 to look for an LED.*

Cost was not a factor in the purchase of the solar panel and the purchase of the team's solar panel was based on availability, i.e. the only solar panel available at RadioShack. Even though the purchase of the solar panel consumed 3/4 ($15) of their overall budget, the team moved forward with building the structure of the canopy and manipulated the cost constraint by providing receipts from Jason's dad's construction business outlining the amount of money ($3) spent on scrap wood, nails, and screws. While cost was a factor in leading the team to abandon the inclusion of the battery pack in their final design, they ultimately chose directly lighting an LED because it met the minimum requirements to make their design "work." They confirmed their assumptions of what was needed to make the design functional by stating, "All it has to do is light the LED and if it doesn't light the LED, then it doesn't work, but if it lights the LED, it works and if it does it works."

Overall, the team did not realize they were constraining the development of their design by adhering to the functionality and applicability parameters from the beginning. They perceived their initial design to be different from their final design due to how they worked within the constraints to ultimately produce a design that worked. Cory and Kelly reflect on this in the focus group interview at the completion of the project.

Focus Group Interview:

Cory: "I think it was interesting to see how much we actually changed from what the starting thing was like. We started out with a two-post thing and we ended up with like a four-post structure. And we were going to power an electrical outlet at first, and we ended up powering an LED. So it's just interesting to see as the steps went through, how it changed.

Kelly: "Yeah, we definitely made it more functional by the end because I pictured it literally as an umbrella, a single umbrella at the beginning which would have been very un-useful and not sturdy. So I feel we turned it into something more useful."

Ultimately, they perceived their final design as functional and possible/ applicable by describing a design that was "useful" and functional in terms of a "sturdy" design that was able to light an LED.

4.1.3 Team 1A Summary

The data suggests that the constructs associated with the institutional context and the project parameters associated with the organizational context were the most salient in terms of impacting Team 1A's design practices. While their concrete vision of the final design was decided on early in the design process, they went through the motions of creating the design artifacts required by the project. They viewed these artifacts as assignments rather than steps associated with phases of the design process and typically overlooked information gained from previous phases. The project parameters related to functionality and applicability were the most salient in terms of their effect on student design practice and led the team to make decisions based on creating a sturdy and functional design. The cost constraint was not salient in terms of greatly affecting design decisions and did not even arise in the early stages of the design process. However, the team did consider the budget overall, but manipulated already completed practices to fit within the cost constraint.

4.2 TEAM 2A

Kevin, Coleman, Jim, and Gary were the members of Team 2A and designed a hydro-powered bridge [light] for the DSEP. The four members did not know each other prior to the design project, but became friends after the project, "Before this project, we were all complete strangers, but because of this project, we are all friends" *(Final Design Report).* This team worked well together over the course of the DSEP; "We were all able to jell [gel] together, which is a blessing since we were randomly put into these groups" *(Final Design Report),* and attributed the importance of group work as part of their DSEP learning experience. The data also suggests that other organizational and institutional factors influenced Team 2A's design practices, and the next sections discuss the impact of each of those contexts.

Overall, Team 2A constrained their search by project parameters, i.e. functional and possible/ applicable, and ultimately used the constraints of the project's structure, e.g. use of the design process and deadlines, to inform design decisions in developing their final design. More specifically, this team used the early phases of the design process to inform later design phases and had a concrete idea for their final design after completing their design sketches. Making a working model was a salient factor throughout the design process and suggestions related to the development of the final design were usually questioned by asking, "but how would that work?". Video design session data suggests the team's focus was mainly on the parameters related to functionality and applicability, but other institutional factors such has workload in other courses impacted assignments related to the DSEP. The following section highlights salient instances related to the institutional context.

4.2.1 Institutional

4.2.1.1 Say, probably, work ahead on things. Time management.

The organization of the DSEP was fairly rigid and instructors determined the project requirements and deadlines prior to the students beginning work on the project; this information was also provided to students in the DSEP document at the start of the project. Team 2A reflected that adhering to these deadlines was difficult at times due to the influence of factors outside of the DSEP. They perceived their DSEP learning experiences with respect to managing their workload and deadlines, i.e. "time management". However, when team members were unable to manage workloads and deadlines appropriately, it impacted the completion of other DSEP design artifacts. The following excerpt suggests that one of the team members prioritized outside assignments, e.g. test, quiz, homework, and DSEP team assignments, e.g. report, prototype, over submitting the required team evaluations as part of their individual DSEP grade.

Focus Group Interview:

Jim: "The importance of deadlines. I didn't turn in my team evaluations even though it's like something really easy. I just forgot to do it."

Later in the Focus Group Interview:

Jim: "I don't know...the one week where we had the test, report, prototype...we had a whole bunch of stuff in one week, and a quiz and a homework just all in one week and one class. Just learning...getting through rough times, because you're not always going to have enough time to do everything so you're going to have to buckle down. Because I get distracted pretty easily with video games and computers and everything. So it was like, I had to discipline myself to eventually just do everything."

Gary: "I think it was just time management and I guess also just the dependence or depending on your group members, just getting everything done as a team."

Assignments that did not affect the team in terms of shared grades or shared workload were not prioritized relative to completing other assignments. For example, the team evaluations were individual assignments and team members received separate grades. Subsequently, team members would often "just forget" or not "think about it" submitting their individual team evaluations if they needed to complete other assignments: *"Like, I had some computer science project due that night right after the test so...I wasn't even thinking about it" (Gary, Focus Group Interview).* While this team didn't focus much of their design session discussion around the amount of other coursework or workload not related to the DSEP, they often expressed how much work they felt the DSEP design activities required during their design sessions: "*And then, this research thing...it's so much work" (Jim, Research Report); "I didn't realize this was all due. This is actually going to be a lot of work" (Jim, Final Design Report).*

In order to manage the workload associated with DSEP design artifacts, Team 2A attributed having a set time and working as a group as two factors that facilitated their completion of the design project.

> *Focus Group Interview:*
>
> *Jim: "Honestly, if we didn't have to or if we couldn't have done it in a group...doing all that work, there's no way. From all of the work we had to do there's no way, if we weren't in a group."*
>
> *Kevin: "Yeah I said working in the group was much better than if we had to do it ourselves."*
>
> *Later in the Focus Group Interview:*
>
> *Gary: "I feel like it was a benefit, like having a set time."*
>
> *Kevin: "That was better...if we didn't have a set time every week, that would've been bad."*

The design session data also illustrates the amount of time spent on the task at hand during design sessions, e.g. writing the research report or producing a sketch, was greater than the time spent on discussing issues not related to the design project. This team completed or completed the majority of the work for the design artifacts during the design sessions. Using the set time to work together not only facilitated the completion of the design artifacts required by the DSEP, but also helped the team members to develop and conceptualize their final design solution as they progressed through the design process. The following section discusses how the structure of the DSEP enabled Team 2A to complete the design project and helped to develop and materialize their final design solution.

4.2.2 Organizational

4.2.2.1 Sketching. We had to make a sketch. Turned out to be beneficial; ***Project Structure (Level 2a)***

Team 2A used the structure of the DSEP, i.e. use of design process, to guide their approach to design and eventually arrive at a working final design solution. While they sometimes went through the motions of completing design artifact requirements by including fabricated information only because it was required, e.g. "include a 1-2 paragraph description of how your team narrowed down the ideas from the brainstorming session to select this design",

> *Sketch Session:*
>
> *Jim: "How we narrowed it down? Like, how did we find this was the best option? Just make it up.*
>
> *Kevin: "Alright let's make it up. It's like 1-2 paragraphs."*

They generally used the requirements of the DSEP artifacts to inform subsequent design decisions throughout the design process, which is evident in Team 2A's brainstorming and sketching sessions.

Additionally, using the design phases to inform each other prevented Team 2A from rejecting ideas too early or imposing imaginary constraints based on their assumptions. For example, before the team began researching solutions that utilized hydropower, their initial assumption was that the main uses for hydropower were dams. After researching and generating multiple solutions during the brainstorming session, the team expanded their search to include design ideas that incorporated water wheels or turbines.

The brainstorming session is also an example of how the team used their time together during design sessions to understand concepts and build off of each other's ideas. Below, one team member reflects on the impact of the brainstorming session and how it affected decisions regarding their path to a final design solution.

Focus Group Interview:

Interviewer: "Was there anything in particular, or one phase of the design process that was more helpful than others?"

Jim: "Generating multiple solutions. When we had to make the brainstorming thing. If we just came in and thought of the first thing...I don't remember what our first idea was, but it probably wouldn't have worked."

Gary: "The rain gutter."

Jim: "Once we started dumping out ideas, one idea contributed to another idea and contributed to something else. And that really helped us make...so we could all be like 'wow, that would probably work or that would be easy to use' instead of just..."

Previous experiences with the course design activities also influenced this team to expand their search for solutions and not rely on initial ideas. Jim reflects on a workshop design activity where his team (not the same as the DSEP team) used their initial idea, which proved to be unsuccessful.

Sketch Session:

Jim: "Or no, remember we had to build that thing? My group was like, 'this is the best idea ever' and we only thought of one idea and did it. And we were like, 'dude, we're going to win.' And it totally wrecked and we were like, 'whoa'."

One difference between how the course design activities are structured and the DSEP is that the DSEP necessitates teams to complete design artifacts associated with each phase of the design process before continuing to the next phase. The preceding data suggests that requiring the team to complete the brainstorming inventory led them to not only generate multiple solutions, but also enabled them to consider different alternatives. Sketching was another design activity and phase of the design process that Team 2A used to conceptualize their design solution and inform decisions related to building or "making" a prototype. One team member particularly found the sketching activity to be useful in their approach to design: *"Sketching. We had to make a sketch. Turned out to be beneficial" (Jim, Focus Group Interview).*

Team 2A members created individual sketches, but worked on the sketches as a team during one of the design sessions. The requirements for the sketch, which included drawing top, front, and right views of the design, led team members to question the exact components of their design and it's overall purpose. The following excerpt from the sketching session illustrates the team's discussion surrounding what they viewed as their final design idea, how to represent it, and what they needed to eventually build.

Sketch Session:

Kevin: "What is the front going to be? Is it going to be the profile of the bridge or going down the bridge?"

Coleman: "I don't think we'd draw the bridge."

Jim: "What would we draw?"

Coleman: "We'd draw the thing we're making."

Gary: "Let's do it. Let's draw the bridge."

Jim: "We have to make it."

Kevin: "The bridge is the thing we're making."

Jim: "Oh no, yeah you're right, it's not...we're making the generator thing."

Gary: "Let's try both.

Coleman: "We're making the spinny thing that connects to the generator. That is our thing."

Jim: "The turbine is what our project is. The other stuff is more like..."

Gary: "But I'm saying..."

Coleman: "The other stuff is more like..."

Gary: "…what the turbine powers."

Kyle: "The bridge is more like..."

Coleman: "…is what it powers."

Jim: "Yeah, we just have to draw the thing that's got the..."

Gary: "The turbine...or I guess something that's connected to what it powers. Are we going to try to do like, a light post?"

Jim: "You can get little Christmas lights."

Gary: "They're just little posts with light bulbs? I was thinking it was huge posts."

The sketch (one example of a design artifact) and the discussion generated by the sketching activity not only helped the team delineate the components of their design, e.g. bridge, turbine, generator, but also prompted the team to discuss how they planned to obtain the resources needed to build a working model. In this case, the structure of the DSEP was salient because it guided Team 2A through the design process and helped them to develop their design ideas. However, the project structure's low constraint regarding what materials students can or should use often led to unclear student perceptions on what materials they needed and how to obtain them. After team members agreed on the components and layout of their design they were still unsure of what they would need to purchase and where they could purchase these resources.

Sketch Session:

Jim: "Now how do we go about...I'm still kind of puzzled on the whole generator and electrical wires and stuff like that."

Kevin: "We should just buy it man."

Coleman: "Yeah we should."

Jim: "I just don't see it anywhere, like I don't see the little electrical engineer generators."

Kevin: "You don't usually need them in everyday life."

Gary: "It's yours, for $19.99 haha".

Kevin: "...go pick up some generators please, we're out. You don't need this. Specialty item."

Jim: "So where are we going to find it?"

Kevin: "I'm hoping they'll tell us in workshop, about where to get some little motors. That's what my roommate said because he did this last year."

Jim: "That's what he told you?"

Kevin: "Yeah."

Later in the sketching session team members suggested going to Wal-Mart to look for generators, or Lowes because other teams planned to shop for DSEP materials/ resources at that location. Interestingly, the team's low constraint on where to purchase design components coupled with the DSEP cost constraint led this team to purchase and deconstruct an emergency or hand crank flashlight at Target. The following paragraphs discuss Team 2A's decision to purchase the emergency flashlight and utilize its components for their design.

After Team 2A decided to include (and ultimately construct) the bridge component in their design, they purchased Popsicle sticks, balsa wood, a hot glue gun, and glue sticks. They viewed Popsicle sticks as *"the best value to construct the model bridge" (Team 2A, Final Design*

Report, p.3), but dedicated over one fourth ($5.79) *(Team 2A, Final Design Report, Appendix A)* of their overall budget to purchase a hot glue gun and glue sticks in order to follow through with the construction of the bridge. With $9.43 dedicated to the bridge materials, the team realized that they would not be able to purchase the remaining components needed for their design individually and remain within the $20 DSEP cost constraint. The following excerpt from the team's final design report illustrates the rationale behind their decision to purchase the emergency flashlight.

> *"Because we had a price restriction on the design, we had to economize. Our group found Popsicle sticks to be the best value to construct the model bridge. Popsicle sticks have a minimum cost and when stuck together are actually sturdy. One of the most expensive items was the glue gun and glue sticks. Since no one in our group had this tool, we had to use part of our budget to provide for it. Our group also had to purchase one thin rod of balsa wood that was used to connect the Popsicle sticks that were used in designing the water wheel. The last item needed was a turbine, battery, and light bulb. Individually purchased, we would have not been able to afford these items. However, our group had the idea of purchasing a hand crank flashlight. By opening the flashlight, we found a battery that was able to be charged by turning a turbine that is already connected to a light bulb. Once we pulled apart the flashlight, we could rewire the connection that allowed us to have more room to work with" (Team 2A, Final Design Report, p. 3).*

Cost was not a salient factor in the early phases of Team 2A's design process in terms of discussion or impact on subsequent design decisions. The design session video data suggests that this team was not conscious of the constraint until they needed to purchase the remaining components not related to the bridge, i.e. turbine, battery, and light bulb. Additionally, they did not discuss distributing the cost between the team prior to one member purchasing all of the materials: *"I'm not trying to be a jerk but like, that stuff I ended up buying cost about $20. I didn't know if anyone wanted to split it up 4 ways" (Jim, Final Design Report Session).* Constraints that were salient in terms of discussion and their affect on design decisions were the factors related DSEP parameters. The following section illustrates how Team 2A used the DSEP parameters to guide design decisions and develop a working model.

4.2.3.1 I said making a working device was a challenge; ***Project Parameter (Level 2b)***

The project parameters related to functionality and applicability influenced Team 2A's design decisions throughout the design process, but were more salient when deciding on a final design idea. The following excerpt from the sketching session highlights that building a working model was a salient factor in considering different design alternatives.

Sketch Session:

Gary: "True, I do kind of like the whole toilet one. I'm not going to lie, I do like it."

Jim: "We were talking about a toilet..."

Gary: "…when you flush it, it powers an air freshener."

Jim: "How are we going to build that?"

Gary: "I don't know, but I just like it, because it is reasonable. I like it."

Jim: "I'm not really sure how, actually, when you turn turbines it actually makes power."

Kevin: "Plus you're going to pee and poop in it. It's disgusting."

In this instance the toilet/ air freshener idea was considered because Gary expressed it was a reasonable solution, but ultimately overlooked the idea because team members did not justify how they would build the design ("How are we going to build that?") or if the design would be possible ("Plus you're going to pee and poop in it. It's disgusting.").

Building a working model was the main factor in how Team 2A arrived at their final design solution. Not only did the team reflect that building the design impacted their choice: "And the fact that we actually had to build a prototype for it restricted what we could do" *(Gary, Focus Group Interview)*.They also expressed that this was one of the main challenges regarding the DSEP: "I said making a working device was a challenge" *(Coleman, Focus Group Interview)*. Additionally, they perceived that constraining their design to a working device made the project more "fun," but constrained them from designing what they "really wanted to do."

Focus Group Interview:

Jim: "If we had to design something or make whatever we really wanted to do...but I don't think it would have been as fun. I don't know, sitting around, hovering over our computer...at least we actually made something."

Although they perceived building and making their design work as salient factors regarding their design practices, the requirements for their design did not change based on the "functional" parameter as they progressed through the design process. After the sketching session, they decided on design requirements, e.g. use moving water, turn a turbine, light a light bulb on the bridge, then used the prototype-building phase to meet them rather than eliminating requirements that they could not meet.

Focus Group Interview:

Coleman: "And then figuring out how to actually make the thing work, like once it didn't."

Jim: "Cause we ran into that kind of early. Our problem was the wheel was really hard to turn. And there was no way from what we had that water was going to be able to turn it. So we had to go in and find...and we ended up using a new motor that was pretty easy to turn but our problem was trying to find the right amount of water that would make it turn. It was a whole bunch of trial and error after we got it designed."

This team was successful in using moving water to spin a turbine that ultimately lit a small light bulb placed on the bridge. Figure 7 displays the constructed final design.

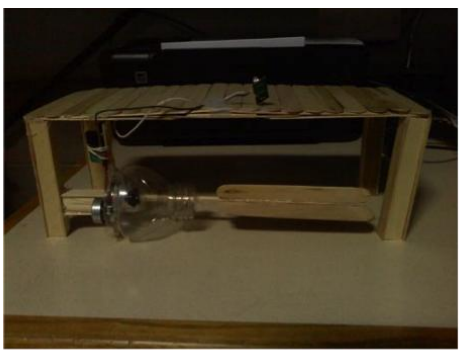

Figure 7. Hydro-powered Bridge Light Side View

One interesting aspect of Team 2A's approach to design was that they constrained their search to design solutions they perceived were possible/ applicable and could be built and function. The constraints of these parameters ultimately led the team to design and develop a solution that was *scalable*. As illustrated in Figure 7, the bridge is not built to scale but their design still represented a solution that the team perceived would fit these parameters, i.e. functional, possible/applicable. An excerpt from the focus group interview data illustrates Coleman and Kevin's reflection on how they arrived at their final design solution.

Focus Group Interview:

Coleman: "It kind of seemed like the most practical one. The one that would probably work the best with a scaled model."

Kevin: "If it was something that probably could happen on a larger life scale, that we probably couldn't pull off on a smaller scale, I don't think we would've done it. This one just seemed doable in both places. It didn't seem like a waste of time and also seemed like something we could pull off and make happen."

Similarly, Team 2A viewed their design as possible and applicable on the large and small scale levels, but also perceived the overall purpose of their design as "beneficial."

Focus Group Interview:

Jim: "But I feel like you could actually do that design [hydro-powered bridge light] and actually kind of be beneficial. We kind of thought or at least I thought of it as, you know when you see the school zone signs and they have a solar panel on there? Even though it's not sunny they still go off because it just charges stuff. Well, if there's water under the bridge, it can do the same thing and just charge. And you wouldn't have to run electricity up there. Especially for those backcountry bridges or something."

Producing a functional and possible/applicable design that was beneficial was salient in terms of how often those parameters came up in Team 2A's design sessions and how it affected their practices regarding design decisions. Other design parameters were not salient or discussed until they were prompted to write about them in the final design report. This practice was more of a post-hoc justification of how their design did in fact fit the parameters suggested by the

DSEP document. For example, discussing the safety parameter was required by the DSEP document when writing the final design report and this prompted the team to consider how their design was safe, but only after they had finalized a design solution.

Final Design Report:

"We believe that our hydro-powered bridge light is ethically sound as well. The only possible environmental problem with the bridge would be if the battery leaked. This outcome is unlikely considering in the full scale design the battery should be placed inside a waterproof box, blocking it off from the river." (p.3)

4.2.4 Team 2A Summary

Overall Team 2A constrained their search to fit the DSEP parameters related to functionality and applicability. These parameters led the team to construct a functional but scaled model of a bridge light powered by moving water and they did not eliminate any of the initial requirements they decided on after they produced a sketch of their design. Additionally, the structure of the project enabled this team to use the design phases to inform subsequent phases. For example, the team's design practices associated with the sketching activity was the most salient in how it affected their final design solution. Specifically, Team 2A members used the practice of sketching their design to discuss and explain to one another their interpretations of the design and determine its functions. While factors related to the institutional context were present during their design sessions, e.g. discussion of coursework/ assignments not related to the DSEP, they did not directly affect this team's design practices. However, coursework related to the institutional context may have influenced practices related to time management, which was a challenge for this team over the course of the DSEP.

4.3 TEAM 3A

Team 3A, or Cullen, Andy, Brett, and Ian designed a collapsible solar cooker for the DSEP. While Team 3A utilized solar energy as their renewable energy source, they did not incorporate a solar panel into their design. Their final budget, $6.06, was one of the few projects that came in considerably under the $20 limit.

Overall, the collapsible solar cooker design evolved from team members' research on small household appliances and personal experience with devices of this nature. Team 3A approached DSEP artifacts as course assignments, but their design session discussions showed that constructing the DSEP design artifacts led them to incorporate aspects of the design process, e.g. research, brainstorming, sketching, into their subsequent design practices. The following sections discuss specific aspects related to the institution and organization that affected Team 3A design practices.

4.3.1 Institutional

4.3.1.1 I'm trying to get this done so I can go back to studying.

Team 3A members faced the same challenge as other students in this study, which was trying to balance the total amount of workload and credits as an engineering student. Cullen was taking 17 or 18 credits at the time of the DSEP, including a time-intensive elective. This elective also imposed additional constraints on his time. This elective, like other engineering-related courses, required the student to travel to an off-campus site (the "Empo") to take tests and quizzes. In this case, the student did not realize that he did not need to travel off campus to take the quiz, but waited 15-20 minutes until an Empo employee was able to help him. This confusion regarding location along with taking the quiz resulted in Cullen arriving late to the team design session. The following excerpt is after Cullen explained the reason for his tardiness.

Research Report Session:

Andy: "My roommate's in that class. I dropped it. I had too many credits."

Cullen: "It's just a lot of shit."

Andy: "For engineering, I know that much."

Cullen: "Especially for engineering. That's not the elective I should have taken."

Andy: [Laughs]

Cullen: "It's not that bad like going to class. Like, the teacher's cool and everything, but still it's a lot of work and you need something that you can just knock out and get an easy grade in it, you know? Especially when you need that grade to boost engineering. I don't know. So you're not taking an elective?"

Andy: "No, I'm not."

Cullen: "That's probably smart."

Andy: "Engineering, English, which I have to take, two math courses, and physics."

Cullen: "That's what I have. And then I have world regions."

Andy: "How many credits are you taking?"

Cullen: "I think it's like 17-18."

Andy: "Yeah that's what I had, but then I figured the workload would be too much."

This data shows that within the context of the institution the students are trying to balance the required engineering courses with what they perceive is the best elective. The best elective being one that does not require much time and work and one that will "boost" their overall grade or GPA. The awareness of workload and tests/ quizzes associated with other courses dominates the discussion before the team begins work on any design artifact during design sessions. They often compare what courses they are taking and their achievement and understanding in those courses. Cullen discusses how he is doing in Calc and the effect of the aforementioned elective on his available time.

Research Report Session:

Cullen: "I haven't had one chance to look at it because I have been doing world regions and now I have to do physics. Can't you just retake a test at the end of the year? I think my teacher said to do that."

Similarly, another team member tries to balance "get[ting] this [final design report] done" with studying for another course, Physics.

Final Design Report Session:

Cullen: "We don't do our report on this Friday, right?"

Brett: "I hope not."

Cullen: "I thought it was next Friday."

Brett: "Okay, so where's...I'm trying to get this done so I can go back to studying for Physics. I haven't started yet. I've been trying to do the quizzes and stuff and it's not happening. I always have to look at my notes and stuff."

The team's perception of the DSEP as a course assignment led them to go through the motions of completing the DSEP artifacts, moving on from one phase to another, and lacked the freedom to go back and refine ideas. Likewise, some team members approached the brainstorming inventory in a very automated nature. The DSEP document required five ideas from each member of the team so this is what the students focused on with respect to the brainstorming design artifact.

Brainstorming Session:

Andy: "Yeah. But you are not limited to just say solar power. You can say whatever. I want to get out of here pretty quick, but Cullen and Ian are taking the Calc test. Is that like an Empo quiz?"

Cullen: "Yeah, it's online. You just take the test online."

Andy: "So do we have time to start? Or should we just mark off ideas I guess?"

Cullen: "I'll do that just so we can, once we get there we can pretty much… pretty much just be like, think of 5 ideas and let's leave."

Andy: "Yeah."

Cullen: "So…"

Andy: "Let's see. They have an example of a wind-powered elevator. I'll go one further; I'll say a hydro powered elevator."

Cullen: "You for real?"

Andy: "Yeah. I wish there was a way we could share screens, I'm going to say that again, it would be so much easier. Just like, go through this and [get it] done."

They attended the team design session to work on the brainstorming inventory, but initially approached this design practice by "marking off" five ideas to end the design session. Additionally, the DSEP document specified that teams were not limited to the renewable energy source they reported in the research phase. They used this (lack of) constraint to facilitate a quicker brainstorming session and did not relate the research and brainstorming phases of the design process.

Heavy course/workloads were salient to Team 3A in terms of how much it came up in their discussion, e.g. "Are you talking Calc?", "Have you studied for the test yet?", as well as how it shaped their design practice related to the DSEP. Due to the constraints of other courses and the time required by these courses, Team 3A approached working on design artifacts from a very automated frame. Their mechanization of design practices impaired Team 3A from relating the phases of the design process to one another.

4.3.1.2 You've got the connections.

Students within the institutional context (but not part of Team 3A) influenced how team members thought about the design project and those resulting design practices. Before the researching and brainstorming phases, this team based their decision not to use wind as the renewable energy source based on Andy’s friend’s experience with the DSEP. This was coupled with their perception of the implementation problems related to wind power.

Research Report Session:

Cullen: “Didn’t she say, didn't our teacher say that everybody either put solar or hydro?”

Brett: “Yeah, I think so.”

Andy: “No one else put anything else.”

Brett: “Mhmm.”

Andy: “Yeah, I think wind would be easy but it's also easy to screw up on.”

Brett: “Yeah, it's hard to make propellers.”

Andy: “That’s exactly what my friend did. They botched theirs…they messed up on stuff to use.”

In the brainstorming phase, Team 3A used the past experiences of their friends to shape their search for possible design solutions. Again, due to time constraints from other courses, this team approached design artifacts from a very functional perspective to complete the requirements as quickly as possible in order to move on to other work.

Brainstorming Session:

Cullen: “My friend said he would give me all of them.”

Andy: “What?”

Cullen: "My friend's giving me a few. He took it last semester. He said water-powered conveyor belt."

Andy: "That would go well in lines with our water-powered elevator."

Cullen: "It'll have to work with gears. And it would be the same kind of concept: water pours, it rotates, it rotates the other gears."

Their stereotype of the problem as an assignment rather than a design problem led them to rely on non-novel concepts, recycling other students' ideas and making slight variations to existing ideas. The water-powered elevator was based on the DSEP document example from the brainstorming inventory, i.e. "wind-powered elevator". These ideas were mainly used as placeholders to fill the brainstorming inventory and ultimately not considered because of their assumptions regarding technical skills needed, e.g. wiring, soldering.

This carried over to other assignments that they completed in order to fulfill DSEP document requirements. The team evaluation design artifact was developed to "(1) provide feedback to your workshop GTA and (2) to provide some guidance for your team" (DSEP document, Appendix C). However, they approached this activity from a very grade-based perspective.

Research Report

Cullen: "Did we have to submit a team evaluation last time?"

Ian: "Nah."

Andy: "No."

Cullen: "So like I'm not penalized for not doing anything?"

Ian: "Nah, you're straight. Someone from last semester, he told me, everyone just gives each other hundreds. Otherwise it'd be...[shakes head]"

In this case, Team 3A members did not use the team evaluations to give the instructor feedback or help to guide their team, but rather used them to improve their overall grade. Team evaluations were the least salient to teams in terms of how important students perceived them and some students even forgot to submit them. Interestingly, the team evaluations were individual assignments and weighted the lightest for the DSEP grade (3-4%). This minimalist approach to completing assignments was further promoted by utilizing information from students within the institutional context. Brett's connections with other students allowed him to obtain study guides for the engineering test.

Sketch Session:

Cullen: "Have you read them all?"

Brett: "No. I was going to skim it this weekend. One of my friends… he took it last semester and gave me note cards."

Ian: "Yeah."

Brett: "So I'm going to look through all those."

Andy: "You've got the connections. Phi Beta Phi."

Brett: "Just ask people, do you remember me? And I got a study guide from one of the kids down the hall he said he'd give it to me. I'll just start looking over stuff."

Andy: "Gosh."

Brett: "It's the American know 'who', not 'how'."

Andy: "Yeah. I'll tell you when I have reading, I read like 50 pages and then I get like a little bit of information out of it."

Ian: "Yeah exactly."

Andy: "It's like playing hide and seek with information. 'Oh this whole page is totally useless. I'm so glad I wasted time reading it.'"

In some cases, e.g. brainstorming inventory, team evaluations, Team 3A members approached these design activities similar to how they approached other assignments within the institutional context. They evaluated what they needed to do to meet the given requirements and facilitated this process by using information and past experiences from other students. They also based effort regarding assignments on their experiences within the institutional context. For example, they compared past experience with public speaking in an English course with different expectations perceived for an engineering course.

Sketch Session:

Andy: "I hate that with team stuff, you know? Everyone gets affected by one person. I remember in our English presentation some girl totally forgot what she was talking about, and we all lost points for it."

Ian: "What?"

Andy: "Yeah I know. And I remember the day before how we were doing our rehearsal for it. She was like 'don't worry don't worry. Come tomorrow I'll have everything written down on a note card, I'll be fine.' I'm like, okay you better be. So she gets up there and…"

Cullen: "It makes sense in English because they want you to be good at public speaking and stuff. Engineers, they know we're not good at that so we'll just sit there and read off the slides and they'll be fine with it."

Andy: "Yeah."

Brett: "Oh he's an engineer, its fine."

Based on one team member's recount of an English presentation, they use their assumptions about engineers to shape later design practices, such as writing the final design report and presentation. They also use this frame to shape their perceptions on how design artifacts are graded and their subsequent practice. The next section discusses the effect of the organizational context on Team 3A's design practice by examining team assumptions regarding the course and workshop leader.

4.3.2 Organizational

4.3.2.1 She'll eat that up; ***Course (Level 1)***

From the perspective of Team 3A, requirements associated with the nontechnical aspects of the DSEP were graded more leniently because they were engineers. In this example, the context of the course, i.e. an engineering course, dictated how team members approached the DSEP research report.

Research Report Session:

Brett: "And [I] just made each of those a paragraph."

Ian: "Oh."

Brett: "I mean I figured that's probably what it's going to end up being anyway."

Cullen: "They're going to be pretty lenient in grading these things. They just want to see that we did something."

Ian: "Yeah, I mean they don't care about the actual structure of the paper."

Cullen: "They know why we're engineers."

Ian: "Exactly, yeah. Exactly."

In the previous example we saw that, in comparison, within the context of an English course professional, skills carried more importance than in an engineering course. In other words, what was salient to Team 3A in terms of their approach to DSEP design artifacts was dependent on the context of the course they participated in. Furthermore, this team used their assumptions of the workshop leader to shape how they approached other design activities.

Team 3A used the phases of the design process to arrive at their final design solution and completed the associated design artifacts for each phase. In the brainstorming phase, the team used the design practice, "idea triggering", to generate possible solutions, acquiring this practice from the course textbook. While this practice actually led them to conceive the idea for the final design solution, they also used it as leverage to impress the workshop leader when they wrote their final design report.

Final Design Report Session:

Andy: "We definitely generated multiple solutions."

Brett: "All right. I guess just take a bullet point and start writing shit."

Cullen: "What do you guys want to do?"

Brett: "I mean do you want to write the gather information thing. Start talking about that."

Andy: "I can do the 'generate multiple solutions' maybe."

Brett: "Okay so you can do that one. Make sure [to write] the different types of brainstorming. The one method..."

Andy: "The trigger method."

Brett: "Yes. Make sure you throw that in there. ***She'll eat that up****."*

Andy: "I'll do triggering."

They approached the final design report as students within the organizational context and used tactics they believed would result in better workshop leader evaluations. Similarly, they identified words and definitions they supposed she (workshop leader) would like to see in the report.

Final Design Report Session:

Cullen: "Is replenishable not a word?"

Brett: "I'm pretty sure it is."

Cullen: "It says 'replenish' 'able'."

Andy: "Yeah you're right."

Cullen: "I'm just going to keep it because I know it's a word. It's in the word document. I'm incorporating a bunch of these definitions. ***She likes that."***

They also used their assumptions of the workshop leader to guide their effort contributed to writing the final design report. For instance, they regularly gauged their efforts on how they perceived the workshop leader would evaluate and grade the submitted DSEP design artifacts. In the following excerpt, team members are deciding what to include in the report and base this on the perceived amount of effort put in by the workshop leader.

Final Design Report Session:

Andy: "How is she going to read all these? I mean…"

Brett: "Just start writing stuff. 'The cat ran around the tree.'"

Andy: "Just randomly insert this in there: 'you're not reading this are you?'"

Brett: "Actually, it's tempting. It really is."

Their assumptions of the workshop leader acted as interpretive schemes, which they used to guide design practices related to creating DSEP artifacts. This student-based approach, i.e. focusing on instructor evaluations, led them to filter and interpret information they perceived as salient within the organizational context.

Team 3A also used their perception of the course to inform their approach to various design activities. For example, a design practice acquired from the course textbook, idea triggering, was utilized during the brainstorming session, but was viewed as “common sense”. The data below suggests that because of the way they viewed the course material, it impacted their views on information related to design.

Brainstorming Session:

Andy: “Then we can… what was the word they used? We can do the idea triggering method.”

Brett: “Oh yeah.”

Cullen: “This stuff is common sense. I hate reading it.”

Andy: “If it has ridiculous stuff, I figured I would.”

Cullen: “Yeah there is a lot of stuff. I'll read it before the test.”

Andy: “I didn't even really study for the last test and I got an 89.”

Cullen: “Jesus.”

Similarly, applying their frame of the organizational context to the DSEP caused some uncertainty regarding how to approach DSEP design documents. The course required students to use a seven-step general analysis procedure for their homework assignments and some teams had difficulty differentiating the context to apply that process.

Sketch Session:

Cullen: “Wait, so do we have to do…”

Ian: “It's on the…”

Cullen: "...the seven-step method for this thing, do we?"

All: "Nah."

Ian: "I hate when they make us do it for stuff that's so irrelevant."

Cullen: "Labview."

Ian: "Yeah, like, what the heck."

Cullen: "Here's my diagram. Go away. Stop asking me this."

Andy: "You know what? I kind of like it. You don't have to write too much."

Ian: "It's not that bad, it's not that bad."

Andy: "I was hitting those problems, where I was turning in homework that was 9 pages. I was like, whaaat?"

The above excerpt from the sketching design session illustrates that their approach to creating the sketch was based on the organizational context. It was unclear to the students when to apply the general analysis procedure (seven-step process), and furthermore when and why it was relevant.

The context of the organization, or course, is evident as the team constructed the final design report. The requirements for the final design report stated in the DSEP document prompted students to reflect on their design process by writing about how they defined the problem, generated multiple solutions, tested and analyzed the solution, etc. The following demonstrates how team members attempted to piece together course concepts such as the design process in order to guide their approach to writing the final design report.

Final Design Report Session:

Brett: "What does SEP stand for?"

Cullen: "Sustainable Energy Project. I can't think right now."

Andy: "Those ideas we had."

Brett: "Didn't we do a document? Or did we write that?"

Andy: "We had a document. Solution table? Solar-power drill."

Brett: "If anyone is writing anything, like how it can be used, you can say on a survival kit or on a marine's back."

Andy: "Nice."

Brett: "There we go."

Cullen: "Does anyone remember what the design process was? Just like the circle?"

Ian: "Oh, yup. It was like... I think I wrote it down somewhere."

Cullen: "I don't feel like logging into DyKnow and searching through all the stuff."

Brett: "You can probably just Google it. Design loop. Let's see what we got here. Evaluate the problem, brainstorm the solutions…"

Cullen: "Type in VT design loop. I think it was in the first lecture."

Brett: "Yeah it probably is. It might be in our workshop slides though."

Andy: "Oh wow, that's pretty cool."

Cullen: "Does anyone have their book with them by any chance?"

Ian: "No."

In this instance, the team tries to refer to the course material to incorporate the design process into the final design report. While the structure of the final design report prompts them to reflect on the various stages of the design process, this also leads them to apply post-hoc applications for their design. In other words, their initial use was an outdoor grill for camping, but they extended their uses to include a survival kit component when prompted to think through their design. This post-hoc consideration of design considerations is also apparent when they are discussing the ethical considerations section of the final report:

Final Design Report Session:

Andy: "We could say our cooker could be the alternative to pollution caused by campfires."

Brett: "Yes that is very clever. Nice."

Andy: "That really helps with global warming. That thing."

Team 3A generally approached the DSEP artifacts as assignments they wanted to "get done" in order to get back to studying for other courses, and they tried to interpret how the workshop leader would evaluate and grade their DSEP artifacts. These practices were based on their experience within the organizational context such as completing course assignments and studying for tests. The structure of the DSEP, i.e. required design artifacts, facilitated students' progression throughout the design process. While Team 3A approached these artifacts from a student perspective they were still able to utilize these practices to inform their design solution.

4.3.2.2 They can't all be golden; ***Project Structure (Level 2A)***

Team 3A framed their approach to creating the DSEP artifacts as assignments that were part of the course. However, following the structure of the DSEP, i.e. completing DSEP artifacts as part of the design process, and answering the questions given in the DSEP document led this team to develop their final design solution. They initially approached the design process by researching "solar energy" and accomplished this through Google searches and answering the questions listed in the DSEP document.

Research Report Session:

Brett: "What's the paper? Just a research paper on solar energy?"

Ian: "Mhmm."

Andy: "A research report."

Brett: "Research report."

Ian: "I got the small-scale applications and I got…I got some advantages and disadvantages [regarding the questions itemized in the DSEP]"

In their initial research stages they relied on basic Internet searches for solar power energy, but later refined their search to highlight small-scale applications.

Later in the Research Report Session:

Cullen: "What did you type in to find it?"

Andy: "I typed in 'solar power energy.'"

(ACTIVITY): Laughter

Ian: "That sounds about right."

Andy: "And it's the history of solar."

Brett: "So what were the small-scale applications? I'll just start throwing stuff down."

Ian: "There's uhh. Well I mean a solar panel. That's for heat."

Brett: "Just throw out a couple names."

Ian: "A photovoltaic PV device."

Brett: "Some integrations of solar power."

Cullen: "And then I also talked about things that used them. Like um... there's solar powered watches, calculators, batteries, flashlights, and fans."

The search for small-scale applications was prompted by the DSEP document question, "Are there small-scale applications (e.g. handheld type devices, off grid applications, etc.) utilizing your energy source?" (DSEP document, Appendix C). The research regarding small-scale application led Team 3A to focus on small appliances during their brainstorming session. However, they went through the motions of completing the brainstorming inventory. The excerpt below reflects the "just think of 5 and we can leave" attitude toward completing the brainstorming inventory as they focus possible solutions around an example from the DSEP document.

Brainstorming Session:

Cullen: "So we have to fill these two pages out and shit?"

Andy: "Yeah. Two to three sentences. The example only has one sentence and it says it doesn't count."

Cullen: "I guess so. It could be one sentence I guess."

Andy: "So I'm thinking the elevator, you could have water go down and it hits like a little, is it turbine? Or what it? What's the little thing that you hit and the water rotates?"

Cullen: (Inaudible)

Andy: "Yeah so it hits that, and that will spin a gear, and it will go up to here connected and it will turn up here, come over and it will lift the object up."

Cullen: "And how will it go down?"

Andy: "Well..."

Cullen: "So you can only go up on this elevator. We should probably not use the elevator though...."

Andy: "Whether we use it or not, it's still an idea."

Cullen: "This is true."

Andy: "They can't all be golden."

While Andy and Cullen mentally bracketed possible design solutions into brainstorming inventory ideas vs. feasible solutions for the DSEP, they made use of the design practice, idea triggering. Further discussion regarding possible design alternatives led Andy to reference a previous experience he had working with a small appliance:

Brainstorming Session:

Andy: "Maybe we can do a solar powered screwdriver. I'll tell you…I was working on that deck over spring break. I couldn't tell you how many times that power drill just kept on dying. We'd recharge it and wait."

Brett: "What was the thought trigger method, or what was that called?"

Andy: "Idea trigger method."

Cullen: "What are these called?"

Andy: "Wind turbine maybe?

Cullen: "What did you say this was though?"

Brett: "Some stand that the screwdriver would sit in."

Andy: "That's a clever little idea. You'd have to have like hurricane force winds."

Brett: "Well this is the idea trigger. How can you go off a screwdriver? A conveyor belt? [Design ideas already listed in the brainstorming inventory]"

Cullen: "What if we were like okay, after each person has 5, you can go."

Brett: "And I was sitting here with 5 left, like, uh!"

Andy: "You would be."

In this example, one team member's personal experience (and resulting user needs) coupled with the practice of idea triggering led Team 3A to brainstorm possibilities for small appliances. This included their final design solution, the solar cooker/ grill. Outside of the brainstorming session, one team member found a design online for a solar grill and suggested/shared this idea with the other team members through Facebook. When they met as a team for the sketch session they focused on the requirements to 1) draw an orthographic sketch of their idea and 2) include 1-2 paragraphs on how the team narrowed down ideas from the brainstorming inventory.

When trying to write a statement on how they narrowed down design ideas, their first response was based on limited perspective of how they brainstormed during the previous design session: "None of us had any better ideas and Google helped us" (*Brett, Sketch Session*). Since they were required to include a 1-2 paragraph description of this process, they reverted to another alternative or "making stuff up."

Sketch Session:

Andy: "You got it? Okay discussion. Time to make up some stuff."

Cullen: "What did it [DSEP document] say? How effectively did you use brainstorming?"

Andy: "Yeah, how did your team narrow down the ideas from the brainstorming session to select this design?"

Cullen: "Brainstorming session. Oh that last one we had."

Andy: "Yeah. We don't want to say we used Google because then she'll be like 'oh... Yeah...'"

Cullen: "Oh I know! What we can say…you know how we had a bunch of household appliances in our last one [brainstorming inventory]?"

Ian: "Yeah."

Andy: "Oh yeah, we can just expand that to oven."

Cullen: "Yeah, like, one person came up with household appliances and then we expanded to...we started with what can opener."

Team 3A worked under the assumption that they needed to "make up stuff" in order to meet the requirements listed in the DSEP document; this persisted over the course of the design process, including the final design report:

Final Design Report Session:

Cullen: "I can do the define the problem if you want."

Brett: "All right, so you'll do the define the problem."

Andy: "The test and implement the solution."

Brett: "All right I'll start pulling shit out of my ass magically then."

Additionally, they continued to rely on their assumptions of how the artifacts were evaluated to inform design practices regarding the testing of the final design solution:

Final Design Report Session:

Cullen: "No, my friend said that. I told him today that we needed that and we didn't test it yet. And the same thing happened to them. He said it's more believable if you say it didn't work the first time."

Brett: "Limited sunshine."

Cullen: "Yeah [say] it was cloudy or something. It is cloudy. We intended on testing it this week but Mother Nature wasn't cooperating."

Brett: "We tested it this week and it was too cloudy."

Andy: "Say it did heat it up a little bit, but not to where we wanted it."

Cullen: "It only charred the marshmallow."

Brett: "Thank God. If anybody asks, we tested it but it was too cloudy to work. That's our story and we're sticking to it."

However, their discussion developed and team members expounded on their actual design practices to include this initial testing of the design solution. The data suggests that since the team was not able to test the design under optimal conditions, they believed they did not perform actual testing or analysis on the design. They later integrated this practice of testing the design on a cloudy day to support their discussion on the "problems encountered" section of the final presentation.

4.3.3 Team 3A Summary

Overall, Team 3A's perception of the organizational context led them to assume some design practices were not feasible. This also stemmed from assumption based on the institutional context regarding other courses and information from other students within this context. At the same time the structure of the DSEP influenced how Team 3A thought about and framed their design as they progressed through the design process. Specifically, this team initially approached DSEP design artifacts as assignments within the organizational context. But due to the way the SED was structured, e.g. required artifacts, questions posed in the DSEP document, this enabled team members to utilize design practices that ultimately helped to develop their final design.

4.4 Team 4A

Team 4A, or Craig, Channing, Neal, and Cody, designed a hydro-powered urinal for the DSEP. Their final design used drained liquid from the urinal to spin a small water wheel connected to a generator inside of the pipe to store electrical power for a later use. Ultimately, they constructed a scaled working model of their final design solution that demonstrated its capacity to produce electricity by lighting an LED.

In general, the team's perception of the course as a "weed-out" course perpetuated a set of constraints over the duration of the project that led the team to treat the DSEP as another time-intensive or "busy work" activity. Their assumptions regarding the purpose or intentions of the course constrained their design practices more than the explicit design constraints of the DSEP; however, they were able to extract insight from personal experiences and apply an approach that took user needs into consideration when making design decisions.

4.4.1 Institutional

4.4.1.1 Yeah, 17 credits suck.

Team 4A's discussion during design sessions was indicative of their perception of first-year courses and their over arching consciousness of credit hours and associated workload. Team members often used this time to gather information and compare their experiences related to the institutional context. The following excerpt from Team 4A's research report session is an example of how team members used their time together in design sessions to compare the number of credit hours each were taking as well as how they worked within the constraints of the institutional context.

Research Report Session:

Craig: "Yeah. It's not bad for me at all because I had a ton of credits coming into college from high school so I have low credit hours for each semester."

Channing: "I've been doing 12-hour semesters because I don't feel like taking that many."

Neal: "Yeah, 17 credits sucks."

Channing: "Phew man, I could not even imagine that."

Cody: "I'm basically only taking 9 credits right now 'cause I got music appreciation online."

In this instance the data suggests how each team member worked within the constraints of the institutional context of required credit hours/ courses (related to the engineering curriculum) but manipulated other aspects to balance the associated time and workload. Specifically, Cody was registered for 12 credit hours, but balanced the remaining engineering course load with an online elective that did not require the same amount of time. Later, Cody and Craig joke about the time and workload required by an online non-engineering course:

Research Report Session:

Craig: "Online? Haha what, you finished in what, 2 weeks?"

Cody: "I haven't even started haha."

Craig: "You haven't started? Haha oh man. Dude, you can finish that in like, 2 weeks."

The amount of work and perceived difficulty associated with engineering-related courses impacted team members' attitude toward these courses and how they interpreted their purpose. Below, team members discuss their perceptions of a required physics course that they based on the instructors making the course "ridiculously hard", subsequently categorizing the course as a "weed-out course" for students.

Research Report Session:

Craig: "I have 3 exams the week I come back."

Cody: "Dude, we got 1206, physics test when we get back."

Channing: "I think 2305 or is it 1205 for physics?"

Neal: "2305."

Channing: "Well that one and 06 or whatever are both weed-out classes. They just make them ridiculously hard."

Cody: "I don't know why I'm not getting the right answers because I took physics in high school and it was so much easier."

Channing: "Yeah because the teachers don't teach you stuff and then they ask you questions. Then they'll show you this easy example and they'll ask you a question that's a

100 times harder. You have to use 4 different formulas and a total of 10 different variables and they give you 2."

Their conversations regarding aspects of the institutional context evolved from comparing courses, *"Are you taking linear algebra*?", and workload, *"I remember hating it because every other week I had at least two tests. Every four weeks I had at least four tests in a week",* to using the design session time to help each other with other course work not related to the DSEP. While this team and other teams in this study generally met on a weekly basis to work on design artifacts associated with the DSEP, they also used this time to work on assignments and online tests. In the following instance, the constraints of the institution, i.e. requiring the same courses for engineering students, facilitated peer instruction during the design session. Data from the final design report session illustrates how Team 4A used this time to work on DSEP artifacts and helped one another with other course work concurrently.

Final Design Report Session:

Cody: "Dude, I can never get these right ever. Do you know what's the problem?"

(ACTIVITY) Looking at homework on Cody's TabletPC

Channing: "Well the last square root plus 6y, you factor that out, and see where it would be zero and make sure that needs to be -2 and 1. Then log cannot be 0 so as long as S is not equal to 6+6/5."

Channing: "So yeah, I'm pretty sure you have the wrong.... I'm trying to remember what Sec is.... Sec is 1/Cos, so it's proper when Cos = 0."

Cody: "So it's..."

Channing: "Pi/2 and 3Pi. Multiples of Pi/2."

Cody: "So how do I know that's in the thing, do I just carry it over"?

Channing: "Do you have a calculator? Well, you do Pi/2 – 2 because it's r+2. Then see what that number is."

(ACTIVITY) Channing looks back at his TabletPC.

Channing: "Then for the overview of the design we can have pictures and other slides of the concepts, features, and intent."

Cody: "Supposedly it's proper. What are the factors of that? Shouldn't that be plus 3?"

The data above is an example of a common theme across teams where the team met to work on DSEP artifacts, but also used this time to work on other assignments, going back and forth between work related to and not related to the DSEP. While material from other courses frequently came up during design session discussions, there was little application of this material to the DSEP. In many instances material from other engineering-related courses would come up in the discussion, but the infrastructure of departmentalized courses, e.g. physics, math, engineering (ENGR 1234), rarely allowed students the opportunity to follow through with applying this material or knowledge from other courses to the DSEP. The following quote from Team 4A's brainstorming session illustrates how the team discussed material or prior experiences from other courses when thinking of ways to wire their design. However, they ultimately obtained a breadboard based on their online search and the DSEP budget or cost constraint.

Brainstorming Session:

Channing: "We had this sort [of] breadboard thing in physics that's a lot better than that one. Like, it really wasn't a breadboard…like, it had a place to put in batteries and a light bulb and stuff. And it had places…it had springs that were already like connected and it had like eight different sets of those. So basically you could put a resistor between that."

While the institutional aspects related to other courses were salient in terms of how often it came up in discussion it did not directly impact DSEP design decisions. There appeared to be possibilities for the team to apply prior experiences or material related to courses within the institutional context but they were often overlooked for other alternatives.

In addition to the team's interpretation of courses within the institutional context as being weed-out courses, they tried to interpret the workshop leader's perspective of the DSEP. The following section examines data related to the team's view of the workshop leader and her approach to evaluating and grading student designs.

4.4.1.2 I mean she's got to be like the majority of other engineers out there.

In need of a basis for decision making, Team 4A often relied on their assumptions of what they thought was valued by the instructor or how they assumed she would approach the evaluation and grading of their design artifacts. These assumptions were usually based on information gathered from other students or their own experiences within the institutional context.

The following excerpt is an example of how this team based some decisions related to the DSEP on their assumptions of the workshop leader. Specifically, when writing and editing the research report, they used information from a student who previously took the course to shape their approach. They used another student's recommendation to "just throw it [research report] together", which was based on their interpretation of the workshop leader as a graduate student and her view on reading/grading design teams' reports.

Research Report Session:

Channing: "I might just change it ...one sentence ends with 'the globe' and the very next sentence starts with 'the globe.'"

Cody: "Just put like, 'the world?' Change it up."

Channing: "I don't think she's going to be too harsh on it."

Cody: "I don't think."

Neal: "She's got to read so many papers."

Channing: "If I were teaching the class and had to grade all of them I would be the easy person. Just be like, 'this is long enough, ah whatever.'"

Neal: "That's what...oh what's his name...when we were working on the homework..."

Craig: "[student]"

Neal: "He said they're [workshop leaders] graduate students; they actually have a life."

Craig: "Yeah, [student] said don't even worry about this thing, just throw it together and go with it."

Channing: "Who was that?"

Craig: "He lives right next door to me in the dorm. But he's a second year and he did this."

They continued to rely on their assumption of the how the research report would be graded based on their perception of the workshop leader and engineers in general. In this case, they wrote and edited the research report with reduced effort because they perceived the majority of engineers were not adept in "English" and therefore they would not be graded or critically evaluated on grammar.

Research Report:

Channing: "Because I heard they would check for grammar stuff. Like you would lose points for commas out of place."

Neal: "On this? I thought I overheard her say she wasn't going to check."

Channing: "My friend that took it last semester told me they did check. I don't know if she taught last semester."

Neal: "Honestly would she know if it was really..."

Cody: "She's obviously not an English major."

Neal: "Yeah so. I mean she's got to be like the majority of other engineers out there."

Craig: "Who [workshop leader]? Dude, my sister goes out to bars with her."

Channing: "So you're saying we're going to get an A on this project, haha."

Similarly, as they manipulated the constraints associated with the specified DSEP budget, they tried to interpret exactly how much they could manipulate these prices based on their assumptions of the workshop leader. In this case, the team had already purchased a breadboard, but the actual price of the breadboard did not fit within the $20 limit. To manipulate this constraint, they performed an online search to find a similar item with a price that fit within the budget. Their decision to include an item that was not actually part of their design was based on their perception of the leniency and knowledgeability of the workshop leader.

> *Final Design Report Session:*
>
> *Channing: "If we say we used a dual mini board with 213 holes, it's $1.99."*
>
> *Craig: "Ok, yeah. Lemme see what it looks like."*
>
> *Channing: "It doesn't look anything like ours, but it's got all of the holes in it."*
>
> *Cody: "It's basically what ours is."*
>
> *Craig: "Dude, I might have that too. But mine's a little better than that. I don't think it was $1.99. She won't be that stupid though. She knows it's a small breadboard."*
>
> *Channing: "I don't think she's going to research all of our prices."*
>
> *Cody: " I don't think she's going to be like [Looks closely at paper]...'no.'"*
>
> *Channing: "She's just going to double check that it's reasonable and then see if we actually have it listed."*

Not only is this an example of how the team used their perception of the workshop leader to manipulate their budget, it also demonstrates a common theme across teams where teams would use a post-hoc application of the budget. In general, teams attempted to stay within the $20 budget throughout the design process but often bought items for their design that they did not report or report accurately.

Overall Team 4A used interpretations of the workshop leader to determine the effort required to complete DSEP design artifacts. While they met the requirements listed in the DSEP document, they often sought methods that required less effort but would not affect the evaluation and grading of these artifacts.

Final Design Report Session:

Craig: "Do you think she cares if we copy and paste from our old evaluations?"

Neal: "I'm sure if she found it she would care."

Channing: "So just don't get caught."

Team 4A used the information they had from the institutional context to shape some of their design decisions when working on DSEP artifacts; this was typically based on assumptions of the workshop leader as well as information from other students. While the team used the context of the institution to inform their approach to design, other courses they were taking also provided a context for how they thought about their design solution. The following section discusses how Team 4A incorporated information from other courses within the institutional context into their design as well as possible missed opportunities for utilizing information from other courses.

4.4.1.3 I guess the only thing that I would really know from this, is what I know from physics

One team member reflected on his DSEP experience in the focus group interview, and the data suggests members from Team 4A did not perceive that they had much engineering knowledge to apply to their design.

Focus Group Interview:

Channing: "Probably, because I would probably know a lot more by that point. We didn't really know much going into this. We just, we didn't know much of a mechanical basis, we just took what little we knew and built it."

Craig: "I'm sure the creative part of it would be a lot better, and the functionality of it would be a lot better too for sure, because we would know a lot more information on what we're doing instead of going from research on the internet. We would actually have a background in something that deals with it. But for the most part, we would have still written out everything…the design and followed out each step and the actual finished product would have been way different."

Other data regarding the institutional context showed that team members were taking engineering-related courses such as linear algebra, physics, and calculus (the same semester as ENGR 1234); however, they did not perceive the material from those courses as applicable to their design or design approach. They informed their technical design decisions based on information from Internet searches as well as trial and error when building their design. In some instances, they thought of approaches to use in the design process that incorporated technical knowledge, but often dismissed these ideas based on the effort required. For example, they briefly discussed calculating specifics regarding the functionality for their design, but decided that approach would result in additional or "too much work."

Final Design Presentation Session:

Craig: "Too bad we couldn't calculate, this is probably too much work but, too bad we couldn't calculate how many times it would probably take someone to use the bathroom in order to save a charge long enough to run a light."

Neal: "I have a better idea, let's look up a statistic to see how many times a guy goes to the bathroom in one year and then in a lifetime."

Craig: "Too much work ha."

Other ideas that incorporated technical knowledge from engineering-related courses did not materialize. Team 4A's initial idea to generate voltage from a changing magnetic field was based on material from one team member's physics course, but was not ultimately incorporated into the design because they found it easier to use a motor they found and purchased online.

Focus Group Interview:

Channing: "I guess the only thing that I would really know from this, is what I know from physics. The voltage and changing magnetic fields, stuff like that. That's about it. Everything else we just kind of learned as we went."

Similarly, team members felt they lacked the technical knowledge to follow through on other ideas they originally wanted to incorporate into their design. For example instead of using calculations to test their design they relied on trial and error because they felt they lacked the necessary technical knowledge. The following excerpt from the focus group interview illustrates how Channing and Craig would have approached the design if they had felt they had more engineering content knowledge.

Focus Group Interview:

Channing: "We would have been able to calculate the correct angle to have the water coming out to the wheel to get the most torque and all that kind of stuff."

Craig: "We would have used a lot more math. This was just kind of put it together and see how it works."

Channing: "Just try out what we could."

Craig: "See I wanted to figure out how much power would be produced, but that was kind of hard. We just don't know what we would do to figure that out. Other than using a voltmeter but we wanted to figure out if water is coming down this fast, how much energy could it produce?"

The data shows that while students are taking physics and math courses (or previously took these courses) the engineering-related knowledge from these courses was insufficient with respect to their design approach. This suggests the departmentalized nature of the institutional context constrained students from fully applying material they did not view as specific engineering knowledge. Furthermore, they felt that after taking other "engineering" courses they would have been able to produce a more functional and creative design. The data also indicates that students were taking several other engineering-related courses; however, there were missed opportunities to incorporate that knowledge into their design process. Likewise, the students' perception of the course (as a weed-out course) led them to impose other constraints on the DSEP and miss opportunities to incorporate material from the ENGR 1234 course into their design.

4.4.2 Organizational

4.4.2.1 I feel like the basis of this class is you're actually willing to do tons of work than actually learn anything ***; Course (Level 1)***

Team 4A's perception of ENGR 1234 (as a weed-out course that's basis was abundant and tedious work) led them to treat the DSEP as another time- and effort- intensive assignment, subsequently limiting their search for design alternatives. For example, they limited their search and rejected ideas in the early stages because they perceived the DSEP as more of a group project rather than a design project.

Brainstorming Session:

Neal: "I feel like they're focusing more on group effort than the actual project."

Channing: "I feel like the basis of this class is you're actually willing to do tons of work than actually learn anything."

Their perceptions of the course came up relatively often in the design sessions and was salient in terms of how it affected their decisions related to the institutional context as well. For example, other students shared and perpetuated the view that this course was designed to weed students out rather than teach them engineering material. Based on this stereotype of first-year engineering courses, one team member contemplated taking another required engineering course at a community college to avoid this type of weed-out course.

Brainstorming Session:

Channing: "Because it's a ridiculous amount of work for two credit hours."

Craig: "It's kind of frustrating."

Channing: "Not to mention workshop's like an hour and 50 minutes."

(ACTIVITY) Members nod heads.

Neal: "I've definitely heard this class is meant to weed people out."

Craig: "I thought it was going to be extremely hard, but it's just a bunch of tedious stuff."

Neal: "Not necessarily busy work, but...for the people who actually do their work, it's hell. For the people they're trying to weed out, it doesn't really affect them in any way."

Later in the Brainstorming Session:

Channing: "I might end up taking 1114 over the summer at a community college…just cause I know you learn the same stuff, but they won't make it ridiculously hard for like, a weed-out class."

Similar to the discussions regarding the institutional context, discussions surrounding the course were also salient in terms of how often it came up and how it revealed perceptions of the course activities. In one instance, students watched a video on engineering ethics (in class) that used a fictional case to demonstrate the implications of ethical dilemmas in an engineering workplace. One team member thought the intention of the video was meant to depict an engineering workplace and team members hypothesized how they would handle the situation. This discussion was concurrent with one team member editing the DSEP research report.

Research Report Session:

Cody: "I don't think it really matters. She doesn't teach us anything."

Craig: "I mean half of the class is announcements and like, previous...from the previous class."

Cody: "And then we watched that video, which was retarded."

Craig: "That video..."

Channing: "Dude, the acting was so bad."

Craig: "It was hysterical."

Channing: [Editing report] "We're at 5 pages. I don't know the fuck just happened."

Neal: "I was not terrified by it. I was like, this is how a job place works?"

Craig: "Dude, if my boss was yelling at me I would be like 'blah' and ditch it and find another job."

Channing: "He was bitching out jobs, like, you're not making me responsible for shit that happens. If you want to do it cheap write down that I want to do it cheap and sign it yourself.

Cody: "Not my fault."

Craig: "And in the end they're like Venseulos is dead or what's his name? Haha."

The above data suggests that team members perceived the engineering ethics video as a course activity and joked about the outcome of the video all while continuing to edit the research report. Similarly, team members would interject discussions regarding DSEP artifacts with questions or comments about the course to confer other related aspects. The excerpt below is another example of how the team would work on specific DSEP design artifacts, but also use that time to discuss other course items, e.g. tests.

Research Report Session:

Craig: "Do you all remember the sustainable energy?"

Cody: "What did we have to pick from?"

Neal: "It was in the workshop."

Craig: "It's in that paper. It says right before we start writing..."

Cody: "I have no idea how to flow chart at all."

Craig: "It's going to be on our next test for sure."

Cody: "I was so glad it wasn't on that last test."

Craig: "I guarantee you we have a workout problem."

Cody: "So there are five [sustainable energies]?"

Channing: "Was it you that's watched the video already?"

Cody: "Are there only five total?"

Neal: "[Looking at DSEP document] Some of the major sustainable resources."

Craig: "It's like common sense it's so annoying."

The team's prior assumptions of the course restricted the ways in which they thought about the design project. The monopoly course assignments had on the students' time led them to interpret it as a weed-out course and subsequently a missed opportunity to learn and apply any new material to their design approach.

Focus Group Interview:

Channing: The one thing about this class, I didn't seem to learn too much new stuff and they just reiterated a lot of common sense stuff. But the 2-credit class took up like 70% of my time with all of the homework and quizzes. One homework assignment took me and my friends, like, six and ½ hours to do it. It wasn't hard; it's just like their process and how much stuff they give out just takes up so much time. I'm in multi-variable calculus and physics 2306 so I really have to study for those classes and I was spending all of my time on this two-credit weed-out class."

The team's assumptions about the course acted as a frame for what they perceived was relevant to the project and what was not. 1024 students were required to follow a process (problem statement, diagram, theory, solution) similar to the design process (define the problem, gather information, etc.) for their homework or course assignments. Subsequently, they viewed the "process" aspect of the course as the only applicable course material to the DSEP.

Focus Group Interview:

Interviewer: "Were you guys able to use any of the concepts you learned in class for the project?"

Craig: "Other than the design process?"

Channing: "Yeah, that's about it."

Craig: "And other than problem solving, not really. We didn't really do anything with Labview or technical graphing really. It was just like, think of design, research…or think of design, prototype, document…"

Channing: "Test"

Craig: "…test, then go back and revise it and write it up again. Get your final product out there. That was main thing."

While team members didn't perceive specific material as applicable to the DSEP, they viewed the "process" aspect from the course as relevant to their project. The DSEP design artifacts were structured around the phases of the design process; however, the linear progression of the design phases and associated due dates rarely prompted this team to move backwards to earlier stages. The following section describes the DSEP's structure and its influence on Team 4A's design practices.

4.4.2.2 That whole section of the paper we had to improvise since we hadn't finished the project yet; ***Project Structure (Level 2a)***

The high degree of constraint in terms of project structure left little degree for Team 4A to pursue new ideas or reverse design decisions. Course material emphasized a design process that was cyclical and iterative in nature; however, due to the demands of the course context, i.e. course planning and deadlines, the structure of the DSEP resulted in a fairly linear process by students. In one example, the final design report was due before the final in-class presentation so Team 4A completed the requirements for the final design report before completing their final design.

Focus Group Interview:

Craig: "We had no idea, we were probably putting this final design report for the DC motor we used, [which] should have been low speed. It [final design report] could have been more detailed and not have as much filler information. I know when we got *together, let's be serious, we're not going to be able to write 4 pages of just, everything about the design. It's a pretty simple design. We're not going to have too much to say about it, but if we had finished the actual product, maybe we would have been able to talk about our problems more and important stuff."*

Channing: "That whole section of the paper we had to improvise since we hadn't finished the project yet. Plus they wanted a whole bill of materials with cost and receipts and everything and we hadn't bought everything."

The team realized they were trying to write information regarding an unfinished design, but due to the constraints and deadline of the final report, they improvised several required sections because they were going to be graded on it.

Focus Group Interview:

Channing: "Definitely need to change the due date for the design report. It was due the week before, and I talked to plenty of my friends and a lot of them hadn't actually finished their final designs, but they needed a picture, and then when you asked about testing a week before it was actually due people hadn't finished it, but they were asking you about it. And you were going to be graded on it."

After testing their design (the week following the final design report), they realized they needed to change the motor (generator) component because they were not able to create enough rpms from their water source for the type of motor (generator) they originally purchased.

Focus Group Interview:

Channing: "So we couldn't really create that many rpms with the motor we used. It needed a really high force of water to do it. But if we had a low speed motor we would've been fine."

Later in the Focus Group Interview:

Channing: "Especially for our price range. And that [motor] was one of the last things we bought so our budget was running out rather quickly. Besides that though, it was pretty good. We decided it produced 9-18 volts but we only needed 2 volts."

Craig: "We only need 2 volts of power for the LED light."

Like other teams, i.e. Team 1A and their solar panel choice, Team 4A originally purchased an easily available component found at RadioShack, which after testing they realized it was not the best component for their design. Due to DSEP deadlines and budget constraints, Team 4A found it difficult to go back to earlier phases or reverse design decisions. Possibly due to the condensed testing phase for Team 4A, one team member reflected that completing the design project over the course of a weekend would have been preferable.

Focus Group Interview:

Craig: "I mean I know it's a whole semester-long project…but I think it would've been fun to just do it all in one weekend or something. You know, just sit down and really do it. Because it became tiresome to just come in every week and do a little bit of it. I mean it helped out with other classes and stuff, but it was a lot of fun."

While Team 4A appreciated how DSEP artifacts and deadlines facilitated a step-by-step process and helped them to manage the project while taking other courses, they were often unclear of the purpose for some DSEP design artifacts and how it related to the design process.

Research Report Session:

Cody: "What are we supposed to do for the next meeting?"

Channing: "It's like a brainstorming thing. So come up with ideas."

Neal: "They really gave us some good insight to this project. What do you want to do? Hydro? Yes. Haha."

Teams in this study generally overlooked the problem definition aspect of the design process in early phases. All teams, including 4A, met the objective of the research report: "To give your group some background knowledge of your chosen sustainable energy source; to inform the class about your topic" (DSEP Document, Appendix C), but did not link this research to an identified problem. Team 4A generally defined the design around the DSEP parameters which stated their design had to use a renewable energy source and be functional. However, Team 4A later approached the design problem by applying user needs in other stages of the design process (discussed in section 4.4.2.3). The following reflection on Team 4A's design illustrates how their final solution was functional, but they never defined a use for power produced by their design.

Focus Group Interview:

Channing: Yeah we never really came up with an actual, I mean we produced power, but we never really decided what it was going to be for, and so we just made it for a later use.

With respect to other DSEP artifacts, Team 4A did not have a clear understanding of the purpose of the prototype and the prototype fair. They used cardboard and other inexpensive materials to construct their "initial design solution" as stated in the DSEP document, but, like most teams, they had difficulty differentiating the purpose of the prototype and final design.

Focus Group Interview:

Craig: "I wish the prototypes were the actual final design for the project. When we finally saw the final designs, it was more like a more detailed version of the prototype. When we went around to each group and looked at their design, and asked about it and we told them the possibilities of what they could change, I'm not sure if they really changed anything... so it was kind of like...."

Unclear problem definition and a *(mis)*understanding regarding the meaning of design activities, led Team 4A to rely on explicit constraints and requirements stated in the DSEP document and design artifact rubrics. Explicit constraints, i.e. project budget or cost, were the focus of scrutiny when making design decisions throughout Team 4A's design sessions.

Their directional goals to incorporate hydropower stemmed from the cost constraint before Team 4A did any research or brainstorming related to design solutions. They primarily eliminated renewable sources other than solar power and hydropower based on cost and ultimately eliminated solar power because of the cost of the solar panel. Which also reinforced their assumption that a solar panel was needed to utilize solar energy.

Focus Group Interview:

Craig: "…I mean, what would be easiest of parts to find to work. Solar, you have to buy the little solar charger thing and that's right there probably like $10. It would be kind of hard to…if you had to implement that with something else, the other stuff might cost just as much or more so."

Similarly, after the decision to use hydropower as the renewable energy source for their design, the cost constraint further restricted their search during the brainstorming phase. They bound their ideas by what they perceived they could build, which, from their perspective, were limited by the $20 project limit.

Brainstorming Session:

Craig: "Too bad we couldn't actually build something sweet. Like if the school gave us like, a 100 bucks or something."

Focus Group Interview:

Channing: "Cost was definitely a major factor, not only for what type but after we had our brainstorming inventory ideas just making a final decision, cost was a major factor. You can't do much with $20 haha."

While the cost constraint was salient in how it led Team 4A to frame the design problem (in terms of what they perceived they could build and stay within the budget), it was not as influential as they progressed to the building and testing phases. Team 4A often manipulated the budget by adjusting the price or description of what they actually purchased in order to stay within the limit.

Final Design Presentation Session:

Channing: "This is cost adjustment."

Cody: "[Workshop leader] doesn't see this stuff."

Channing: "Dude, they want us to build something with $20 but they also want high quality. It's like, come on now."

Craig: "It's like Pedro in that video of the Mexican plant."

Channing: "We're not doing that bad. If it comes to a real project, I'd talk to the company and be like yeah this isn't safe but this is a 1024 weed-out class design project. Which is more of a pain in the butt than it needs to be."

The data from the excerpt above also illustrates the influence of the organizational context where team members associate the DSEP with elements of a weed-out course. Because they perceived the DSEP as a course project or assignment, the cost constraint is merely another requirement tied to a grade for the course.

Final Design Report Session:

Craig: "We'll see how much it all costs first. See if we can cut back on stuff."

Cody: "I mean she's not going to take off for cost now."

Channing: "Well, it's on the rubric thing. It's like... 'Cost within limits: less than $20, plus 5 [points]; less than 25 [dollars], plus 5 [points]', which means, if we're under $25, we'll get half points."

As an additional basis for decision-making, the team referred to the DSEP document and rubric and increased their reliance on assumptions about the workshop leader and how the artifact would be evaluated. Rather than evaluating the tradeoffs associated with budget, quality, and grading of the DSEP, they used or reported items that did not violate the cost constraint. Another salient constraint of the DSEP that influenced Team 4A's design practices throughout the design process was their focus on the functionality parameter and the interesting/innovative parameter; the next section highlights their design practices related to these salient constraints.

4.4.2.3 We just thought it was an awesome idea; ***Project Parameter (Level 2b)***

This team based their design approach on creating a functional and interesting design solution, but ultimately eliminated different alternatives based on their estimation of required effort to incorporate certain aspects of these parameters. The requirement to produce a functional design or a design that they could demonstrate using a working model led Team 4A to ultimately decide on the hydro-powered urinal. When asked in the focus group interview how they arrived at their final design solution, Craig and Channing reflected on the functionality of their design.

> *Focus Group Interview:*
>
> *Craig: "It would've changed our ideas, but then our ideas wouldn't be as practical. It would've gone farther and imaginative into this fairytale world. And then it might not work, so with this at least it worked to produce energy. We really saw what we had done."*
>
> *Channing: "I think we were just trying to think of something we actually do, because biomass, I wouldn't be able to think of how we would use that. So, originally we were*

down to solar and hydro because those were like two most common and the easiest to play around with."

Not only did they value the focus on the functionality parameter of the design project, they also valued the interesting/ innovativeness aspect of their design and used that as a basis for decision making in their design approach. The appeal of a design that incorporated a urinal led team members to choose it for their final design solution: *"Ok, the urinal is a pretty bad-ass idea. Let's do it" (Channing, Sketch Session)*. The team's perceived innovativeness of their design idea also led them to consider additional innovative requirements such as meter that indicated the amount of power produced, but this team ultimately rejected this idea because they could not "figure out" how to implement it.

Focus Group Interview:

Craig: "We just thought it was an awesome idea. It was pretty fun, and the comedy about it just really made us want to do it. We wanted to do something that other people would think was cool, funny, you know…some of the other projects, like the solar panel light up book bag or something, it's just kind of generic."

Later in the Focus Group Interview:

Channing: "Kind of our original idea that didn't get implemented was like a little meter on it that went up as you peed. And showed you how much power you did produce. That would've been great if we could've figured that one out haha."

Craig: "I felt like that would have interested a lot of people."

Channing: "Yeah that would have got more people involved."

Producing an interesting design was salient in terms of how it influenced their final design decisions and design practice. However, the data suggests that the feasibility and implementation of these ideas led them to prioritize functionality over the interesting/ innovative parameter. In addition to producing a functional and innovative design, Team 4A based some of their decisions regarding design solutions on personal experience and user needs.

They reflected on their brainstorming experience and highlighted the fact that many of their ideas were based on personal experience or interactions they had with water and their research on hydropower and waterwheels.

Focus Group Interview:

Channing: "We just came up with a lot of ideas. I mean, they were pretty much all of the same. They were just [based on] everyday contact we had with water, like a water fountain or a bathroom shower. And thought about how we could implement a water wheel or something with it. So that it's not being wasted. Our initial design was to have an actual urinal, but we couldn't afford that either so."

Team 4A's final design solution was not produced to scale due to budget constraints and the ultimate feasibility of their ideas. However, they chose their final design solution over other alternatives by prioritizing user needs and applicability.

Focus Group Interview:

Channing: "Plus if they implemented it for every urinal it would add it up. I mean one urinal might not produce that much power but implement it in one that has the most bathrooms."

Craig: "The main reason why we thought about doing this was, we were thinking about large areas where there were a lot of people, like airports, they would have like 30 urinals in there."

Even though Team 4A perceived the DSEP as a course project or assignment and used that to inform some of their design practices, the data above suggests that they framed the design problem differently when removed from the institutional and organizational contexts.

Focus Group Interview:

Craig: "I wish we could have…. I wish the money budget were a lot larger so we could really design something. Like, go out do a little research on what people would think about it. That would've been fun."

Later in the Focus Group Interview:

Craig: "You never know… it could be a really good working design. Some businessperson out there hears about a freshman at Tech University in an engineering design class, it could open up some new stuff. Just being able to go out there and ask people what they would think about it, and do a small survey would have helped a lot too. Less restrictions would have made it a lot better."

4.4.3 Team 4A Summary

Overall, Team 4A's perception of the DSEP as a course project constrained them more than the explicit constraints of the DSEP. While the data suggests they had a different approach to framing the problem and ideas that incorporated clients and user needs, they ultimately relied on their assumptions related to the institutional and organizational contexts. While the constraints of the DSEP structure, or the explicit DSEP requirements and deadlines, facilitated Team 4A's progression through the design process, very high constraints resulted in assumptions about the project as an element of a weed-out course. In this case, Team 4A might have benefited from more explicit constraints in early design stages, such as user needs analysis with respect to problem definition and helped them make sense of the requirements of the later DSEP artifacts.

4.5 Summary of Within-case Analysis

The within-case analysis was designed to answer *RQ1*: *What aspects of the design project are salient to students*? It was guided by the constructs from Nested Structuration Theory. I analyzed team design session data by identifying and examining the aspects that came up frequently in student discussion as well as aspects related to the institutional and organizational contexts that impacted design decisions. Under this framework, for each team, salient aspects existed at the institutional level, and at three levels of the organizational level, i.e. course, project structure, and project parameter.

This chapter demonstrates that teams are never fully removed from the context(s) in which they design. With respect to the institutional context, teams were constantly immersed with coursework not related to the DSEP. This impacted their approach to completing DSEP artifacts such that students went through the motions to meet the requirements in order to "get back to" studying or completing other assignments. Additionally, they have frequent and comparative discussions regarding the number of credits, what course, and what work they have due for these other courses within the institutional context. Furthermore, other students within the institutional context and the previous experiences of those students with the DSEP arise in team discussions, and the teams often use this information to inform their design decisions or approach to the project.

The findings also show that the organizational context, at the course level (1) and project levels (2a and 2b) is imminent and students base their design approach on their perception of the course that encompassed the DSEP. Some teams perceived this as a weed-out course and students subsequently treated the design project as another course assignment. In doing so, teams tried to interpret and predict instructor evaluations based on their perceptions of the instructor and guided the completion of the design artifacts accordingly.

At the project level (Levels 2a and 2b), the structure and parameters of the project both impacted student design decisions. Overall, when the students were unclear about the project objectives and requirements, most teams chose to focus on explicit constraint of the design project and often manipulated them to fit their actual practices. Figure 8 summarizes the resulting practices for each team and the salient factors for different levels.

One major finding of the within-case analysis is the development of a modified Nested Structuration model where we see the existence of sublevels within the organizational context, e.g. course and project, and is illustrated in figure 8. In this study I nuanced the framework when appropriated in educational setting and illuminated the presence and impact of multiple sublevels related to the organizational context. The next chapter discusses the patterns and salient

Team 1A

Institutional	▪ Coursework associated with team members' other courses often dominated team discussions and impacted design project decisions. ▪ Often based design decisions on a roommate's previous experience with the course and project.
Organizational (Course)	▪ Went through the motions of creating design artifacts required by the project and viewed the artifacts as course assignments.
Organizational (Project Parameter)	▪ Focused on the functional & possible/ applicable parameters but manipulated the cost constraint.

Team 2A

Institutional	▪ Time management was a self-identified issue due to other coursework but the team identified the benefits of meeting every week/ having a set time to meet. ▪ Used prior students' experiences to inform their approach to the project.
Organizational (Project Structure)	▪ Used design artifact requirements to inform subsequent design phases and artifacts.
Organizational (Project Parameter)	▪ Focused on making a working device that was possible/ applicable as well as beneficial if implemented on a larger scale.

Team 3A

Institutional	▪ Went through the motions of creating design to get back to other coursework. ▪ Used previous students' experiences to guide their design approach and decision-making.
Organizational (Course)	▪ Relied on their assumptions of the workshop leader and design artifact evaluation to inform design practices.
Organizational (Project Structure)	▪ Used design artifact objectives & requirements to inform subsequent design phases.

Team 4A

Organizational (Course)	▪ Perceptions of the workshop leader and the course as a weed-out course impacted team design practices
Organizational (Project Structure)	▪ Followed the step-by-step process of the project; this also led them to manipulate other design artifact requirements.
Organizational (Project Parameter)	▪ Focused on a design solution that was functional and beneficial if implemented on a larger scale; also based their decision on a solution they perceived as "cool" or interesting.

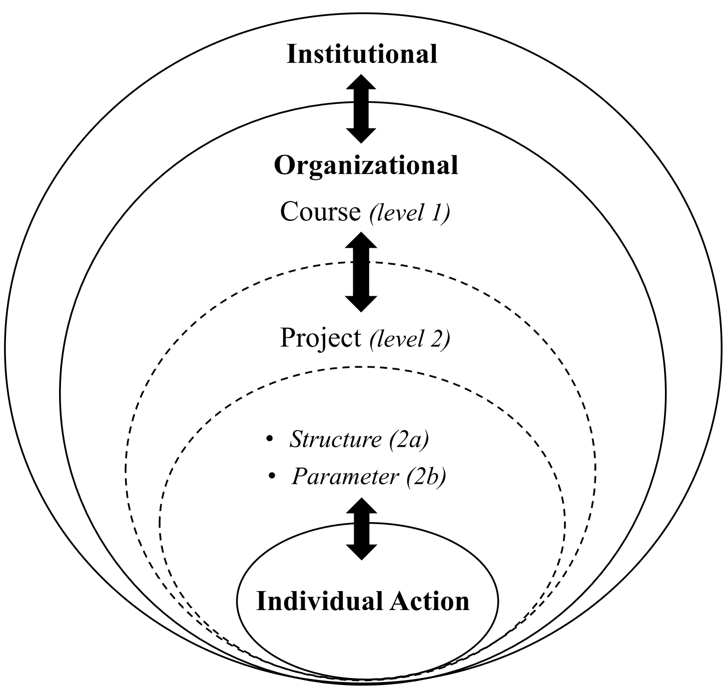

Figure 8. Summary of Within-Case Findings and Modified NST Model

CHAPTER 5: RESULTS: CROSS-CASE ANALYSIS

This chapter reports the findings from the cross-case analysis as described in section 3.7.5 and was constructed to answer RQ2: *How do these salient aspects affect their design practices?* Sections in this chapter are organized by common themes across cases and are based on the institutional and organizational constructs and sub-constructs (see Table 7). I discuss the salient aspects of the design project in terms of how these aspects across all teams affected design practices. Instances from team design sessions are provided to support findings related to the salient aspects and their impact on practice. Figure 9 offers an illustrative overview of the final designs for Teams 1A, 2A, 3A, and 4A.

Team 1A	**Team 2A**	**Team 3A**	**Team 4A**
Solar Canopy	**Hydro-powered Bridge [Light]**	**Solar Cooker**	**Hydro-powered Urinal**
			

Figure 9. Team Final Designs

Figure 10 below is a compilation of the factors salient to design teams with respect to the overarching contexts, e.g. institutional, organizational, related to design. Several factors were common across teams for each of the different contexts and other factors were not salient across all teams. Again, Figure 10 illustrates the overall salient factors for each context and the following sections in this chapter delineate and discuss these factors as they related to design practices across the team in this study.

INSTITUTIONAL CONTEXT			
Team 1A	**Team 2A**	**Team 3A**	**Team 4A**
▪ Amount of other coursework ▪ Comparisons of other courses ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Comparisons of other courses ▪ Institutional infrastructure (Students; Departmentalized nature of courses)

ORGANIZATIONAL CONTEXT COURSE *(Level 1)*			
Team 1A	**Team 2A**	**Team 3A**	**Team 4A**
▪ Weed-out perception of course ▪ Perceived DSEP as a course assignment ▪ Connection to course content (lack of)	▪ Course aspects **not** salient in terms of discussion or impact on design practice	▪ Connection to course content ▪ Perception of the workshop leader impacted design practice	▪ Weed-out perception of course ▪ Perceived DSEP as a (weed-out) course assignment ▪ Connection to course content (lack of) ▪ Perception of the workshop leader impacted design practice

ORGANIZATIONAL CONTEXT PROJECT STRUCTURE *(Level 2a)*			
Team 1A	**Team 2A**	**Team 3A**	**Team 4A**
▪ Step-by-step process (time management) ▪ Interpretation of DSEP document/ design artifact objectives and requirements ▪ Go through the motions of creating DSEP design artifacts	▪ Step-by-step process (time management) ▪ Low constraint and uncertainty ▪ Use of DSEP document/ design artifact objectives and requirements	▪ Use of DSEP document/ design artifact objectives and requirements ▪ Go through motions of creating DSEP design artifacts	▪ Step-by-step process (manipulate other requirements) ▪ Interpretation of DSEP document/ design artifact objectives and requirements

ORGANIZATIONAL CONTEXT PROJECT PARAMETER *(Level 2b)*			
Team 1A	**Team 2A**	**Team 3A**	**Team 4A**
▪ Possible/ Applicable (something 'useful') ▪ Functional (chose stability over cost)	▪ Functional (making a working device was a challenge) ▪ Possible/ Applicable (producing a beneficial and scalable solution)	▪ Possible/ Applicable (guided by user needs) ▪ Functional (solution that was easy to build)	▪ Interesting/ Innovative ('fun', 'cool' solution) ▪ Functional (relative to their required effort) ▪ Possible/ Applicable (on a larger scale)

Figure 10. Overview of Salient Aspects

5.1 The Institutional Context

Several themes related to the institutional context frequently occurred in team discussions and/or impacted student design practice. This observation is supported by data from all teams' design sessions. I identify these themes and discuss them in the following section. Again, in this section, the common salient aspect found across teams is related to the institution, or the university in this study. Figure 11 summarizes the salient aspects for each team with respect to the institutional context.

INSTITUTIONAL CONTEXT

Team 1A	Team 2A	Team 3A	Team 4A
▪ Amount of other coursework ▪ Comparisons of other courses ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Institutional infrastructure (Students within the institutional context)	▪ Amount of other coursework ▪ Comparisons of other courses ▪ Institutional infrastructure (Students; Departmentalized nature of courses)

Figure 11. Overview of Teams: Institutional Context

Students' course load and resulting amount of workload was salient across all teams and was present in design session discussion, and even dominated at times. Furthermore, it affected their design practices related to the DSEP. Teams 1A, 3A, and 4A discussed courses not related to ENGR 1234 and/or the DSEP (this was also true for 2A, but it was comparatively minimal). These teams compared the amount of coursework as well as the number of credit hours for the semester throughout the design sessions. This type of discussion would typically develop to include additional comparisons of the instructors and assignments/ tests with respect to other courses. Students used these comparisons to gauge their own progress and advise one another on the amount of time and effort required by the discussed assignments.

The data also showed that not only did these recurring discussions arise while students worked on their DSEP artifacts in design sessions, it also impacted how they completed and assigned work. Teams used the designated design session times to complete design artifacts required by the DSEP document and decided how to divide tasks based on the institutional factors. Specifically, Team 1A assigned sections of the research report based on the perceived amount of effort required to write each section coupled with the amount of work outside of the DSEP each member had. An example of this division of labor based on workload is illustrated in Team 1A's research report session (Section 4.1.1.1) where Eddie states that team members who don't have as much other coursework should write the longer sections of the paper: *"Is anyone like really busy this week? Cause I would just say, if you're not that busy this week, then you would take the longer one. That makes more sense."*

Other teams used the amount of other coursework to guide their approach to writing the research report, but used the shared time together during design sessions to work on and complete design artifacts with the assistance of one another. For example, Team 3A assigned sections of the final design report to everyone on the team, but helped each other complete sections that other members were still working on.

Team 3A, Final Design Report:

Brett: "I mean I was just going to do the summary when I was done. Wait, is somebody already doing that?"

Ian: "No, I'm doing the gathering information."

Brett: "Okay, I'll just keep going then with the summary."

Ian: "What else should I do?"

Brett: "I mean just help him out then."

Teams generally used this collaborative approach with one another to make the design sessions go faster so they could return to studying for other courses or completing other coursework: "I'm trying to get this done so I can go back to studying for Physics" *(Brett, Team 3A, Final Design Report)*. Team 1A also used this approach during the brainstorming session where they needed to generate 20 ideas in order to complete the brainstorming inventory (DSEP artifact).

Team 1A, Brainstorming Session

Kelly: "We should just all think of 20 and then we'll label... you know what I mean?"

Cory: "Or each of us comes up with 5."

Kelly: "Yeah, but say someone came up with 4...just, you know what I mean? That will make this go by faster. We can get this done now instead of having to submit it later."

The impact of coursework led other teams to not submit or completely forget to do additional DSEP artifacts. For example, a member from Team 2A did not complete a required team evaluation (DSEP artifact) because he was preoccupied with another course project that was due at the same time as the team evaluation: *"Like, I had some computer science project due that night right after the test so...I wasn't even thinking about it" (Gary, Focus Group Interview).* In one instance, students' focus on other coursework led one student to plagiarize his section of the DSEP research report: *"No, it's completely my fault. My bad. I just had 17 things to do so I was just like, maybe I can get away with this. Clearly I didn't though" (Eddie, Team 1A, Brainstorming Session).* In addition to the amount of course work from other courses within the institutional context, the framework or infrastructure of the institution affected student design practices related to the DSEP.

The framework of the institutional context was salient regarding impact on design practices across teams. More specifically, design teams in this study often used information attained from roommates, hall mates, or students in other organizations within the institution. For example, Teams 1A and 3A used information from students who previously took the course (ENGR 1234) and developed their own DSEP. Teams in this study used information from other students to inform decisions on what type of renewable to use, the feasibility of implementing specific solar energies, and how to approach the graded DSEP artifacts. The following excerpt illustrates this common theme of students relying on roommates or students from previous semesters to guide their approach more specifically:

Team 1A, Prototype Discussion Session:

Cory: "I'll talk to my roommate about the solar panel and hopefully...and if we can't use his, I'll go out and buy one."

Team 1A reinforced their decision to use solar energy and continued to support subsequent decisions regarding design building based on one team member's previous experience with the DSEP. Additionally, Cory referenced what he knew from his roommate's experience to guide how Team 1A interpreted and manipulated DSEP requirements, e.g. "My roommate said too for stuff they...they bought stuff and theirs ended up being $21, or something. They just went on eBay and found the price and printed out a receipt" *(Cory, Team 1A, Prototype Discussion Session).* Similarly, Team 3A used information from a student from the previous semester to interpret how they approached the team evaluations. When asked how they should evaluate one another based on their contributions at the time of the evaluation Ian referenced what he learned from another student who previously took the course during the research report session (Section 4.3.1.2): *"Nah, you're straight. Someone from last semester, he told me, everyone just gives each other hundreds. Otherwise it'd be...[shakes head.]"*

Another example from Team 4A illustrates this approach with respect to writing the DSEP research report. Here, they utilize information from another student regarding an interpretation of the workshop instructor to guide how much effort they were willing to put into this DSEP artifact. They discuss if the workshop instructor will be too harsh on the paper citing that she has to read so many papers that her critiques on individual papers wouldn't be that "harsh". Furthermore, the team members used information from other students to inform the team's perception of the workshop leader and subsequently how they would work on design artifacts: *"Yeah, [student] said don't even worry about this thing, just throw it together and go with it." "He lives right next door to me in the dorm. But he's a second year and he did this." (Craig, Team 3A)*

Team 2A on the other hand, did not use information attained from students within the institutional context to interpret DSEP requirements, but they did reference other students' experiences in order to try to clarify where they could acquire resources/materials. When discussing how they would obtain a motor for their project Kevin hoped they would find out from the workshop instructor, referencing his roommate's experience from the previous semester (Section 4.2.2.1).

Across teams, I found that students were generally unclear on where to obtain the resources/ materials they required for their designs. The type of materials and where to purchase them usually resulted from internet searches and teams rarely, if not at all, referenced any content knowledge from their engineering-related curriculum.

Data from teams' design sessions shows that students in this study took physics and math courses; however, they did not specifically incorporate that content knowledge into their design practices and was not necessitated by the design project. Furthermore, the engineering-related knowledge from these courses was perceived as insufficient with respect to their design approach. Team 4A, for example, felt that after taking other "engineering" courses, they would have been able to produce a more functional and creative design. And Team 3A rejected any design solution they thought was too technical, in other words they perceived that they did not have enough engineering-related knowledge. These findings suggest the departmentalized nature of the institutional context constrained students from fully applying material they did not view as specific engineering knowledge. At the same time the nature of the design problem may have also contributed to students' approach because it didn't specifically require the design teams to do so.

Overall, the salient aspects across teams with respect to the institutional context were 1) the other courses students were taking as part of the first-year engineering student curriculum and 2) the infrastructure of the institution. The other courses/ curriculum specifically influenced design practices related to how students completed the artifacts associated with the DSEP. The abundant amount of coursework that students were responsible for outside of the DSEP enabled a more collaborative approach to completing artifacts. At the same time, this also led students to approach these artifacts as another task to be completed in order to move on to other required coursework. The second salient aspect across teams is the infrastructure of the institution. More specifically, students within the institutional context, e.g. roommates, hall mates, etc., informed the decisions and design practices of student design teams in this study. They used other students' prior experience to guide how they approached DSEP artifacts and what they perceived as feasible designs. This information enabled students to direct the search toward more feasible solutions, but at the same time constrained students from interpreting the DSEP requirements and objectives on their own. Another instance related to the infrastructure included the other courses students were taking. In this case, students saw these courses from a departmentalized frame and were unable to apply knowledge they did not perceive as engineering-specific. Figure 12 illustrates the salient aspects and resultant design practices from across teams.

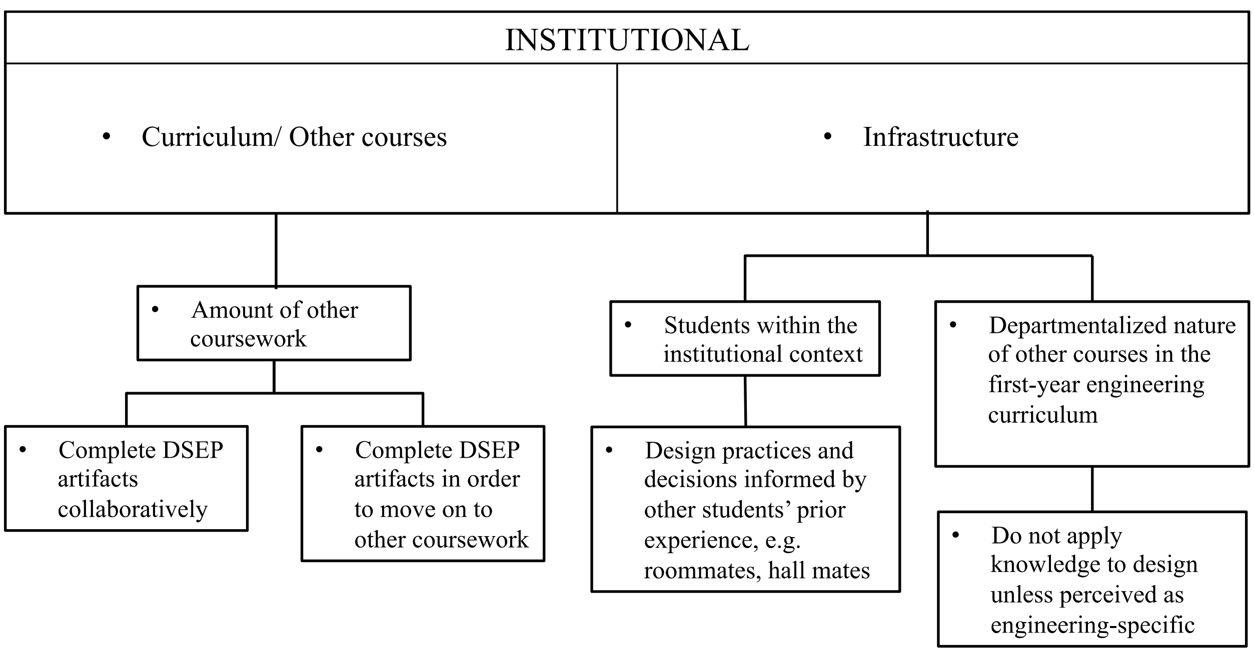

Figure 12. Overview of salient aspects and resulting design practice related to the institutional context

5.2 The Organizational Context

In this section I discuss several common themes across teams based on the organizational context. These are grounded on the framework developed for the coding scheme (see Table 7), including the constructs: Course (Level 1), Project (Level 2) and Project Structure (Level 2a), Project Parameter (Level 2b).

5.2.1 Organizational: Course (Level 1)

This section discusses salient aspects related to the course ENGR 1234, specifically how students perceived these aspects, and the resulting design practices. The salient aspects identified for each team are presented in Figure 13 below.

ORGANIZATIONAL CONTEXT			
COURSE *(Level 1)*			
Team 1A	Team 2A	Team 3A	Team 4A
▪ Weed-out perception of course ▪ Perceived DSEP as a course assignment ▪ Connection to course content (lack of)	▪ Course aspects **not** salient in terms of discussion or impact on design practice	▪ Connection to course content ▪ Perception of the workshop leader impacted design practice	▪ Weed-out perception of course ▪ Perceived DSEP as a (weed-out) course assignment ▪ Connection to course content (lack of) ▪ Perception of the workshop leader impacted design practice

Figure 13. Overview of Teams Organizational Context: Course

The salient aspect for the majority of teams regarding the course was students' perception of the course itself. Teams 1A and 4A expressed their view of the course regularly throughout their design sessions and respective focus group interviews. Characteristics that students attributed to "weed-out" courses included instructors making the course "ridiculously hard", requiring abundant amounts of work (usually tedious work), and making it difficult to pass. Teams 1A (Section 4.1.1.3) and 4A (Section 4.4.2.1) perceived the course as "a bunch of tedious stuff" (Craig, Team 4A) or "all about learning how to pass" (Jason, Team 1A). Additionally, the weighting of the course (in comparison to their other courses) factored into how students viewed the amount of required work for ENGR 1234: *"...I'm in multi-variable calculus and physics 2306 so I really have to study for those classes and I was spending all of my time on this two-credit weed-out class." (Channing, Team 4A).*

This outlook of the course impacted how students approached the DSEP in terms of how they thought about the design project and completed design artifacts. In particular, these teams viewed the DSEP as another course assignment and completed DSEP design artifact in order to submit an adequate assignment. For example, Channing (Team 4A) separated his view of the course and his practice within the context of the course from how he would react in a professional or real life situation (Section 4.4.2.1) The following excerpt from Team 4A's final design presentation sessions supports this perception of the course and resulting design practice: *"We're not doing that bad. If it comes to a real project, I'd talk to the company and be like yeah this isn't safe but this is a 1024 weed-out class design project."* Similarly, Team 1A approached DSEP artifacts as tasks to be completed or assignments as part of the course. They focused on the number of ideas required by the DSEP and continually reassured each other that they "just needed ideas" and did not consider their previous research on solar energy: "it doesn't have to be solar it can be any source". One team member attempted to introduce a concept from the course (idea triggering), but it was quickly overlooked when another team member suggested just thinking of 20 ideas to complete the necessary amount of ideas (Section 4.1.1.3).

While Team 1A attempted to incorporate concepts from the course into their brainstorming practices, another team (3A) proposed the idea triggering method and incorporated it into their design practices. Overall, the data from Team 3A suggested that this team did not perceive the course as a “weed-out” course, but more of a typical [engineering] course. In other words, this team did not refer to any of the characteristics associated with a weed-out course, e.g. ridiculously hard, requiring abundant work to weed-out or discourage students, etc., but discussed their perceptions of the course. Team 3A’s brainstorming session (Section 4.3.2.1) illustrates how Team 3A members viewed the course [material] and their incorporation of a course concept, idea triggering.

At the same time, their perception of ENGR 1234 --as a typical course-- led them to revert to behaviors and practices typical to a student participating in a course. Particularly, during the creation of design artifacts, students would use their perception of the workshop instructor to guide how they approached the DSEP artifacts. For example, Team 3A chose to include more definitions and specifically wrote about how they utilized the idea triggering method in order to elicit positive instructor feedback citing that the workshop instructor would “eat that up” (Section 4.3.2.1).

Team 4A, on the other hand, used their perception of the workshop instructor to gauge what practices they needed to do versus practices that were not necessary based on the workshop instructor. Team 4A members discussed their perceptions and evaluating what they needed to do based on that (Section 4.4.1.2). In this case, they are evaluated whether or not to check for grammar on the DSEP research report based on the idea that the workshop instructor was “obviously not an English major” (Cody, Team 4A).

Overall, the salient aspects related to the course were based on the students’ perception of the course. While student perception was not identical across all cases, teams in this study perceived the course as a specific type, or weed-out course, or they perceived ENGR 1234 as a typical [engineering] course. Viewing it as a weed-out course led students to treat the DSEP as an assignment, or a design project that was “more of a pain in the butt than it needs[ed] to be” *(Channing, Team 4A, Final Design Presentation Session).* This view also led teams to overlook or even dismiss concepts from the course as they applied to the design project. On the other hand, the team that viewed the course as more of a typical [engineering] course was more inclined to incorporate course concepts into their design practices. Additionally, students with this perception were not removed from the context of the course and used their perception of the instructor to guide their approach to DSEP artifacts. Figure 14 illustrates the relationship between the salient aspects and subsequent practices.

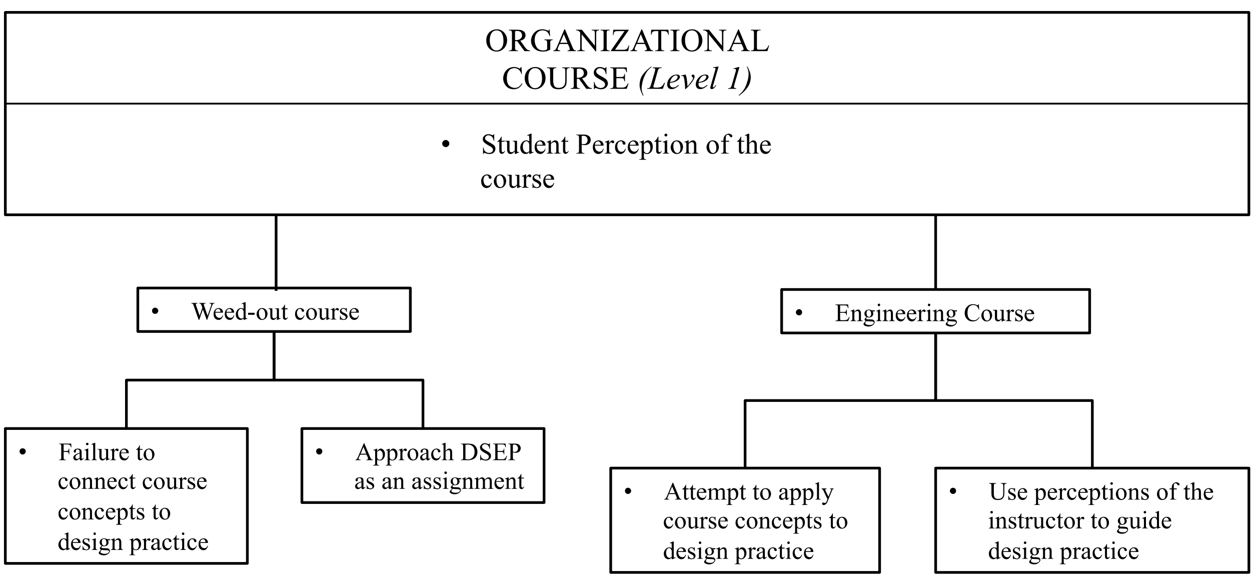

Figure 14. Overview of salient aspects and resulting practice related to the organizational (course) context

5.2.2 Organizational: Project Structure (Level 2a)

This section discusses common themes and design practices across all teams related to the organizational context (Level 2a), project structure. Examples of the aspects related to project structure include, DSEP artifact objectives, requirements, and deadlines for these artifacts. In other words, this section examines how the format of the project impacted students' approach to design. Figure 15 provides an overview of the salient aspects for each team.

ORGANIZATIONAL CONTEXT

PROJECT STRUCTURE *(Level 2a)*

Team 1A
- Step-by-step process (time management)
- Interpretation of DSEP document/ design artifact objectives and requirements
- Go through the motions of creating DSEP design artifacts

Team 2A
- Step-by-step process (time management)
- Low constraint and uncertainty
- Use of DSEP document/ design artifact objectives and requirements

Team 3A
- Use of DSEP document/ design artifact objectives and requirements
- Go through motions of creating DSEP design artifacts

Team 4A
- Step-by-step process (manipulate other requirements)
- Interpretation of DSEP document/ design artifact objectives and requirements

Figure 15. Overview of Teams Organizational: Project Structure (Level 2a)

The step-by-step nature of the DSEP, i.e. necessitating sequential due dates for design artifacts, impacted teams' 1A, 2A, and 4A's approach to design. The sequence of the due dates and associated design artifacts followed the design process given to students in class. For example, the research report (research phase) was due in week 7, the brainstorming inventory (generate multiple solutions) was due week 8, the sketch (analyze and select a solution) in week 10, and so on. This aspect was viewed by students as more of an approach that facilitated time management rather than an approach that addressed each phase of the design process. The following excerpts from Team 2A's focus group interview is an example of this outlook.

Team 2A, Focus Group Interview:

Kevin: "And I thought the way, it wasn't a really short amount of time and it wasn't really a long amount of time we had to do the project. And the way we had certain stuff due at a

> *certain time worked well. It made it like so it didn't stack up on us so it had to progress with the project. So I liked that."*

The deadlines for each design artifact enabled teams to fit the design project in with their other coursework. They "liked", or saw, this as a benefit with respect to their position in organizational context. More specifically, having each design artifact due sequentially and in weekly or biweekly intervals enabled them to manage their time so that the project "didn't stack up" on them and "made it less stressful." Team 4A recognized that the step-by-step nature of the project helped out with other classes, but this team reflected that they would have preferred a more condensed scheduling: *"I mean I know it's a whole semester long project…but I think it would've been fun to just do it all in one weekend or something. (Craig, Team 4A).* While 3A did not participate in the focus group interview to provide data regarding their perspective on the step-by-step nature like other teams in this study, data from Team 3A's design sessions suggest that this team also approached the design project in discrete phases based on project deadlines.

> *Team 3A, Prototype Building Session:*
>
> *Andy: "So we have prototype due and we have team evaluation. And then we'll have two weeks and we'll do the final design report. And then next week we have the team demo and presentation. So the whole thing is actually due in two weeks."*

Project deadlines facilitated teams' progression through the design process and necessitated them to address each phase of the process by creating the associated design artifacts by the assigned due dates. However, the linear deadlines for these artifacts did not encourage students to revisit any of the design phases or approach design as an iterative practice. The highly constrained deadlines even led students to manipulate the requirements related to explicit constraints such as deadlines. Team 4A described how the due dates for the final design report and final presentation constrained them from reporting an accurate account of how they constructed and tested their design in section 4.4.2.2, citing that the final design report required a picture of their design and they hadn't even finished or tested their design at the time of the report due date. Furthermore, they felt that they were forced to misrepresent pictures of the final design and bill of materials because they were "going to be graded on it" (Channing, Team 4A), but hadn't completed the project before they were required to report on these items in the final design report. By manipulating the requirements for the final design report, e.g. improvising the bill of materials and using a picture of their *not-so*-final design, in order to submit a completed report by the required deadline, the team chose to go through the motions of creating DSEP artifacts rather than connecting phases of the design process.

In addition to inducing a 'go through the motions' approach, the linear progression of design phases based on project deadlines did not encourage and actually constrained teams from going back and revisiting design phases or making connections between these phases. This also impacted how teams approached the requirements for the DSEP artifacts. In the following example, Team 2A is trying to discuss and write about the required sections of the final design report, e.g. "define the problem", "gather information"; however, some team members did not make the connection between the artifacts and how it related to the design process that they were required to write about in the final design report.

Team 2A, Final Design Report Session:

Cullen: "But there's a lot of things we have to do."

Gary: [reading from DSEP] "define the problem, gather information..."

Jim: "But we didn't do that."

Kevin: "What"?

Jim: "We didn't like, gather..."

Cullen: "That was our report."

Gary: "That was our 5 page paper."

Jim: "We didn't test it though."

They also reflected on skipping the "define the problem" phase of the design process early on because they were not explicitly required to do so in the design artifacts that were due earlier: "So I guess, in that sense, we didn't really define a problem" *(Jim, Team 2A, Focus Group Interview).* The data from the final design report session and the focus group interview further supports teams' approach of going through the motions of creating DSEP artifacts to meet the given requirements.

Another requirement associated with the project structure was the bill of materials, requiring teams to stay under a $20.00 budget, which they had to include proof of in their final design report. This explicit constraint led all teams to focus on and manipulate it in order to report that their design was under the given budget. The following examples or excerpts from team discussions illustrate this finding.

Team 1A, Final Design Report Session:

Jason: "This was 15[$]...the panel was 15 [$]. This [wood used to make the model]; I'll write up a statement from my dad's business that it was $3 haha. And that gives us $2 to look for an LED."

Team 2A, Final Design Report Session:

Jim: "And I got glue sticks and a glue gun. But I figured get rid of the receipt for the engine, if we're not going to use that thing. And whenever we're going to...when's this due?"

Team 3A, Final Design Report Session:

Ian: "I'm just going to say the ones that we bought, just a receipt from Kroger."

Any: "Okay."

Ian: "I mean we don't need to show it, do we?"

Brett: "True."

Andy: "Yeah, it says include a copy of all receipts. How do you do that?"

Andy: "Why don't you just say market price. Just because I don't want her to come back and take points off because you didn't actually include the [correct] receipt."

Team 4A, Final Design Report Session:

Channing: "We're not putting down, matching printed circuit board. We're just saying breadboard. And then we're going to reference radio shack. I don't think she's going to be checking all of our shit, so."

Channing: "This is cost adjustment."

Similarly, many of the teams also exhibited a sunk-cost perspective in terms of time and not money due to the explicit constraints such as project deadlines and budget. In other words, due to the rigid deadlines of DSEP, artifact teams would buy additional materials and supplies if their design concept did not work instead of going back to earlier phases to redesign. They would then report what they could manipulate to fit within the budget. For example, Team 4A purchased a high-speed motor, but after testing realized they needed a low-speed motor. However, they already had completed all of the design artifacts except for the final presentation/ demonstration. In this case, they had reported that they bought and used the high-speed motor so there was not documentation of the actual component used in their final working model.

Another outcome of the DSEP artifact's objectives and requirements was that it also enabled teams, at times, to relate the design phases to one another. For example, the objective of the sketch was: "To communicate a detailed design solution that emerged from the preliminary design phase; to improve hand-sketching skills" and it required teams to: "Include a 1 to 2 paragraph description of how your team narrowed down the ideas from the brainstorming session to select this design; pay special attention to the role that your research played and why you ended up with your selected design." While all teams' initial response was to "make something up" for these required paragraphs, it ultimately, prompted a discussion where teams thought about how they arrived at the design solution. In Team 3A's sketching session they addressed the sketch requirement to write a 1-2 paragraph explanation by initially making it up but after thinking through what to include in the made up description they concluded they chose the final design idea because their idea generation led them to consider small household appliances. (Section 4.3.2.2)

Initially the team attributed their design selection to their use of Google and searching for results related to solar power. Because they were prompted by the DSEP document to think about the brainstorming phase, which they completed prior to the sketching phase, they reflected on their process and how they generated multiple solutions. This type of outcome was also found across cases when teams used the sketch to discuss and hash out features of their conceptualized design to inform building in later phases.

Overall, the aspects of the organizational context related to the project structure that was salient across teams were the 1) step-by-step nature of the project and 2) the objectives and requirements for the artifacts given in the DSEP document. Teams perceived the step-by-step nature of the DSEP to facilitate their time management practices and this also led to teams addressing each stage of the design process. On the other hand, the linear deadlines led students to manipulate the explicit constraints such as budget and artifact requirements and experience sunk-costs related to time. The objectives and requirements for the design artifacts given in the DSEP enabled students to understand and connect certain phases of the design process to one another; at the same time, these given requirements induced design practices where students went through the motions of creating the artifacts. The “go through the motions” approach also induced students to focus on explicit DSEP constraints, which they ultimately manipulated to meet the requirements. Figure 16 below provides an overview of this section’s findings.

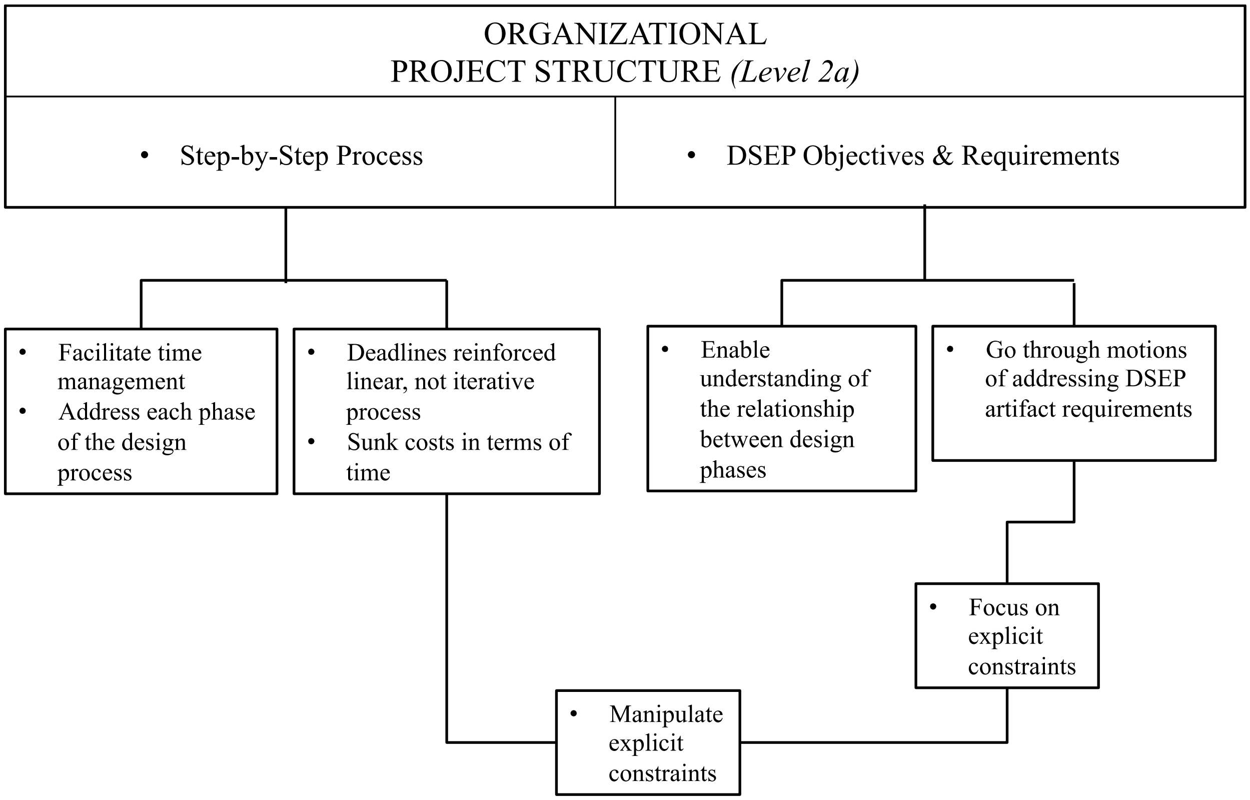

Figure 16. Overview of salient aspects and resulting practice related to the organizational: Project Structure

5.2.3 Organizational: Project Parameter (Level 2b)

This section discusses the common themes related to the DSEP parameters (organizational context, level 2b) as defined by the DSEP document and other emergent parameters the teams considered. Specifically, the given and/or considered parameters were:

Parameter	Definition or Explanation
Functional	It should showcase the creation of energy from a renewable source, not just as a conceptual model, but a physical implementation. Even though you may not be able to make your design full-scale, your project should adequately demonstrate the intentions of your group’s design when scaled up.
Safe	Your design should not harm anyone who uses it, and should have a minimal adverse affect on the environment.
Innovative/ Interesting	Be creative! Think outside the box on this project. Using a solar panel you get in a science project kit to power a light bulb is not very interesting. Make your design unique.

Renewable Energy Source	It must highlight one or more key components of a renewable energy source.
Educate/ Entertain	It should strive to educate and entertain as well as generate further inquiry and interest in renewable energy sources.
Possible/ Applicable	A possible and applicable solution that benefits or addresses the needs of a user.

I highlight common and salient aspects regarding the DSEP parameters and provide instances from the teams in order to explain how salient aspects related to the project parameters affected design team practices and design decisions. Figure 17 provides an overview of the four teams and specifies the aspects important to each team.

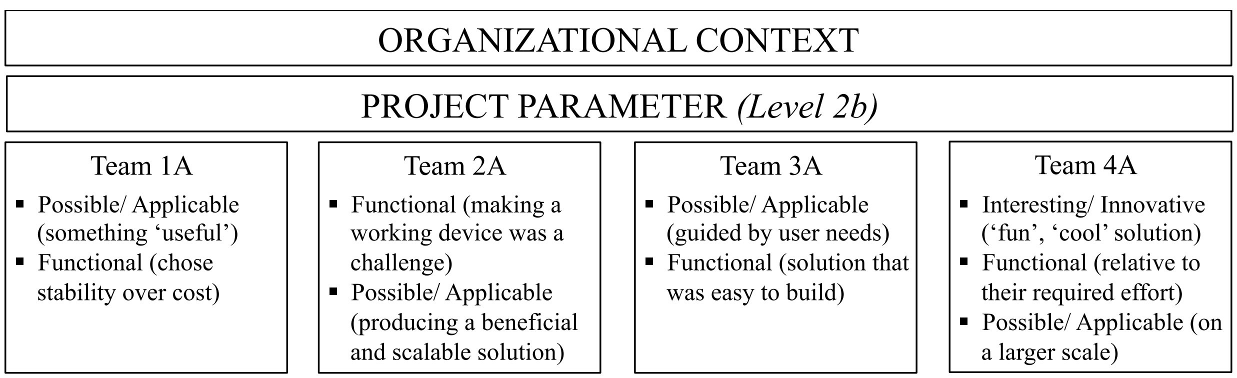

Figure 17. Overview of Teams: Organizational, Project Parameter (Level 2b)

Across all teams the common parameters that students focused on were the functional and possible/ applicable parameters. While all teams also utilized a renewable energy source in their design solution, this concept was not prevalent or important to the students when trying to conceptualize design solutions. In other words, teams did not consider using any sources other than a renewable energy. Furthermore, they only considered renewable energies listed in the DSEP document, "Each team will start with an energy source of interest from the list of the of sustainable energy categories (solar, wind, hydropower, biomass, or geothermal)." One outcome of teams using a mutual, given list of possibilities was that teams came up with similar ideas during the brainstorming session, but had differing methods of implementation for these ideas. Specifically, Teams 1A and 3A both contemplated an idea that used a renewable energy source to power road lights. However, 1A considered using geothermal and 3A considered using either solar or wind energy. Similarly, 1A and 3A also contemplated an electric or circular saw, but 1A wanted to use hydropower and 3A wanted to use solar. Additionally, 1A ideated a lawnmower powered by biomass and 3A wanted to power the lawnmower using solar energy. Another similarity between Team 1A and 3A, which differed from 2A and 4A's approach, was that 1A and 3A chose to brainstorm using all suggested the renewable energies, i.e. solar, wind, hydropower, biomass, and geothermal. This was different from 2A and 4A's approach where they only brainstormed ideas using the renewable energy source they chose to research for the research report design artifact. Teams 2A and 4A did not have as many common ideas for their respective brainstorming inventories, but they both considered the hydro-powered urinal for their final design solution. What led these teams to gravitate to certain ideas and reject others was their perception of whether or not they could make the design functional, e.g. "But how would we build it?", "How would we make it work?"

All teams set goals and worked toward making a functional device. They also all arrived at what they perceived to be a final functioning model. Teams 1A (solar canopy), 2A (hydro-powered bridge [light]), and 4A (hydro-powered urinal) represented the functional aspect of their design by lighting an LED, and Team 3A (solar cooker) justified the functionality of their design by reaching a specific temperature to cook a marshmallow. How students perceived the feasibility of their design solutions, based on the functional parameter, differed between teams. For example, 2A and 4A both conceived the idea to produce the hydro-powered urinal, but 2A rejected this solution because they were not able to conceptualize how it would ultimately function (Section 4.2.3.1). Team 4A on the other hand did not work under the assumption that the idea was unfeasible based on functionality and chose this idea for their final design solution based on the interesting/ innovative parameter, e.g. a bad-ass idea or awesome idea (Section 4.4.2.3). However, they used the scalability concept to limit their search and reject other options they discovered during the research phase of the design process:

Team 4A, Focus Group Interview

Craig: "There weren't too many options because there aren't many ways in which water can produce power. The research we did was mostly, we found mostly it was water wheels or sometime of rocking mechanism with a generator. Those were used really on the large scale with waves or the tide and stuff like that. We were pretty limited with our designs. Most of ours were waterwheels."

Another common theme across teams related to their interpretation of the functionality parameter was whether or not team members assumed they could construct a scalable model for the final design. Teams 1A, 2A, and 4A built scaled models of a canopy, bridge, and urinal, while Team 3A was the only team to build their design to scale. This concept of scalability in team design practices impacted how they chose or eliminated design ideas, but was not consistent across all design possibilities. For example, both Teams 1A and 2A considered a solution that utilized hydropower to produce electricity for a yacht (1A) or sailboat (2A), but rejected these ideas because they perceived them to be unfeasible based on building the final model. However, they built their final designs, i.e. the solar canopy and the hydro-powered bridge [light], as scaled-down models. The following excerpts from Team 1A's design sessions illustrate their perceptions regarding design ideas and functionality.

Team 1A, Sketch Session:

Eddie: "I kind of like my yacht idea."

Cory: "What was that?"

Eddie: "I thought of this one. You build a bottom of a boat, right? So say you're cruisin along and underneath is a little turbine that moves. That turbine that spins is going to just collect the energy from the spinning water. You're already using energy to spin it, so this is just collecting it sort of. And that collected energy; you can use it to power the electricity on board."

Cory: "I don't know how we'd do it though. It'd be pretty cool though."

They reflected later in the focus group interview on some of their design practices with respect to building design solutions and what was feasible from their perspective.

Team 1A, Focus Group Interview:

Eddie: "I wanted to do the yacht personally. I thought of a yacht; there was a turbine underneath it and as the boat was powered along, it could spin the turbine beneath the yacht and power the electricity on board. Because yachts are nice."

Cory: "I'm sure we could've come up with bigger ideas, like city ideas or something? The example they used was a wind-powered elevator. That's unbuildable."

Kelly: "That was so unreliable."

While building a working or functional model of their conceptual design was a driving force for all teams throughout design sessions, the possible/ applicable parameter also impacted student design practices, mainly with respect to how they evaluated various solutions and chose the final design solution. For example, all teams considered final design ideas that met the needs or benefited a user. Team 1A's discussion during their research report session (Section 4.1) is an example of how teams identified user needs based on personal experience or hypothetical situations. Specifically, Team 1A framed their decision to design the solar canopy based on Kelly's need for power outlets when lying out by the pool or beach. Similarly, during the brainstorming phase, Team 3A referenced personal experiences including working on a deck over spring break and needing tools, e.g. power drill, that did not lose power or could be easily recharged (Section 4.3.2.2). Team 2A (Section 4.2.3.1) and Team 4A (4.4.2.3) reflected in their focus group interview that they chose ideas that were beneficial to certain user groups. Interestingly, while Team 4A felt restricted in terms of building a working model and staying under budget, at the same time, they perceived their design as beneficial on a larger scale. *"Plus if they implemented it for every urinal it would add it up. I mean one urinal might not produce that much power but implement it in one that has the most bathrooms" (Channing, Team 4A, Focus Group Interview).*

In general, teams guided their conceptualization of design ideas by identifying user needs, where the user was either himself or herself or a user group that could benefit from their proposed design idea. Additionally, a common theme across all teams was a post-hoc consideration of the other parameters that were not addressed until later phases, including the final design report. Specifically, the final design report prompted students to discuss and write about the other parameters such as safety, e.g. "Please discuss the ethical implications of the design you chose." And "Could the user or another person be injured by your design? If so, what measures have you taken to prevent such injury?" When prompted by the questions in the

DSEP document, teams were initially not able to identify or explain these parameters in relation to their design. This also generally resulted in team members suggesting to one another that they "make up" material to address these concepts in the final design report.

Team 4A Final Design Report/ Presentation Session:

Craig: "There's a section on ethical, like you know..."

Channing: "We don't have anything for ethical. Who would we have offended by this? It's not going to hurt anybody; it's not going to hurt the environment."

Team 3A, Final Design Report Session:

Andy: "Help me out with the ethical..."

Ian: "Let me just finish this up."

Brett: "Just start making stuff up."

Andy: "Utilitarianism and deontology."

Ian: "That sounds weird."

Cullen: "I had to learn all that stuff last semester it was dumb. Dumb stuff."

One outcome of prompting design teams to think about design parameters that they did not initially consider was that it did lead teams to discuss the overarching issue of sustainability and environmental effects. Later in Team 3A's final design report session (after the discussion on making up material to write about ethics), they continued to think about their design in terms of its impact on the environment (Section 4.3.2.1).

Overall, I found that the common themes across teams related to the organizational; project; parameter construct were that teams focused on 1) the functionality parameter and 2) the possible/ applicable parameter and generally did not consider other parameters until prompted to do so, usually occurring in the later design phases. In general, teams guided their design practices of generating possible design solutions by considering user needs and then evaluating final design solutions by how feasible it was to produce a functional model. Figure 18 illustrates the salient aspects with respect to the organizational context; project parameter and the resulting design practices.

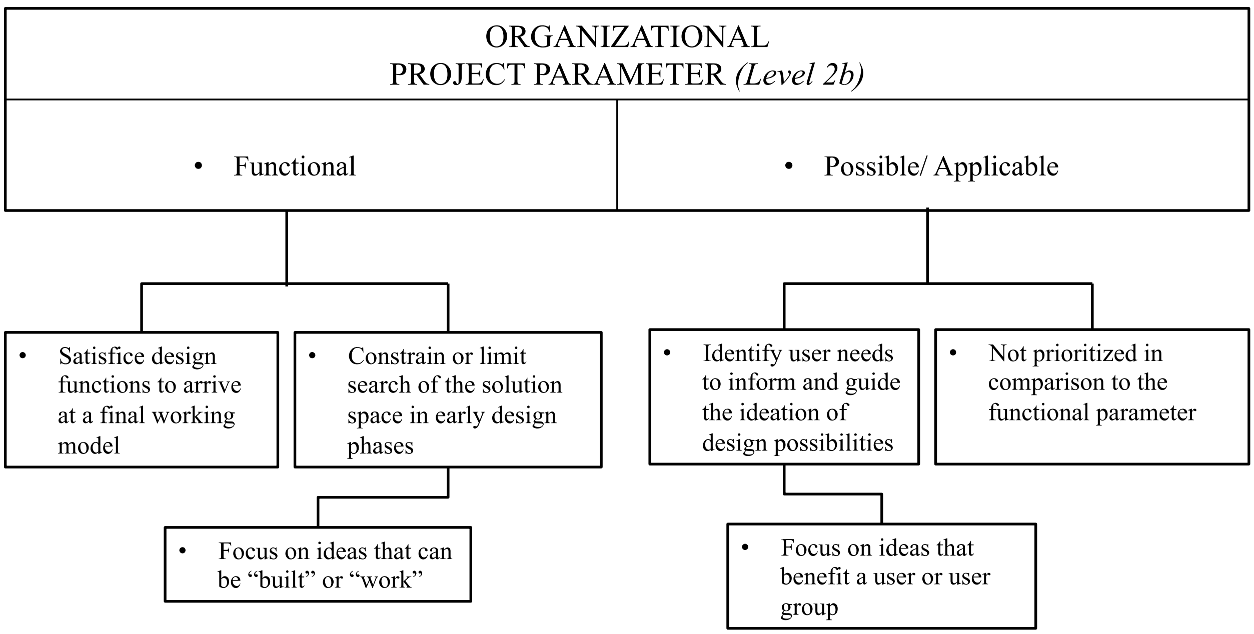

Figure 18. Overview of salient aspects and resulting practice related to the organizational: Project Parameter context

5.3 CROSS-CASE ANALYSIS SUMMARY

The analysis in this chapter provides a more comprehensive explanation of the salient aspects of the design project and their impact on student design practice. The cross-case analysis indicated that several aspects were common across teams and impacted student practice in either an enabling or constraining nature. The following paragraphs discuss how the salient aspects, i.e. aspects that came up frequently in discussion or influenced decision-making, impacted student design practice. I identify common themes based on this study's theoretical framework in order to understand the impact of the over-arching contexts, e.g. organizational, institutional, and discuss them below.

The data suggests that the common aspects related to the institutional context pertained to the 1) students' courses other than ENGR 1234 and 2) the infrastructure of the institution. Specifically, the work associated with other courses was ever-present in team discussions and influenced team's decision making. Students' concern regarding the amount of other coursework was evident from their dialogue throughout design sessions; one outcome of this finding was that while students wanted to complete work associated with the DSEP and "just get it done," this approach also enabled them to work more collaboratively. Teams wanted to complete all or the majority of the design artifact during their time together in design sessions, which promote students to assist one another with completing the artifact.

The second salient aspect across teams was related to the infrastructure of the institution, specifically the students within the institutional context and the departmentalized nature of the institution. The first characteristic of the infrastructure was related to other students within the institutional context such as roommates, hall mates, and friends from student organizations. Teams in this study interacted with these students and used information from their previous DSEP experience to guide the teams' own design practices. Information obtained from other students enabled the design teams to direct their search based on what did or did not work for these other students, yet constrained the teams' search by forcing them to rejects ideas in the early stages. The second characteristic related to the institutional infrastructure was the departmentalized nature of the courses in the engineering curriculum, i.e. separate courses into math, physics, English, or engineering. This constrained design teams from integrating or applying any of the knowledge from other courses to the design project.

Not only did courses from the engineering curriculum affect students, but specific aspects of the ENGR 1234 course influenced student design practice as well. Data from the design sessions and focus group interviews indicated that the students' perception of the course (ENGR 1234) was an influential factor in determining how students approached design. Specifically, students perceived the course as either 1) a "weed-out" course or 2) more of a typical engineering course. Teams that viewed the course as a weed-out course approached the DSEP as an assignment; their view that the course was about "learning how to pass" or that its purpose was to "weed people out" constrained the team from applying course concepts to the project. In contrast, students that viewed the course as another engineering course also approached the DSEP as a course assignment, but in this case, the students' perception of the course enabled them to apply material from the course instead of dismissing it. At the same time, thinking about the DSEP in terms of an assignment led students to use their interpretations of the workshop instructor, i.e. the individual who graded/ evaluated DSEP artifacts, to guide their approach when creating design artifacts. Similarly, the students in this study used DSEP characteristics and their interpretation of these characteristics to guide their approach to design.

The project's overall make-up or structure, e.g. aspects related to the organizational level 2a: project structure, also had an effect on student design practices. Data showed that the salient aspects related to project structure across teams were related to the 1) step-by-step nature of the project and 2) the project's objectives and requirements with respect to the DSEP artifacts. More specifically, students viewed the step-by-step nature as one aspect of the project that facilitated their time management practices and enabled them to address each phase of the design process. Prior work illustrates the importance of sequencing assignments such that they support student work in terms of helping students stay on track during the design process and using design documents to build off of one another (Paretti & Burgoyne, 2005). The deadlines associated with submitting these artifacts reinforced a linear progression through the design process and constrained design teams from revisiting phases. This also led teams to incur sunk costs in terms of time. In other words, due to the time constraints of the project, teams did not return to earlier design phases to redesign anything that was not working. If their design was not materializing as they planned, and time was a cost that teams had already incurred and could not recover, students manipulated the other constraints of the project. For example, instead of redesigning or revisiting earlier design phases when solution was not materializing as planned they often pushed forward with the design process by fabricated sections of the final design report or adjusting the bill of materials to fit within the project budget. Similarly, the second aspect related to the project's structure or the objectives and requirements of the project/ design artifacts led students to go through the motions of completing the artifacts. In one case the brainstorming inventory required each member to produce five ideas so team members would generate ideas they perceived as unfeasible in order to meet their required quota. Teams' uncertainty or *(mis)*interpretation regarding certain objectives or requirements led them to focus on explicit constraints, such as cost, and then manipulate those constraints to fit what was required by the project. At the same time, explicated objectives and requirements for DSEP artifacts enabled an understanding between design phases in some cases. Team 2A illustrated this case during their sketching session where the sketch design artifact required students to produce a sketch of the design solution and a 1-2 paragraph description of the design and how they chose the final solution. The required paragraph regarding an explanation on how they chose their design prompted Team 2A to consider their experience with the "thing", i.e. brainstorming inventory, they worked on the previous week.

Similarly, another characteristic of the project, or the DSEP's parameters, influenced student design practice. The DSEP parameters' effect on students design practice was influenced by the 1) functional and 2) possible/ applicable parameters specifically. Teams' disproportional focus on the functional, e.g. a physical implementation showing the creation of energy from a renewable source, constrained their search in early design phases and led them to focus on ideas that they perceived could be built or "work." On the other hand, by focusing on the functional parameter, teams satisficed initial design functions and arrived at a functional final model of their design. The second parameter teams focused on was the possible/applicable parameter, e.g. a possible and applicable solution that benefits the user. Teams addressed this parameter by applying personal experiences or thinking of the needs of a user in various situations. Focusing on this parameter enabled students to think about their design in terms of benefiting a user or user group. However this parameter was not prioritized in comparison to the functional parameter. Furthermore, teams focused disproportionally on the functional and possible/ applicable parameters in comparison to other the given parameters such as safety and innovativeness.

The cross-case analysis of teams 1) identified the common salient aspects across the teams in this study and 2) described and explained how those aspects impacted student design practice. Guided by the theoretical framework of this study I found that influential aspects occurred at the institutional level, and organizational levels, e.g. course, project structure, and project parameter. Figure 19 provides a comprehensive representation of the salient aspects from the cross-case analysis and their resulting impact on design practice in first-year engineering design teams.

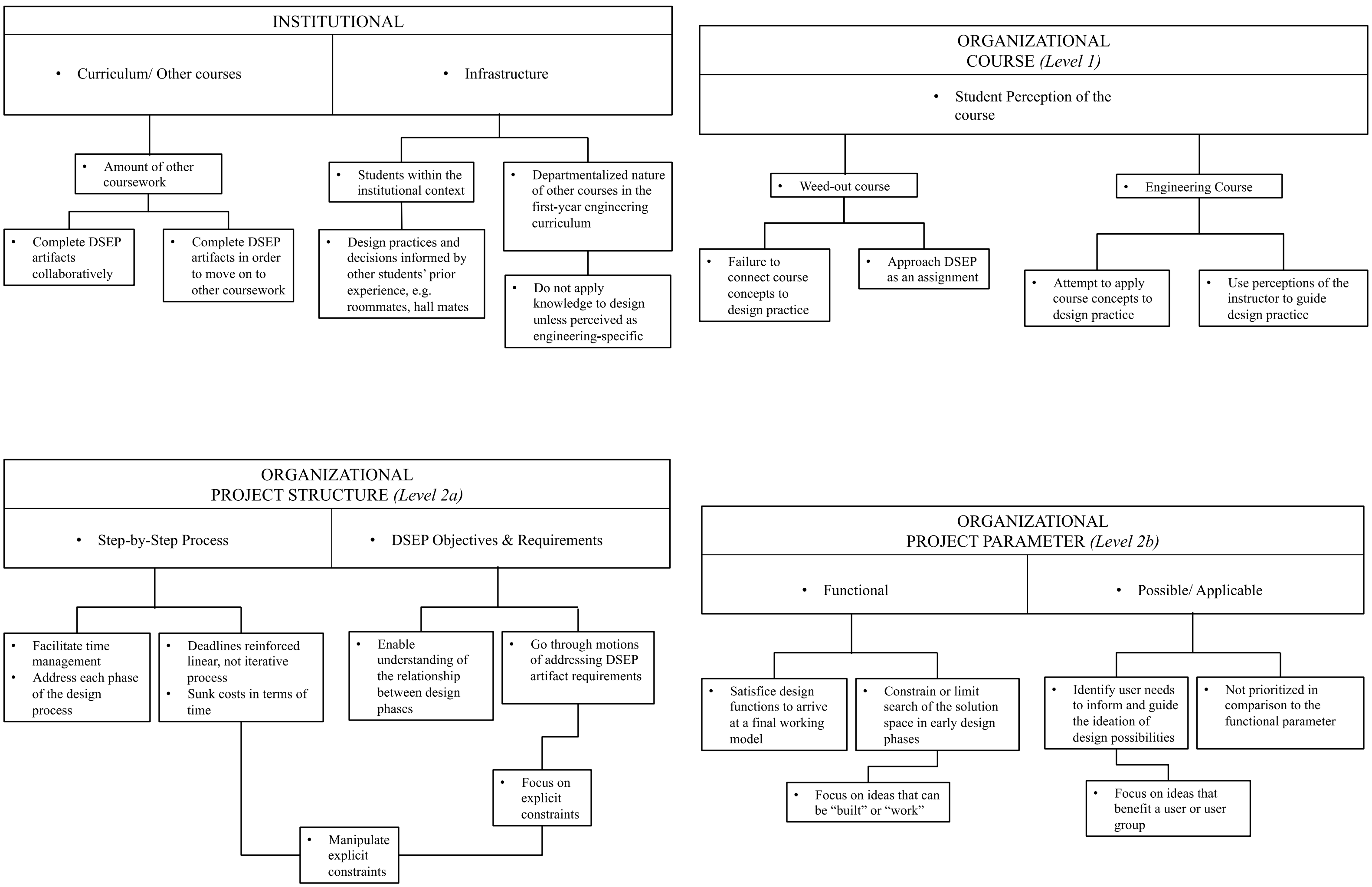

Figure 19. Overview of Cross-case Analysis Findings

CHAPTER 6: DISCUSSION

In this chapter, I discuss findings from the analyses and the overall fit of my data with the Nested Theory of Structuration. These findings will also be situated in current literature. Important findings include the impact of the institutional and organizational contexts on student design practices. In addition to describing the findings with respect to the Nested Structuration theoretical framework, I discuss the implications for design education, contributions to Nested Structuration, and conclude with implications for design educational research.

6.1 REVIEW OF THE STUDY

The study described in this dissertation was designed to understand first-year engineering student design practices and how various aspects of the design project affect those practices. Also, this study examined aspects related to the overarching contexts in which design takes place. Understanding the institutional and organizational contexts in which design takes place help researchers and practitioners understand what constrains and enables student design practices in an educational setting. This study employed qualitative case study methods to examine how students design in context in an effort to situate the findings with respect to designing in an educational setting. In doing so, this work adds to the literature regarding the importance of context in design and the nature of design problems (Gero, 1996; Jonassen, Strobel, & Lee, 2006). The findings also illustrate that there is still much to be understood in terms of how researchers study student design practice and reveals what really goes on when student teams get together to design.

6.1.2 Findings

Overall, the results provided evidence that the institutional and organizational contexts as well as various aspects of the design project affected student design practice in both constraining and enabling ways. Factors related to the institution and organization, including both the course and the project, were found to influence students' approach to design. Specifically, based on team discussions and their decision-making practices, I found that students were inextricably connected to overarching context in which they designed. In other words, the students were never fully removed from the institutional or organizational contexts and attempted to fit the design project into their other practices as students. For example, students were consistently cognizant of their responsibilities regarding other coursework and utilized practices such as time management and working collaboratively to control all of the responsibilities associated with their curriculum. I also found that within the institutional and organizational contexts, students have difficulty framing their design approach *not* from a student perspective. They usually approached the DSEP and associated design artifacts as course assignments, which typically caused students to "go through the motions" of the design process. On the other hand, the DSEP required teams to submit design artifacts such as research reports, sketches, prototypes, etc. and this feature enabled or guided students to address each phase of the design process. At times, this also facilitated an understanding of how the phases of the design process related to one another.

I used the constructs of the Nested Structuration framework to guide my analysis and further consider how design practice was shaped by the larger context. First, I found that the larger institutional and organizational contexts had a reinforcing relationship on student practice at the team ("individual") level. Second, I found that the team (individual) practices restructured the institutional level as well. The data showed, through team discussions, that students who previously took the course and participated in the design project became part of the institution that structured current ENGRE 1234 students' design practice. To support this multilevel, mutually, reinforcing relationships, data from succeeding semesters should be examined to identify any change at the organizational and institutional levels.

6.2 Implications for Nested Structuration Theory

6.2.1 Nested Structuration Theory

The initial motivation of this study was to understand how students design in the context of higher education using Nested Structuration Theory as a methodological and analytical framework. While the nested structuration framework allowed for the consideration of factors at multiple levels, i.e. the institution, the course, additional interpretations of these findings using structuration as a lens are warranted.

In accordance with the structuration theory, I first discuss how, through their own actions, students created and recreated the context in which they accomplished their work. Their enactment of practices within the context of an educational setting is fundamental to understanding students' approach to design projects. The institutional context of higher education, in this case the undergraduate engineering degree, shapes student practices and, in turn, collaborative work and knowledge sharing. Additionally, the context of the institution places constraints on students requiring specific courses, number of credit hours, all of which are directly linked to student grades and grade point average. Furthermore, an engineering student's success with respect to the undergraduate engineering degree is contingent upon grade point average, further propagating the importance on grade point average to a student. Grades weigh heavily on students, (often determining continuation in the program and sometimes scholarship, funding, financial aid, etc.) and influence and direct student practice. Students often try to optimize and even minimize efforts regarding coursework in order to meet their requirements comprehensively. Subsequently, instructors within the institutional and organizational contexts reinforce this practice by creating new mechanisms to amend this degradation of effort, i.e. create additional requirements for student work. The inclusion of additional requirements is evident in the modification of the design project document over several semesters. When the DSEP was first implemented (Spring 2007) in the ENGR 1234 course, all design artifacts were "supplemental assignments" and "NOT MANDATORY: *they are voluntary and will not affect your grade*" (Appendix E, p. 241). The design project document still detailed the design artifacts and detailed requirements, suggestions, and overall objectives and it also stated that supplemental assignments elicited instructor feedback. The complete list of design artifacts associated with the project has even changed over the lifetime of the design project as part of ENGR 1234. Specifically, when design artifacts were not mandatory, possible or supplemental artifacts included a team proposal & evaluation matrix, international perspectives (report), logbook, supplementary advertisement (video), use of recycled materials (list), and a 3D drawing of the design.

These aforementioned design artifacts were not mandatory and not suggested as part of the design project document at the time of data collection for this study (Spring 2010) and I can only speculate how students in this study would approach non-mandatory assignments as part of their design projects. All design artifacts described in the design document (for design teams in this study) were required as part of the project and graded. The types of design artifacts that were non-mandatory and not graded when the project was first introduced as part of the course were not described or suggested as artifacts to include in the design process for the Spring 2010 design teams. The second semester, Fall 2007, the course design artifacts became “project assignments” and carried a specific weight for each assignment. The required design artifacts for this semester were similar to the artifacts discussed as part of this study, i.e. request questions, brainstorming inventory, sketch, prototype, team log, team demo & presentation, and design brief. Comparing the design document from the Fall 2007 semester (Appendix E) to the Spring 2010 semester (Appendix C) reveals the modifications with respect to creation of additional requirements for each of the design artifacts. The implications for

Instructors, while making these organizational changes, are often driven by institutional and even field level concerns. At the same time the course structure and topic is also driven by ABET considerations. Subsequently, instructors are constrained by temporal and material (related to content knowledge) structures and must work within these constraints to meet requirements associated with an undergraduate engineering degree. Sustainability, for example, is a topic of interest across the world and particularly in academia given topics such as climate change. In this case, the implementation of a project on sustainability was driven by larger considerations. One aspect of the project was to: “develop a Promotional Innovation that publicizes awareness of a renewable energy source” and aspect was not directly tied to an evaluation metric. However, students often overlooked this aspect of the design project and focused more on the constraints explicated in the design document, which were tied to graded evaluations. This decision was typically explained by students wanting to “get back to” studying for other courses or assignments and focusing on what was required in order to attain a good grade in the course. We saw that the design project was embedded within the course, which was embedded within the organization, and the organization and institution within larger systems, – following the framework of nested structuration and illustrating the reinforcing relationship that these contexts have with one another.

At the same time, a short 8-week design project embedded within a required freshmen-engineering course had significant influence within the larger educational ecosystem. This was evident how students' perceptions of the course and design project as well as their time and effort afforded to the course and project impacted their interactions within the larger institutional context. For example students expressed that they were spending all of their time and effort on what they perceived as a two credit "weed-out" course, which impacted how they approached other courses in the larger educational ecosystem. Since the course was required as part of the engineering curriculum students felt they needed to prove that they were "willing to do tons of work" and ultimately be part of the engineering program. This project is a small part (10%) of the overall grade for the course. In actuality, its influence is limited, yet students place significant importance on the project in terms of how it will be evaluated and how they perceive it will affect their overall performance in the course. At the same time when students place the ENGR 1234 course in the context of the institution, they view the course as a two credit weed-out course and often question the motivation for the amount and type of work required. Yet, since it is the only engineering course, or course offered within the college of engineering, freshmen students typically undertake in their first semester, it can shape their attitude towards engineering disproportionately in comparison to other subjects. For example, the format in which the institution structures these courses places a type of value on each course through the practice of weighting courses by credit. This practice of the institution influences how students perceive a course, and subsequently, student practices related to that course. So the institution structured ENGR 1234 as a two-credit course and the organization structured the design project as 10% of the course, both of which impacted how students approached the design project, often treating it as another assignment as part of the larger educational ecosystem. Similarly, the organization of the course and the assignments reverberates across the institution through its influence on students' participation in other courses and activities. By playing a role in determining the

GPA of students, the course – and the design project – also plays a part in the majors selected by students and their motivation for pursuing that major. Given the embeddedness of the course and the instructors within the academic institution structure, particularly within a college of engineering, funding from external sources also shapes course organization, and, in turn, the course shapes the ability to attract funding.

We also saw in the data that the context in which students learn enabled and constrained their practices, which was similar to the way the specific $20 project limit both constrained and enabled design teams' approaches. The structure of the project necessitated students to work in teams for the DSEP, and subsequently structured the ways in which teams worked collaboratively to complete the design project. Additionally, the structure of the deadlines also necessitated students to complete the design project in a specific format. As the students discussed, the weekly submission deadlines forced them to submit their work, but at the same time allowed them to focus on what was due and to get it accomplished. However, within this structure, students had agency and different teams reacted differently. For example, some teams came to the collaborative design sessions, looked at what was due, assessed the requirements explicated in the design document, and started work on the design artifact. Other teams prepared in advance and then compiled a comprehensive artifact. In some cases, teams initially used a divide and conquer approach, but the time together in a mutual space led to a more collaborative approach where team members helped one another on their "assigned" sections. This observation supports the benefits of having detailed projects guidelines for students. Paretti (2008) highlights the affordances of design courses for developing design skills, e.g. communication, wherein instructors' explicit communication of assignment requirements helps students to understand they "why" (p. 500) of communicative practices. It also alerts us to the reality that different groups based on their collaborative pattern will leverage the guidelines different. For example, the design document provided an explicit constraint for the project budget and teams leveraged that differently, i.e. manipulated actual costs to fit within the budget or looked for alternative solutions that fit within the budget. Furthermore, the students were very self-aware of the context in which they designed and continually questioned the constraints associated with the context. On some occasions they felt that the constraints were artificial (one of the teams commented that the project could have been better over a weekend), or enforced to induce more tedious work. In these instances we see that structures and norms are interpreted continuously through interactions with multiple contexts.

A reflexive view on this research shows how the teams' collaborative work can be interpreted as being shaped by the context of the research project. As part of the data collection process, the research team assured student design teams who volunteered to participate that they would be provided with a space to meet and work. This characteristic of the study structured their activity wherein they met at specific days and times to work on their projects. Other groups in the course, but not part of the study, most likely followed a similar pattern. However, teams that participated in the study met consistently based on scheduled weekly time for their design sessions and the research project data collection.

While one limitation of the study is that it did not capture possible variances in design practice characteristics of student teams that selected not to participate and meet in a designated space on a weekly basis, other studies have looked at the effect of space and time on work practices. Paretti, Ritcher, and McNair's (2010) study of design teams notes how institutional factors shaped teamwork. Specifically, issues of scheduling time and space to meet impacted teamwork. Providing opportunities for teams to engage in both physical and virtual interactions they suggest is a critical component of the design course.

Even within the teams we see variation once again indicating that structures shape interaction to a large extent, but do not determine them. Similarly, in Goncher, Johri, and Sharma's (2010) study on Industrial Design (ID) students, they found that the context and space in which ID students design differed from the context of first-year engineering students, but still had an effect on student design practices. The ID students' context for design was structured so that students spent 3-4 hours weekly or biweekly in a collaborative workspace; this collaborative time together was required as part of their curriculum and teams worked together on their design project during "studio time." The mutual required studio time for ID students is the norm in this community and it facilitated them to share design ideas. Specifically, they discussed their role as a design and user with one another and structure of the required studio time allowed for more frequent and iterative feedback between team members. This suggests that external constraints, such as requiring teams to design in a mutual space for a given amount of time, influences the students' overall approach to designing. In engineering capstone design practices Pembridge and Paretti (2010) while faculty members and student design teams interacted outside of class, including meeting in the lab or workspace, the studio model was rarely used in capstone courses.

Following Nested Structuration Theory, it is interesting to observe that there are immense similarities in the patterns of interactions of student teams. The structures and the norms of being a student are shared informally between students within the context of the course and institution. The analysis of student conversations showed that roommates and hall mates played a significant role in shaping students' educational experiences. Prior knowledge transmitted within their community of practice guided their participation in the larger educational community, which also accounted for the organizational knowledge that certain courses are designed to "weed out" students by "making them ridiculously hard". At the same time, students participate in multiple communities, e.g. dormitories, fraternities, etc., and share different information, which can account for the variability of information shared. The shared rules and resources that students get from their community of practice often overtake the rules they are provided as part of their course assignments and the informal overtakes the formal. This is a critical and important observation as it alerts us to what is salient for students in terms of ideas as well as individuals not directly involved in an educational context. As students go about "doing school" (Pope, 2001), their peers, who often went through the same educational experiences, are more important in their decision-making as compared to formal advice they receive from instructors or TAs. To a large extent, informal norms, networks, and peers' advice shape the students' educational experience. It is also evident from the data that not only do the informal networks of the institution shape the individual student's educational experience, these students in turn shape the institutional context. Students who previously took the ENGR 1234 course were shaped by the institutional and organizational contexts during their experiences, and at the completion of the project became part of the context that shaped student experiences in subsequent semesters— further reinforcing the operationalization of Nested Structuration.

6.2.2 Contributions to Nested Structuration Theory

This work exemplifies Nested Structuration Theory and structuration theory through its findings on how interactions exist at multiple levels, which ultimately structure and restructure one another. Notably, however, it also extends Nested Structuration Theory by showing that, when appropriated in an educational context, we see that there are sublevels at the organizational level emerge. Additional sublevels showed mutually reinforcing relationships between the course and project levels, both encompassed by the organizational context. At the same time these sublevel both had reinforcing relationship on individual or student practice. In comparison to Perlow et al.'s (2004) work, which studied the interactions within a workplace, this work illuminates the existence of sub-organizations that operate semi-independently, but are influential on one another. In contrast to Perlow et al.'s work, studying higher educational contexts using nested structuration theory elucidated the view of the institution as more of a loosely coupled system where students take different courses related to the engineering curriculum, but little interaction exists between courses within this type of system. This highlights a different perspective of the institution as it relates to higher education from an institution as it relates to the workplace, which is typically more cohesive. By using this framework as a lens to identify how contexts encompassed by an education system affects practice at the student design team level I nuanced Nested Structuration Theory for different setting. Prior studies using Nested Structuration Theory mainly address contexts related to business/industry and organizational sciences, however the findings from this study show that a modified model of Nested Structuration Theory should be considered when appropriated in contexts of a different nature.

6.3 Implications for Design Education Practice

While students and design educators have less control over the larger contexts, this study suggests that design educators can use characteristics of these contexts and findings from this study, i.e. how they affect practice, to more effectively enable students and facilitate the progression through the design process.

Table 10 below identifies the specific breakdowns in the design process encountered by first-year student design teams as they interacted within the context of the project, course, and institution, and proposed solution to enable design practice. This section discusses implications based on the proposed solutions that leverage the constraints of the context in which students design.

Table 10. Breakdowns in the design process and proposed solutions

Breakdowns	Proposed Solutions
1. Students have a context for the institution but not for design	1. Apply the STEM Integration (iSTEM) approach.
2. Linear approach to design	2. Promote iteration of design steps through coordinating project deadlines that either allow or require students to revisit design steps, e.g. prototyping/ testing.
3. Cognitive inertia and sunk costs related to time	3. Structure the design project deadlines with less rigidity related to design artifact deadlines in order to promote easier transitioning between design phases (but in conjunction with proposed solution 2).
4. Focus on explicit constraints	4. Define design artifact requirements more explicitly in order to facilitate conceptual understanding regarding the purpose of design artifacts and provide context for how each artifact or phase contributes to the design process as a whole.

First, students are bound to their other required courses and must take engineering-related courses as part of the engineering curriculum. In order to be part of the engineering program students must take specified classes that are all weighted by credit and all carry a certain workload. Their previous educational experience arguably followed a similar model where students participated in various courses with respective amount of work. Their practices, derived from years of experience within an educational setting, allowed students to allocate their time and attention among the responsibilities associated with an educational setting. In this study, we saw that first-year students had a context for the institution, i.e. students were familiar with the practices relating to taking courses, managing time and coursework, but they did not have a context for design. First-year students perceived the process of design as another assignment that often took time away from their other responsibilities related to the institutional context.

Based on the tacit views of the institutional context and how courses within an educational system are structured students did not indicate they viewed any explicit relationships between their design project and the other courses they were taking. Most students viewed the primary content knowledge associated with the design project as learning or problem solve.

The data in this study illustrated that aspects of the institutional context, e.g. the departmentalized nature of subject areas, constrained students from integrating knowledge from their engineering-related courses into their design practices. While design educators have arguably less control over the structure of the larger engineering curriculum, they can use this aspect to enable students by helping to reinforce material from these other courses into design projects rather than treating the design project as a separate entity or opportunity to meet the inclusion criteria of certain engineering material that may not otherwise be addressed in the curriculum. One application of this idea related to utilizing the material and knowledge from other courses in a first-year engineering student's curriculum is the iSTEM or STEM integration approach. This idea is based on producing and maintaining the central STEM (Science, Technology, Engineering, and Math) concepts through representations, objects, activities, and social structures (Nathan, Srisurichan, Walkington, Wolfgram, Williams, & Alibali, in press) and aligns with tenets of engineering design and claims to promote student understanding of STEM concepts by incorporating activities that promote the "cohesion" of central concepts in the engineering classroom. This approach is applicable in relation to the institutional context where first-year engineering students take science, technology, and mathematics-related courses at the same time as they learn design. Schunn (2009a), however, posits that a large structural shift would be required to integrate all four (at least at the K-12 level) and advocates for the integration of math into the science, technology and engineering instruction. The first-year students in this study identified possible instances to integrate mathematical concepts in building or testing their design but often overlooked these ideas because of the amount of perceived effort, which was not explicitly required by the design process or design project documents.

Applying an approach that integrates concepts from STEM areas by “threading” (Nathan et al., 2013, p.2) conceptual relationships through mathematical representations, scientific laws, social structures, etc. to the design project– explicitly in the design project documents— will promote students to utilize that knowledge rather than to compartmentalize it.

Second, I found design teams liked the step-by-step nature of the design project due to its facilitation of time management within the context of their other work. This also prompted students to address each phase of the design process by creating artifacts associated with each phase, e.g. researching, brainstorming, and prototyping. At the same time, students approached the creation of design artifacts as assignments that were part of the course and went through the motions in order to complete or meet the given objectives and requirements. Furthermore, the deadlines related to the step-by-step nature of the DSEP promoted a linear approach through the design process. Specifically, the linear deadlines of the design project artifacts did not stimulate students to revisit or easily make transitions between design steps. The benefits of easily transitioning between design steps and being able to spend an adequate amount of time on the product realization and final stages of design are apparent in Atman et al.’s (1999) comparative study of freshmen and senior designers. Atman et al. found that *how* students spent their time, i.e. transitioning between design steps throughout the process, resulted in higher quality designs.

With respect to the third identified breakdown, the first-year students in this study did not have ample opportunity to easily transition between steps based on the rigid project deadlines for each design artifact and often encountered cognitive inertia, i.e. reluctance to revise their assumptions, and sunk costs in terms of time, i.e. unrecoverable costs. In other words, once students made design decisions and submitted their artifacts, the time did not exist to reverse or redesign their ideas because materials associated with the next phase of the design process were typically due the following week. Students had little control over the project deadlines leading them to work strictly under the time constraints. Furthermore, since many decisions could not be reversed due to time constraints, students often manipulated the given constraints, such as cost, and fabricated or improvised various sections of the final design report. To differentiate breakdown two from three, I argue that amending the linear approach to design through the restructuring of deadlines may not always account for cognitive inertia or sunk costs. For example, students who commit to design ideas or approaches early in the design phases and refuse to rethink fundamental ideas regarding their design could still go through the motions of creating or revising design artifacts in order to meet the requirements of the project.

While design educators have less control over the time constraints of a course (given that a course must be completed within a semester, or two in some cases), design educators can change the structure of the design project deadlines in order to promote a more iterative approach to design. Schunn (2009b) found that when learning engineering, iterative cycles were better than single design cycles. Revisiting design phases should not only help students have the ability to redesign and make changes, but also provide opportunities for learning engineering. Furthermore, revisiting design phases and design artifact facilitates a better understanding of the purpose of each design phase. This implication of revisiting design phases or allowing for more repetition of design activities is supported by Newstetter's (1998) study on student design teams' discrepancies between the "learning view" of the instructor and students' "institutional view." Students' conceptual understanding in design was based on an institutional view that framed design activities as another set of methods or procedures or "procedures to be mastered or faked" (p. 122), so in order to give meaning to design activities she recommends the repeating activities and placing them in context outside of the classroom and institutional view.

Fourth, the data showed that students often focused on explicit constraints given in the DSEP document when they did not understand the design artifact requirements. For example, design teams often had trouble interpreting or defining the design problem so they leaned toward the explicit constraints, such as the cost, and utilizing a renewable energy source; one team even reflected that they did not define a problem. Similar findings from Newstetter's (1998) study implicated failed affordances based on students' approach to design. In other words, students viewed design activities as tasks to be completed rather than opportunities for learning about design. However, we see in this study that students met or attempted to meet the given requirements of the design project and fit the given constraints. The findings from this study suggest that first-year students will work within the explicit statements or requirements of the design document, i.e. do or attempt to do what they are instructed to do with respect to the requirements of the design project. Design educators can capitalize on this finding by designing requirements that better fit the intentions or objectives related to the design artifacts and the design process. For example, participants were unclear about the requirements and purpose of the prototype and often based their practices related to constructing the prototype on previous students' experiences. Design educators should be more explicit when communicating the objectives of prototype as part of the design process. More specifically, the design document states the objective of the prototype is to: "To construct the initial design solution; to receive feedback from peers that will inform improvements to the final design; to provide meaningful feedback on other design team's prototypes." (APPENDIX D) However, the instructor should be more explicit by adding "While your design may not be fully functional at this point, the purpose of the prototype is to construct a model you will be able to test. Testing your design at this stage is important so you can identify any issues you need to address before the final report and demonstration is due in class." Being explicit about the objectives and requirements associated with design artifacts may prevent students from feeling compelled to "improvise" or "make something up" in subsequent phases of the design process.

6.4 Implications for Design Education Research

In addition to illuminating an additional perspective of Nested Structuration Theory or a modified NST model when appropriated in a higher educational setting, this work also demonstrates the limits of experimental design studies. Specifically, studying design under experimental conditions does not account for the contextual factors that affect design, which were found in this study. For example, design educators may develop a course design project taking into account findings from research on ideation and design fixation or prototyping and the use of representations but these approaches may be limited to the classroom or limited to the time and attention student design teams have to allocated to the design project. This study illuminated the factors external to the design process and their impact on actual student practice. In other words, if students do not feel have the time (usually because they need to attend to other coursework) to develop a brainstorming inventory they are not going to use the idea triggering method but instead make up unfeasible ideas or gather information/ ideas from roommates and other students. When students are working on the design project outside of the classroom or workshop (much less working on design outside of experimental conditions), the factors associated with the institutional and organizational context are vary salient as to how they approached design. The idea of "making something up" was rarely questioned or challenged within teams and student design practices were typically shaped by how much time and effort they had available to spend on designing.

While it is important to understand the effects of specific variables and isolating those variables in experimental conditions, the result of this study show students can behave very differently with respect to design practice when working in different contexts. My findings illustrate that experimental studies or research done in controlled design settings is limited if applied to more naturalistic settings. I argue that this work does not directly invalidate experimental studies—instances of students implementing or attempting to implement best design practices did exist—but when placed in a setting outside of the lab or classroom the findings show that informal practices often overtook formal practices.

This study and the findings from this study illustrate the importance of types of engineering education research that takes into account the educational setting when studying engineering design and how students undertake design. Furthermore, this work contributes to the engineering education community by exemplifying a thread of research that can show the application and impact of research regarding engineering students. Experimental studies on design education are bound by context in which they take place; a context that often does not account for factors external to the design process. If the engineering education community intends to translate research into practice, researchers and practitioners must consider the impact of aspects related to the larger, overarching contexts. Not only does this have ability to more effectively translate research into practice, I argue that this line of research is needed in order to secure sustainable funding and promote the importance and relevance of engineering education research to individuals and organizations outside of the field.

Newstetter's (2008) study showed similar effects of the institutional context on engineering design practice and pushed for similar recommendations regarding design education. However her work does not take into account the role of agency of the students. Regardless of the restricting of the institutional contexts, students will exert some form of control over the situation and try to optimize their situation. The aggregate of Newstetter's work and this study highlight the role of context and the individual and how they reinforce one another.

6.5 Future Research

This type of study, which examined the importance of the context in which students design and was guided by the Nested Theory of Structuration, would benefit from additional longitudinal data to help explain or elucidate the mutually reinforcing relationships at the organizational and institutional levels as suggested by the Nested Theory of Structuration. One line of research would be to examine the organizational and institutional contexts in subsequent semesters to identify any change and if so, how that reinforced design team practices at the individual levels.

Similarly, longitudinal studies in terms of student design teams at varying levels of academic standing, e.g. first-year, senior/ capstone, would further an understanding of how the organizational and institutional contexts affect student practice as they design within these contexts over the course of an undergraduate experience. For example, how do senior or capstone design teams approach design based on the impact of these larger contexts? Dannels (2000) and Paretti (2008) studied the communicative practices of capstone design teams but have not looked at capstone design practice in general. Findings from both types of future longitudinal studies would also strengthen research practice by revealing the impact of context on research design. In other words, can we study first-year students in the same context as capstone design students? How do their practices differ based on senior/ capstone student institutional views? The idea of research within context can also be extended to institutions and organizational contexts of varying infrastructure. For example, large first-year programs and course design projects vs.

smaller studio-based design projects. Contextual factors such as resource commitment and the physical space where students practice design can vary widely depending on aspects of the environment, .e.g. course enrollment, institutional infrastructure. While this study exemplifies the impact of context on student design practice, additional work highlighting variations in context would augment how we understand the role of contextual factors associated with an educational setting.

6.6 SUMMARY

The findings from this work should not be seen as overly critical on how students approach design or how the contexts within higher education are structured, but as a realistic view of student engineering design that can be used to enhance both teaching and research. Although teams' final designs did not represent significant ingenuity or creativity, their discourse showed significant creativity in how they accomplished the body of coursework required of a first-year engineering student. This is promising in terms of preparation for future careers and even their remaining educational career. It also aligns with Dannels (2000) and Paretti's (2008) findings on student practice and transfer of adaptability to the professional context. Students/ designers/ engineers will always be working within the contexts of an institution and an organization and the completion of many tasks or projects will be required of them. While students may not take the "instructor view" on valuing design practices as they relate to good design or best practices, they are a) able to evaluate their time available, b) identify what is required or expected of them, and c) determine how to optimize the available resources. Additionally, by working under a set of given constraints they accomplish these tasks collaboratively as a design team.

The findings also show how, in spite of neat compartmentalization of courses and projects, students are not cognitively disconnected from their other experiences and other students' experiences. For students in a higher educational setting, it is a seamless environment in which they have to undertake multiple activities. This characteristic is representative of the environments students will face once they complete their education. At the same time, the concern raised by this observation is the inability of students to integrate their multiple educational activities and experiences. For example, students learn technical concepts in other courses, but never apply them to their designs, and typically fail to do so because it is not required by the project or structured that way. The structures that students work within allow for multiple activities to take place but do not force them to integrate those activities. I recommend that design educators and workplace or design firm managers use information about the context in which students or engineers design to manage and leverage these structures and the mutually reinforcing interaction between them.

Overall, this work contributed to the field of Engineering Education by highlighting factors of the design project and overarching contexts associated with an educational setting that were salient to students. Identifying and understanding how these factors affect student design practice contributes to a) how design educators structure course design projects, b) how design education researchers design their studies and contextualize findings, and c) an advance to the theoretical framework of Nested Structuration by illuminating the additional sublevels that exist when appropriated within the setting of higher education.

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APPENDIX A: OBSERVATION PROTOCOL

DESIGN MEETING FOCUS:

Date:
Time:
Observer:
Team:

Protocol

Individual Team Meeting OBSERVATION NOTES

Number of team members present:	
Technologies Present:	
Technologies used/ Users of the technology:	
Main ideas that were brought up:	
Points of agreement during the meeting:	
Points of disagreement during the meeting:	
Key words & phrases used:	
What were the interactions between team members? One main discussion? Or side conversations? How many?	
What ideas were discussed?	
Concept Generation	
How did the team determine what ideas to discuss and what ideas to dismiss?	

What was the variability in the ideas discussed during the brainstorming session? Were the ideas very different from each other or were the ideas variations of each other?	
Did the team discuss/ mention which ideas are more creative than others?	
Did any technologies play a role in the ideas that were discussed or used in the brainstorming session?	
Did the team decide on a final idea? How did they come to a conclusion or pick an idea to use?	
Other observations:	

APPENDIX B: DSEP FOCUS GROUP INTERVIEW PROTOCOL

Form:

Semi-Structured; Posing Questions and Appropriate follow up questions

Begin:

Have students begin by writing down their thoughts and experiences with both the DSEP and the ENGR 1234 course.

Interviewer: What are some of the things that come to mind? What stands out about the project?

[Provide time for students to write topics down on paper individually]

1. Sustainable Energy Design Project (DSEP)
    - a. What role did each of you play?
    - d. What did you think about your final project?
    - e. How did you decide on your final solution?
    - f. What were your other options and how did you choose?
    - g. What did you think about the other projects in the class?
    - i. What would you change about your project? Or the structure of the project in general?

2. Technology Use
    - a. How did you work on the project?
    - b. Did you use technology?
    - c. Did you use the tablet feature of the PC?
    - d. How did you use the tablet?
    - e. How did you sketch?
    - g. What did you think of DyKnow?

3. Overall
    - a. Did you encounter any conflict during this experience? Describe the conflicts that arose.
    - b. What do you think design is?
    - c. What do you think engineering design is specifically?
    - d. What are your intended majors? Do you think that made a difference?

4. Closing
    - a. What did you learn from this experience?
    - b. Is there anything else we did not cover you wanted to discuss?

APPENDIX C: DSEP DOCUMENT

Sustainable Energy Design Project (DSEP) Information Sustainable Energy Design Project (DSEP) Information

Introduction

Today, the call for a focused effort to research and design alternative means of energy production in the United States and the rest of the world is clear. While many agree that we must diminish our dependence on fossil fuels, few agree on the exact methods for doing so. The engineering community will undoubtedly play an important role in the outcome of this global dilemma. As an engineering student attending an institution which is committed to improving sustainability, you will need to develop an awareness of current energy research efforts, both in our country and abroad, as well as the impact these innovations will have on the environment and society.

In lecture, you were given the following definition of sustainability:

“Sustainable development meets the needs of the present without compromising the ability of future generations to meet human needs and aspirations.”

-World Commission on Environment and Development (WCED) – 1987

A suitable definition for sustainable energy, then, "is energy which is replenishable within a human lifetime and which causes no long-term damages to the environment." As such, sustainable energy promotes sustainability; it represents both self-sustenance and the ability to foster sustainable development.

Assignment

You have been assigned to work as part of a team of 4-5 students on a ten weeklong design project. Successful completion of this project should demonstrate your ability to:

Apply the principals of sustainability to the design of a product, system or process.

Apply the design process to solve an engineering problem as part of team.

Effectively describe your team’s product and convey your team’s challenges, solutions and reasoning both orally and in writing.

Your assignment is to develop a “Promotional Innovation” that publicizes awareness of a renewable energy source.

Assume your audience is other freshman-engineering students, who may have varying levels of knowledge related to renewable energy sources. Please consider the following parameters for your design:

It should be functional, safe, and innovative.

Functional - It should showcase the creation of energy from a renewable source, not just as a conceptual model, but a physical implementation. Even though you may not be able to make your design full-scale, your project should adequately demonstrate the intentions of your group's design when scaled up.

Safe - Your design should not harm anyone who uses, and should have a minimal adverse affect on the environment.

Innovative - Be creative! Think outside the box on this project. Using a solar panel you get in a science project kit to power a light bulb is not very interesting. Make your design unique.

It must highlight one or more key components of a renewable energy source.

It should strive to educate and entertain as well as generate further inquiry and interest in renewable energy sources.

Design Categories

There are three broad design categories to guide your design solution and include:

I. Renewable Energy Systems.

Designs in this category include large scale renewable energy systems.

Examples from previous semesters include the wave powered lighthouse and a methane plant located in a landfill.

II. Renewable Energy Solutions for the Developing World.

Designs in this category include renewable energy solutions appropriate for communities in the developing world, which have limited access to manufactured resources.

Examples include the solar powered hearing aid and a portable light reading mat.

III. Consumer Products and Renewable Energy.

Designs in this category include a range of consumer products that utilize renewable energy sources.

Examples from previous semesters include the solar powered drink mixer, the hydropower pencil sharpener, and the solar water lantern.

Materials

The total value of all components in your final design may not exceed $20.00 per team. You must submit receipts for all materials purchased, or proof of "fair market value" for items not purchased (donated, recycled, etc.) with your final design. Fair market value of new items may be determined by locating the sale of a similar device in a retail or wholesale advertisement; for used items, you must choose a reasonable percentage of the "new item purchase price" and write a short justification for your chosen amount.

Timeline, Deliverables, and Grade Distribution

This project counts as 10% of the overall course grade. It will be carried out over ten weeks and involves a series of individual and team assignments (see Table 1 below).

Table 1. Project Assignments

Assignments	Grade	Due Date	Individual/Team
Research Report	15%	Week 7 (3/4-5)	Team
Brainstorming Inventory	10%	Week 8 (3/18-19)	Team
Team Evaluation 1	3%	Week 8 (3/18-19)	Individual
Meeting with GTA	5%	Week 9 (3/25-26)	Team
Sketch	10%	Week 10 (4/1-2)	Individual
Prototype	10%	Week 11 (4/8-9)	Team
Team Evaluation 2	3%	Week 11 (4/8-9)	Individual
Final Design Report	20%	Week 13 (4/22-23)	Team
Team Demo and Presentation	20%	Week 14 (4/29-30)	Team
Team Evaluation 3	4%	Week 14 (4/29-30)	Individual

In the table, week numbers correspond to the week numbers listed on the course syllabus, with the actual completion dates given in italics. Unless otherwise announced, all assignments are due by 11:59pm the night before your workshop during the indicated week. Assignments listed as “individual” require each team member to complete and submit their own work; grades for these assignments will be assigned to each student individually. Assignments listed as “team” will require each team to submit one copy of their collaborative work; a team grade for these assignments will be given to each member of the team. Poor ratings from fellow team members in team evaluations may constitute grounds for the lowering of an individual’s grade on a team assignment (after consultation with the GTA).

A detailed description of the requirements for each assignment is given below:

Team Log:

Though there is no separate grade for the team log, you will need to present the team log during your meeting with the GTA and should keep one as a record of your team’s activities. The team log should at the very least be a written record of all meetings and activities your team does. Things like meeting times, locations, who attended each meeting, work that was done during the meeting, and work that was to be done before the next meeting, should be recorded in the team log. This document can also serve as a collection of all the relevant points and resources you have gathered that you can always go back to for a reference if an updated form of the document is kept in a public place or an updated form of the document is e-mailed to all team members after each meeting. Your TA will ask to see the team log during the meeting with the GTA during week 9. If you do not have a team log points will be deducted. Also, if there are any problems brought up in the team evaluations your TA may ask to see your team log as another source of information.

Research Report (Due Week 7):

Objective: To give your group some background knowledge of your chosen sustainable energy source; to inform the class about your topic.

Each team will start with an energy source of interest from the list of the of sustainable energy categories (solar, wind, hydropower, biomass, or geothermal). Your group is to research the current, past and possible future applications of the renewable energy source. In the body of the report, please answer the following questions:

What historical benchmarks in technology are associated with your selected energy source?

What are some of the current technologies used to harvest your selected energy source?

How do they work?

What kind of power output do these technologies generate?

What are their advantages and disadvantages?

What are some current global usage statistics of your selected energy source? Usage statistics for the US?

Are there any global regions or countries that use this source more than others?

Are there any natural conditions that are necessary for the technologies to be effective?

Are there small scale applications (e.g. handheld type devices, off grid applications, etc.) utilizing your energy source?

What are the possibilities for future technologies?

The report should be 3-5 pages, double spaced with 1" margins, in either 12pt Times New Roman or 11pt Calibri. It should also have a bibliography (not counting toward the page limit) that uses APA or another formal format (MLA, etc.) for citing references. Even though reports are to address the questions listed above, the report should still be written as a well composed, cohesive document, not merely a sloppy conglomeration of responses to the given questions. Keep your audience in mind; common technical jargon may be used, but word or phrases limited to a specialized field should be clearly defined.

Reports are due by 11:59pm on Wednesday October 7th, and should be uploaded by this time to the appropriate assignment link on your workshop blackboard site. The research reports will be graded on content, the quality of the writing, and the quality of evidence used to back up your claims. After all groups have submitted their research reports, ungraded copies of each group's research report will be posted on blackboard for other groups to use as reference. Please make sure that each team member's name is in the header of the report, along with your team number (if assigned).

Brainstorming Inventory (Due Week 8):

"The best way to have a good idea is to have a lot of ideas." Linus Pauling

Objective: To facilitate the creative development of ideas in your team's search for solutions.

A worksheet for the brainstorming inventory is provided to you on page 10 and 11 of this document for you to fill out. Please copy the provided tables into a new Word document. You may need to make additional rows for more entries. You are not limited to the sustainable energy source you wrote about in your research report, and you may use the research reports of other groups as references. This will be an opportunity for your team to generate as many ideas for the project as you can. At this stage, there is no "right" or "wrong" answer, although potential solutions should be supported by some level of reason. On the form, you should provide a listing of each potential solution, a short description (2-3 sentences) of what is involved in each solution, and the last name of the team member(s) who came up with the idea. There is no maximum number of ideas, but it is expected that at a minimum each team member will contribute 5 ideas. Despite this requirement, brainstorming should be done as a group, with people exchanging and building off of each other's ideas. Though the document will ideally be graded such that all team members receive the same grade, if any team member does not have initials next to at least five ideas, then points will be deducted from his or her individual grade on the assignment. For this reason each team member should ensure that they have their initials next to at least five ideas before the assignment is submitted.

Brainstorming inventories are due by 11:59pm on the night before your workshop during Week 8, and should be uploaded by this time to the appropriate assignment link on the workshop blackboard site. Be sure the names of all of your team members and your group number (if applicable) are in the name of the file and at the top of each page of the inventory.

Team Member Evaluations (Due Weeks 8, 11, and 14):

Objective: To provide anonymous feedback on your team's performance and to allow the GTA to intervene as needed in the case of any major problems.

There are three separate team member evaluations assigned during key stages of the design project. These forms have been developed to provide feedback to your GTA about how the group is doing and to provide guidance and reflection as you move through the team experience. All forms (Team Member Evaluation I (pp. 12-13), Team Member Evaluation II (pp. 14-15), and Team Member Evaluation III (pp. 16-17)) are included at the end of this document. Please note that each form has two pages. Create a new Word document and copy the contents of the appropriate form into that document.

As a team member it is expected that you will:

1) attend all meetings unless other arrangements have been made and acknowledged by the team.

2) behave professionally and to treat your team members with respect.

3) value the thoughts and ideas of each member of your team.

4) contribute and complete the team assignments in a timely manner.

During the semester, many teams will experience challenges which can be a valuable aspect of the learning process. As an effective team member, preventing and resolving these issues in a respectful manner is essential and can usually be done just by maintaining open communication and planning ahead.

NOTE: In extenuating circumstances, when failure to meet the above criteria is evident, a team member may receive lower grades on any one or all of the team assignments. In such cases, the member will be notified by the GTA and provided the opportunity to discuss the situation before alterations are made. The team evaluations are kept private and only viewable to the GTA and course instructor. Even in the case of grade alterations, your name will never be connected with your comments.

Team evaluations are due by 11:59pm on the night before your workshop during Weeks 8, 11, and 14, and should be uploaded by this time to an assignment link on your workshop website. Please be sure to fill out the correct form in its entirety.

Meetings with GTA (To be held sometime during Week 9)

Objectives: To provide timely formative assessment of the team's progress toward completing the project goals; to allow each team the opportunity to engage in a dialogue with the GTA about their chosen project at a critical stage of development.

Once during the project, you will be required to set up a team meeting time with your GTA to discuss your team's progress. These informal meetings will serve as a way for your GTA to stay informed about your team's project; more importantly, these meetings will be a time where you can ask questions, discuss problems, and justify decisions regarding your team and/or your project. During these meetings, your GTA will review your team log, field your questions, and provide constructive feedback to guide your team and the development of your project.

The meetings will last approximately 10-15 minutes and should be conducted either in workshop (time permitting) or during the GTA's office hours. For teams to get credit for the meeting, at least two members out of a four person team or three members out of a five person team must attend. Meeting times will be discussed and set up in workshop during week 8.

Sketch (Due Week 10):

Objectives: To communicate a detailed design solution that emerged from the preliminary design phase; to improve hand-sketching skills.

Submit a hand sketch communicating your team's design solution. The sketch should be done in a OneNote file on the graph paper template. By this point, your team should have decided on which design they would like to implement. Each group member will submit a separate orthographic sketch. It must be properly formatted (align all 3 views in the correct orientation). Each part in the design must be clearly labeled. Below your sketch, include a 1 to 2 paragraph description of how your team narrowed down the ideas from the brainstorming session to select this design; pay special attention to the role that your research played and why you ended up with your selected design. Also, include a description of the function of your team's design. This sketch and accompanying descriptions should strive to effectively communicate your teams design solution to someone unfamiliar with the project.

Sketches are due by 11:59pm on the night before your workshop during Week 10, and should be uploaded by this time to an assignment link on your workshop website.

Prototype (Due Week 11):

Objectives: To construct the initial design solution; to receive feedback from peers that will inform improvements to the final design; to provide meaningful feedback on other design team's prototypes.

Your group will construct a prototype of your design and bring it to workshop. During this workshop, you will receive feedback on your prototype from both your peers and your GTA. The feedback received by your team may be used to improve your design before the final design is due in Week 13. Your design may not be fully functional at this point, but you should have at least some model to show the progress your group has made toward developing the final design, and you should be able to clearly explain what your group intends to implement in the final design. When determining the overall cost of your design project, any portions of your prototype not included in the final design may be exempted.

Prototypes are due at the beginning of your workshop during Week 11, and should be brought to workshop with you.

Final Design Report (Due Week 13):

The final report should be no more than 10 pages, single spaced with 1" margins, in either 12pt Times New Roman or 11pt Calibri. Good reports are generally four or more pages without appendices but the reports will be graded on content rather than length. The report should include the following sections in the order listed below:

Define The Problem

In this section you should introduce the design project assignment and briefly discuss the project requirements. Discuss the importance of sustainability and the use of renewable energy sources.

Gather Information

In this section you should discuss the research your group conducted (either in your research report, other groups' reports, or additional resources that you used) on renewable energy, summarizing the main conclusions that were important to the ideation and development of your design.

Generate Multiple Solutions

Discuss the thought process and progression that your team went through during the brainstorming portion of the project. Briefly discuss some of your “top ideas”. If any of your ideas were a synthesis of other ideas, discuss how your group combined different ideas into other solutions.

Analyze and Select a Solution

Explain how your group decided on the final solution that you implemented. Describe the constraints and criteria both for the project itself and for the implementation of your fully developed product into the real world, and how these affected your decision to not choose your other “top ideas” in favor of the selection that you ended up making. What seemed to be the most important factors influencing this decision?

During weeks seven and nine we also discussed engineering ethics. Please discuss the ethical implications of the design you chose.

What problems might your design cause and what problems might your design prevent.

Could the user or another person be injured by your design? If so, what measures have you taken to prevent such injury?

If your design were implemented on a larger scale, what negative impact, if any, might it have on the environment or surrounding area?

Test and Implement a Solution

Describe in detail the final design your team built:

What is its function?

How does it accomplish this task?

Include at least one digital photo of your design to show what your project looks like, and refer to it as necessary.

Include a full bill of materials in a table listing everything that was used to construct your team’s final design and the cost or fair market value of each item used. Show the final cost of the whole project (should not exceed $20). Make a reference to the receipts included in Appendix A.

Describe how you tested your design

How did you test your design as you made it to be sure that it worked?

Did it work as expected right away? If not, how did you identify the problem(s) and what did you do to fix it (or them)?

Summary

What do you feel was the most important thing(s) that you learned from this design project?

What was the general role of each team member? Was one person in charge of different aspects of the project or did each person do the same thing?

Did you enjoy working on a team? What lessons did you learn about teamwork from this project?

If you had to do this project all over again, what would you or your team do differently? Why?

Overall, do you feel that you accomplished what your group set out to do? Why or why not?

Appendix A: Receipts/ Fair Market Value

In this section you should include a copy of all the receipts for any items your group purchased as part of this project (new or used). Brand new items that were donated must be priced according to current market value from a retail or wholesale supplier. If you had used items donated or made use of used items, show the fair market value of such items by providing some sort of documentation (advertisement, store listing, etc); price adjustments from the current "new item price" should be accompanied by written justification describing why your team thinks the adjusted price is fair. You can assume that you would buy in bulk for fair market values and can ignore shipping costs associated with online purchase. Also note that E-bay and other online auctions usually start far below fair market value and are therefore not good sources for fair market value. Suppliers such as McMaster and MSC are much more reliable sources.

The final report is due by 11:59pm on the night before your workshop during Week 13, and should be uploaded by this time to the appropriate assignment link on your workshop blackboard site. Be sure the names of all of your group members are in the name of the file and in the header of the report.

Team Demo and Presentation (Due Week 14):

During Week 14, your team will give a brief presentation and demonstration of your final design in workshop. This is a team assignment worth 20% of your final project grade. Your presentation and demonstration should be no longer than 5-6 minutes with an additional 1-2 minutes for a very brief question and answer session. Your presentation should consist of 4-6 slides, in addition to the title and reference slides, and should briefly cover the following content:

- Brief background on your team's renewable energy source

- Overview of your team's design

- Key concepts and unique features incorporated into your team's design

- Ethical implications of your design and measures you have taken to minimize these.

- Any problems your team encountered and how your team overcame these issues.

- Bill of Materials (list of all construction materials and associated prices/fair market values as described in the requirements for Appendix A of the Final Design Report)

During the presentation, your team will also have an opportunity to show/demo your final design product. Due to time constraints, it is necessary that your team stay within the specified limits, so please plan accordingly.

Presentation files are due by 11:59pm on the night before your workshop during Week 14, and should be uploaded by this time to the appropriate assignment link on your workshop site. Be sure the names of all of your group members are in the name of the file and on the title slide of the presentation.

"Sustainable Energy Design Project: Brainstorming Inventory"

Instructions: This form has been provided to record the results of your team's idea generation process for the sustainable energy design project. The objective of this assignment is to increase the quantity of your team's potential design solutions. Focus on generating as many ideas as possible from which your team may select, elaborate, or combine on one or more of these. Your team should provide at least 20 potential solutions (minimum of 5 ideas per group member) and a brief (2-3 sentence) description. Solution ideas that do not have complete descriptions will not be graded and will not count toward your team's total number of solutions.

"The best way to have a good idea is to have a lot of ideas." Linus Pauling

Potential Solution	Description (brief overview and how it would work when implemented by the end user)	Team Member
Example: a wind powered elevator	An elevator powered by a wind turbine, will construct a model apartment complex with a wind powered generator that lifts the elevator from the bottom to the top floors	JSM

Section: ________ Team No.: ______

Student's Name:________________________ Date: ___________

ENGR 1234 Sustainable Energy Design Project Spring 2008

Team Member Evaluation I

Instructions: Your team evaluation final grade is based on the completion of three evaluation forms (Team Member Evaluation I, II & III) assigned throughout the design project. These forms have been developed to (1) provide feedback to your workshop GTA and (2) to provide some guidance for your team. There are two sections that you are required to complete. Section 1 includes questions which you need to provide a meaningful response (i.e. a paragraph where appropriate). Section 2 includes an assessment of yourself and your team members. NOTE: There is no "right" or "wrong" answer, your team evaluation grade will be based on completion of the form(s).

Section 1

1) Were all team members able to attend the team meeting(s) up until this week? If not, what were the reasons and how did your team handle this issue?

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☐ yes, everyone attended ☐ no, some team members were absent

2) Did your team have clearly defined objectives for your meeting(s) including a start and end time which were made clear to all team members? Describe your team's method of establishing and communicating these objectives.

Section 2

Evaluate each member of your design team including yourself using ONLY the numbers 5, 4, 3, 2, 1 or 0. Base the score on the level of effort and contribution of that individual to the team design project. Team members may receive the same score. Your evaluation and comments are confidential.

Guidance on scoring:

5 - Coordinates or attends all the group meetings. Keeps group focused. Works well with all team members. Key person for the success of the group. Creates results., but does not take over project. A major team player.

4 - Participates regularly. Always does what is assigned and on time. Is concerned about the success of the project, but not a driving force. Works well with other team members. A successful team player.

3 – Participates the majority of the time. Usually does what is assigned on time, is interested in the success of the project. An average team player.

2 – Participates occasionally. Usually does what is assigned, possibly late. Is not particularly concerned about the success of the project, OR Tends to “take over”, often domineering and critical. A below average team player.

1 - Does little for the group, not concerned about the project timeline. Whenever asked to do some tasks, usually has an excuse for not being able to contribute to the project, OR, undertakes a major portion of project alone without considering ideas of others or allowing others to contribute. A poor team player.

0 – does practically nothing for the group. Rarely shows up. Gets little or nothing done. Always has an excuse. A detriment to the team.

	NAME	Score
Teammate #1:	Yourself	____

Teammate #2: ___________________________________ ____

Teammate #3: ___________________________________ ____

Teammate #4: ___________________________________ ____

Teammate #5:____________________________________ ____

Justification for Scores given:

Section: _______ Team No.: ______

Student's Name:____________________ Date: ___________

ENGR 1234 Sustainable Energy Design Project Spring 2008

Team Member Evaluation II

Instructions: Your team evaluation final grade is based on the completion of three evaluation forms (Team Member Evaluation I, II & III) assigned throughout the design project. These forms have been developed to (1) provide feedback to your workshop GTA and (2) to provide some guidance for your team. There are two sections that you are required to complete. Section 1 includes questions which you need to provide a meaningful response (i.e. a paragraph where appropriate). Section 2 includes an assessment of yourself and your team members. NOTE: There is no "right" or "wrong" answer, your team evaluation grade will be based on completion of the form(s).

Section 1

1) Discuss briefly your team in terms of skills, interest and commitment to the design project. What are your team's strengths and what are some areas for improvement?

2) How effective has your team been in terms of equitably dividing the workload and meeting the project assignment deadlines? Please describe your team's process.

Section 2

Evaluate each member of your design team including yourself using ONLY the numbers 5, 4, 3, 2, 1 or 0. Base the score on the level of effort and contribution of that individual to the team design project. Team members may receive the same score. Your evaluation and comments are confidential.

Guidance on scoring:

5 - Coordinates or attends all the group meetings. Keeps group focused. Works well with all team members. Key person for the success of the group. Creates results., but does not take over project. A major team player.

4 - Participates regularly. Always does what is assigned and on time. Is concerned about the success of the project, but not a driving force. Works well with other team members. A successful team player.

3 – Participates the majority of the time. Usually does what is assigned on time, is interested in the success of the project. An average team player.

2 – Participates occasionally. Usually does what is assigned, possibly late. Is not particularly concerned about the success of the project, OR Tends to "take over", often domineering and critical. A below average team player.

1 - Does little for the group, not concerned about the project timeline. Whenever asked to do some tasks, usually has an excuse for not being able to contribute to the project, OR, undertakes a major portion of project alone without considering ideas of others or allowing others to contribute. A poor team player.

0 – does practically nothing for the group. Rarely shows up. Gets little or nothing done. Always has an excuse. A detriment to the team.

	NAME	Score
Teammate #1:	Yourself	____
Teammate #2:	___________________________________	____
Teammate #3:	___________________________________	____

Teammate #4: ________________________________ ____

Teammate #5:_________________________________ ____

Justification for Scores given:

Section: _______ Team No.: ______

Student's Name:____________________ Date: ___________

ENGR 1234 Sustainable Energy Design Project Spring 2008

Team Member Evaluation III

Instructions: Your team evaluation final grade is based on the completion of three evaluation forms (Team Member Evaluation I, II & III) assigned throughout the design project. These forms have been developed to (1) provide feedback to your workshop GTA and (2) to provide some guidance for your team. There are two sections that you are required to complete. Section 1 includes questions which you need to provide a meaningful response (i.e. a paragraph where appropriate). Section 2 includes an assessment of yourself and your team members. NOTE: There is no "right" or "wrong" answer, your team evaluation grade will be based on completion of the form(s).

Section 1

1) How well has your team handled a crisis or been able to avoid difficulties? Please provide a specific example(s).

2) How would you assess your team in terms of effectively working towards the project goals? What were some areas of strength for your team and/or others that needed improvement?

Section 2

Evaluate each member of your design team including yourself using ONLY the numbers 5, 4, 3, 2, 1 or 0. Base the score on the level of effort and contribution of that individual to the team design project. Team members may receive the same score. Your evaluation and comments are confidential.

Guidance on scoring:

5 - Coordinates or attends all the group meetings. Keeps group focused. Works well with all team members. Key person for the success of the group. Creates results., but does not take over project. A major team player.

4 - Participates regularly. Always does what is assigned and on time. Is concerned about the success of the project, but not a driving force. Works well with other team members. A successful team player.

3 – Participates the majority of the time. Usually does what is assigned on time, is interested in the success of the project. An average team player.

2 – Participates occasionally. Usually does what is assigned, possibly late. Is not particularly concerned about the success of the project, OR Tends to "take over", often domineering and critical. A below average team player.

1 - Does little for the group, not concerned about the project timeline. Whenever asked to do some tasks, usually has an excuse for not being able to contribute to the project, OR, undertakes a major portion of project alone without considering ideas of others or allowing others to contribute. A poor team player.

0 – does practically nothing for the group. Rarely shows up. Gets little or nothing done. Always has an excuse. A detriment to the team.

	NAME	Score
Teammate #1:	Yourself	____

Teammate #2: ___________________________________ ____

Teammate #3: ___________________________________ ____

Teammate #4: ___________________________________ ____

Teammate #5:____________________________________ ____

Justification for Scores given:

APPENDIX D: COMPREHENSIVE CODEBOOK (3 PRIMARY CODES: PROJECT, TECHNOLOGY, & DESIGN)

Theme	Code		Description	*Inclusion Criteria*	*Exclusion Criteria*	*Example*
Project	Cost constraint	P-CC	$20 Overall Project Budget	References and decisions related the cost constraint/ budget given in the project requirements. Suggestions on use of project budget.	Not related to the cost of final design, resources, or other aspects that affect student design practices.	"I wish the money budget was a lot larger so we could've really designed something."; "Cost was definitely a major factor, not only for what type but after we had our brainstorming inventory ideas just making a final decision, cost was a major factor. You can't do much with $20 haha."
	Time Constraint	P-TC	Decisions or discussions based on timing of deadlines.	Project deadlines, scheduling, other time constraints.	Not related to the timing of project deadlines, external time constraints, or scheduling issues that affect student design practices.	"That whole section of the paper we had to improvise since we hadn't finished the project yet. Plus they wanted a whole bill of materials with cost and receipts and everything and we hadn't bought every thing."
	Team	P-T	Team related or based issues	Issues that reference or deal with more than one team member. Can include team dynamics, structure, etc. and how these relate to design practices.	References to experiences on other teams if not related to student practice or interaction with the current team (DSEP team).	"He (team member) was pretty good with the electrical stuff…he had a breadboard and played around with some of that. And I've built a couple things before."; "The only real hiccup we had been people missing the meeting, which is understandable when you have a group of 5. I mean they were missing it for legitimate reasons but we were really able to work around that pretty well."
	Grading	P-G	Related to grading of the project, course, etc.	References to how assignments are graded or student perceptions of how assignments are graded or weighted and the resulting practices.	Grading of assignments outside of the course or references to grading that do not have an impact on student practice.	"You just give each other all 100s so no one gets screwed."

	Project Structure	P-PS	Requirements, Rubrics, Objectives, Goals, and Constraints of the design project	References to or issues related to project components. Specifically related to the given requirements, objectives and other details stated in the rubrics, and associated constraints.	If parameter does not have a relationship to or effect on student interaction with the institution, course, or project.	"I think that would be hard to model, like a prototype. That's probably going to be our limiting factor how to prototype."
	Project Parameter	P-PP	Project Parameters (as defined by project rubric): Functional, Safe, Interesting/ Innovative, Renewable Energy Source, Possible & Applicable	Instances, circumstances, or existing conditions related to the design project (DSEP). Specifically the functionality, safety, innovativeness, use of energy, and applicability of the design solution and its relationship to or effect on student practices.	If parameter does not have a relationship to or effect on student interaction with the institution, course, or project.	"Solar, you have to buy the little solar charger thing and that's right there probably like $10. You can't do much with $20 haha."
	Course Parameter	P-CP	Related to ENGR 1234	Instances, circumstances, or existing conditions related to the context of the engineering course (ENGR 1234) Can be related to resources, content material, requirements for class/workshop/ project/homework. Also includes student perceptions of these parameters.	If parameter does not have a relationship to or effect on the student interaction with institution, course, or project.	"I feel like they are focusing more on the group effort than the actual project." "The basis of this class is you're actually willing to do tons of work rather than learn anything."
	Institutional Parameter	P-IP	Related to the Institution/ University	Instances, circumstances, or existing conditions related to the institution. Can be related to resources, curriculum structure, requirements of the college (engineering) or institution.	If parameter does not have a relationship to or effect on the student interaction with the institution, course, or project.	"I'm in multivariable calculus and Physics 2306 so I really have to study for those classes and I was spending all my time on this two credit weed out class."

Technology	Use of tablet PC	T-PC	Use of the tablet PC	Student use or perceptions on their use of the tablet PC in class, out of class, or in design sessions. Specifically the use of features unique to the tablet, e.g. pen, swivel screen, interactive features.	Not referencing the tablet PC related to the project, course, or institution.	"The tablets were pretty fun, they did… they helped; they made the homework a little more fun to do. Haha. I mean writing it down on paper would have taken a little less time and graphing on normal engineering paper, but um, electronic submission stuff wasn't too bad because you could do it anywhere and you didn't actually hand the paper in. "
	Tablet PC constraints	T-PCC	Constraining features associated with the tablet PC	Features of the tablet PC students perceive to be limiting factors or constraining based on the tablet pc itself. E.g. cost, memory.	Other technological requirements of the course (ENGR 1234) but not directly related to tablet PC itself. E.g. LabVIEW, electronic submission.	"I mean it might hold some people back from getting into engineering. You know because of cost and everything. I use this (Mac) and I'm fine but it doesn't say anything about other options on the website."
	Student/Client wiki	T-W	Use and interaction with the student client PBWiki	References to or the use of the Pbwiki. May include students posting questions to client, students reading client responses, or discussions based on client text from the wiki.	Reference of client needs not based on information provided in the wiki.	"And they don't really cut down trees. Well they don't really have to is what they said (looking at wiki). They could but they don't have to."
	OneNote	T-ON	Use of OneNote sharing session	Implementation of OneNote sharing sessions as part of the design meeting or reflections on the use of OneNote.	Use of OneNote, which does not utilize the sharing function or the tablet PC.	"It (OneNote sharing sessions) helped with drawing the design because everybody could see it on their computer at once."

	DyKnow	T-DK	Related to DyKnow software	Student use or perceptions related to DyKnow. Can be the use of DyKnow in class or outside of the classroom.	Not referencing DyKnow related to the project, course, or institution.	"She takes class attendance through that, and if you honestly can't make it, but you're still going through the slides as she's putting them up you can still consider that attendance. It was pretty helpful, and when she would ask us questions and she would have polls it was cool to see the ratio of class on the answer. It's really helpful when she would put a problem up like flowcharting and draw it out. Then she would just take them from the class and put them on the big screen. It was pretty interesting. It was helpful because, you don't want to not do it because if she's taking them and chooses yours you don't want it to be blank. It made you really think about it and start working on it."
	Programming	T-P	Knowledge and use of programming skills	Instances or references to programming skills in various languages/ programs.	References to experiences with technology but not specific to programming. (See "Previous Knowledge & Experience)	"I bought this thing called an Ardino board, and it's a basic programming, it uses language C and C++. I was going to get into that. I was actually going to take a C++ class next semester."
	Labview	T-LV	Related to Labview programming or software	Student perceptions or use of regarding Labview; their use of Labview in class, workshop, homework, design sessions.	Not referencing LabVIEW related to the project, course, or institution.	"It's going to be much quicker to learn LabVIEW; it doesn't take 2 semesters to learn how to do programming. And you can also learn how to do visual things in LabVIEW almost immediately where as in...."
	Previous Knowledge & Experience	T-PK	Previous knowledge and experience with technology	Student experience with other technology and the effect on current practices.	Referencing the lack of previous experience with technology.	"Yeah I've use CAD before in some of my high school drafting classes but we don't have anywhere to use it here. Or at least I don't know."
Design	Engineering content knowledge	D-ECK	Knowledge related to engineering and science concepts.			"And the motor, and of course you can't have anything like leaning on the housing because that would slow the axel process down. Another major problem we had was the actual motor. It was a high-speed motor, which means I guess the rpms have to be set at…9 18 volts at 9 rpms."

	Prior knowledge/ experience	D-PK	Prior knowledge and experiences related to engineering and/or design			“We would have been able to calculate the correct angle to have the water coming out to the wheel to get the most torque. And all that kind of stuff.”
	Identity	D-I	Identity of team's final design, e.g. wanted final design to be different from peers, wanted final design to function in the presence of peers			"We just thought it was an awesome idea. It was pretty fun, and the comedy about it just really made us want to do it. We wanted to do something that other people would think was cool, funny, you know…some of the other projects, like the solar panel light up book bag or something, it’s just kind of generic. I wish ours, I mean ours was kind of generic in the sense that other students have done this in the past but I really wish our stuff could have been more creative. "
	Fixation	D-FX	Barriers to solution based on real and perceived constraints			"Wind would be easy but it's also easy to screw up on." "Yeah because it's hard to make propellers."
	Functional	D-FN	Related to the functionality or working model of the final design			"The things with solar is that you can't really prove that it happened." "Yeah but do you have any other idea what we're going to make?"
	Knowledge or use of the design process	D-DP	Concepts related to the design process			"It was just like, think of design, research…think of design, prototype, document, test, then go back and revise it and write it up again. Get your final product out there. That was main thing."; "The sketch was really fun to do. It wasn’t really needed because we all had the idea in our head and we had already talked about it, but the sketch did clear up a lot of things. They also helped us with drawing and lines and stuff and point out to everyone else. "
	Transfer of knowledge	D-TK	Knowledge applied to the design project from classes, previous experience. Also lack of knowledge transfer			

	Design strategy	D-DS	Approach to the design project			"I think we were just trying to think of something we actually do, because biomass, I wouldn't be able to think of how we would use that. So, originally we were down to solar and hydro because those were like two most common and the easiest to play around with."
	Design context	D-DC	Related to the farm and/or client teams are designing for			"Yeah but it said they're not really looking for something to make, one a little more efficient, they're looking for something new and different."
	Search of the Solution Space	D-SS	Search for possible solutions			"We went through all the different options that we thought would be viable like the solar panel or wind energy and stuff like that, and we listed all the good and bad things for both of them. And that started, once we had listed those we had taken a good hard look at the farm and the setting, and what not, I think that made it harder during brainstorming because it was afterwards."
	Modeling	D-M	Design ideas modeled after existing ideas			"I went to Michigan and they have solar powered meters, for cars."

APPENDIX E: DSEP DOCUMENT FOR PREVIOUS SEMESTERS

Tech University Department of Engineering Education ENGR 1234 Spring 2007

Appendix A

From: Your ENGR 1234 Instructor and Workshop Leader Date: February 7, 2007 Subject: Sustainable Energy Design Project

The recently formed Dean's Taskforce on Energy and Sustainability seeks to coordinate, promote, and position Tech University's educational, research, and outreach efforts to achieve sustainable and secure energy systems. This task force plays a key role in implementing the university's strategic plan. The strategic plan has identified Energy as one of its broad area's of discovery that recognizes Tech University's strengths and its ability to address societal needs. *(http://www.research.vt.edu/energy/index.html)*

As an engineering student and a member of the Tech University community, you will need to develop an awareness of current energy research efforts, both in our country and abroad, as well as the impact these innovations will have on the environment and society. In lecture you were given the following definition of sustainability:

"Sustainable development meets the needs of the present without compromising the ability of future generations to meet human needs and aspirations."

World Commission on Environment and Development (WCED) – 1987

A suitable definition for sustainable energy, then, "*is energy which is replenishable within a human lifetime and which causes no long-term damages to the environment*." As such, sustainable energy promotes sustainability. Sustainability, here, is twofold, as it constitutes self-sustenance and the ability to foster sustainable development. (*http://www.jsdnp.org.jm/susEnergy.htm*)

Assignment:

You have been assigned to work with a team of students on an eight week long design project. The main objectives of the project are to develop: i) your understanding of sustainable energy, ii) a basic understanding of the engineering design process, and iii) team and communication skills.

Your assignment is to develop a "Promotional Invention" that promotes awareness of a renewable energy source. Your team will be assigned one of four renewable energy topics by your Workshop Leader that includes: *Hydropower, Solar, Wind, and Biomass*. You can assume your audience is the general public, who may have limited knowledge of renewable energy sources. Please consider the following parameters for your design:

-It should be functional, safe, and interesting. -It must highlight one or more key components of a renewable energy source. For example (*but not limited to)* the collection of solar power, the conversion of hydropowerto mechanical work, the potential for wind power to create electricity, etc.

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-It should strive to educate and entertain as well as generate further inquiry and interest renewable energy sources. -It should aim to have broad appeal, across gender, age, race, and nationality.

Materials:

Your team will be allowed to purchase materials up to $20.00 per team. You must submit receipts for all materials purchased, or proof of "fair market value" for nonpurchased materials (donated, recycled, etc.) with your final report.

Timeline and Grade Distribution:

This project counts as 15% of course grade. It will be carried out over eight weeks and involves a series of individual and team assignments, see Table 1 below. The project will culminate with a competition. Designs selected from each of the six workshop sections will be showcased on Week 13 (date to be announced). A panel of faculty will select one "best design" and two "honorable mention" finalists.

Table 1: Project Assignments

Optional

Supplemental Assignments: In addition to the assignments listed above, five additional "Supplemental Assignments" have been included for students/teams who wish to go further with their design project, see Table 2 below. These assignments will be collected and returned with instructor feedback. They **will not be graded** but provide an opportunities to improve your team's design and to further develop your knowledge of renewable energy, and design skills. For further details on these assignments, see "Assignment Details" (*below*).

Table 2: Supplemental Assignments

Assignments

Grade

Due Date

Individual/Team

Research Paper

10%

Workshop 6 *(2/22-23)*

Individual

Brainstorming Inventory

5%

Workshop 7 *(3/1-3/2)*

Team

Team Proposal & Evaluation Matrix

10%

Workshop 8 *(3/15-3/16)*

Team

Sketch

10%

Workshop 9 *(3/22-3/23)*

Individual

Prototype

5%

Workshop 10 *(3/29-3/30)*

Team

Logbook

10%

Workshop 12 *(4/12 -13)*

Individual

Team Demo

10%

Workshop 12 *(4/12 -13)*

Team

Final Report

40%

Workshop 12 *(4/12 -13)*

Team

Supplemental Assignments

Grade

Due Date

Individual/Team

International Perspective

N/A

Workshop 6 *(2/22-23)*

Individual

Concept Sketches

N/A

Workshop 7 *(3/1-3/2)*

Team

3-D Drawing

N/A

Workshop 9 *(3/22-3/23)*

Individual

Use of Recycled Materials

N/A

Workshop 10 *(3/29-3/30)*

Team

Supplementary Advertisement

N/A

Workshop 12 *(4/12 -13)*

Team

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NOTE: *These assignments are NOT MANDATORY; they are voluntary and will not affect your grade*. All or some of these “Supplemental Assignments” may be completed. It is not required to complete the entire set of “Supplemental Assignments.”

Peer Evaluation:

Please download and review the peer evaluation form from class Web site. It is important that you make an effective contribution in completing this group project. All students will be requested to evaluate their group members' contribution using this form. The results from this peer evaluation will affect the final grade you receive on the team components of the project.

Logbook

Your team is required to meet at least six times during the span of this design project. A record of these meetings should be created in a logbook according to the guidelines provided.

Assignment Details:

Due Date

Assignment

Requirements

Details

Workshop 6 (2/22-2/23)

"Research Paper"

Objective: To increase general knowledge of a renewable energy source, which includes a definition, key benefits and trade-offs associated with the source.

Individual Font size12 pt. Times New Roman Single Spaced

Cite all References

-Submit a two page document that addresses the following topics concerning the renewable energy source your team has been assigned: a definition of the energy source, benefits associated with this source, key trade-offs or challenges associated with this source.

Workshop 6 (2/22-2/23)

Supplemental Assignment "International Perspectives"

Objective: To increase general knowledge of international perspectives on renewable energy sources, which includes examples of renewable energy applications worldwide.

Individual Font size12 pt. Times New Roman Single Spaced

Cite all References

-Submit a one to two page document that addresses an international perspective concerning the renewable energy source your team has been assigned. Include relevant information on countries that are developing these renewable energy technologies and provide examples of applications.

Workshop 7 (3/1-3/2)

“Brainstorming Inventory”

Objective: To facilitate the idea generation process in your teams search for solutions

Team Form provided on the course BB site

-Record your team’s potential solutions, a brief description, and team member’s initials on the form provided. There is no “right” or “wrong” answer, nor an upper limit to the number of ideas. Your team should provide at least 4 ideas per person.

“The best way to have a good idea is to have a lot of ideas.” Linus Pauling

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Workshop 7 (3/1-3/2)

Supplemental Assignment “Concept Sketches”

Objective: To improve creativity, sketching and communication skills during the idea generation process.

Team On Green Engineering Paper, use pencil

Provide “concept sketches” of your teams potential design solutions. Three to five of these sketches should fit on an 8.5 x 11 sheet of paper. The sketches should clearly communicate the essence of your design solutions. They *do not* need to be detailed nor to follow sketching protocol (i.e. orthographic projection, isometric, etc.).

Workshop 8 (3/15-3/16)

“Team Proposal & Evaluation Matrix”

Objectives: To refine and communicate potential solutions. To perform a feasibility study.

Team Font size12 pt. Times New Roman Single Spaced 2 page limit

Submit a maximum two page document in which your team identifies at least three potential design solutions (team ideas) which address the design assignment. These solutions should be given a name, and a brief description. Include an evaluation matrix (see P 108- 109) where these three potential solutions are rated according to design constraints and criteria

Workshop 9 (3/22 – 3/23)

“Sketch”

Objective: To communicate a detailed design solution that emerged from the preliminary design phase. To improve hand sketching skills.

Individual On Green Engineering Paper, use pencil

- Submit a hand sketch communicating your team’s design solution. Each group member will sketch the same design solution, independently. This sketch may be isometric or orthographic, properly formatted, titled, clearly label all parts, and include a brief description of its function. This sketch should strive to effectively communicate your teams design solution to someone unfamiliar with the project.

Workshop 9 (3/22 – 3/23)

Supplemental Assignment “3-D Drawing”

Objective: To develop computer generated design skills.

Individual Printed on a 8.5 x 10” sheet of paper

- Submit a computer generated 3-D drawing of your team’s design solution using “Inventor” or other CAD software program.

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Workshop 10 (3/29-3/30)

“Prototype”

Objectives: To construct the design solution. To receive feedback from peers that will inform improvements to the final design. To provide meaningful feedback on other design team’s prototypes.

Team

Your team will bring a prototype of your design to your workshop session and will receive feedback from classmates.

Workshop 10 (3/29-3/30)

Supplemental Assignment “Use of Recycled Materials”

Objectives: To incorporate recycled materials in the design solution.

Team List recycled materials on an index card

Use recycled materials in your teams design. Communicate the use of these materials by recording these materials on an index card and presenting it to your instructor.

Workshop 12 (4/12 -13)

“Team Demo” “Final Report” “Logbook”

Team

All teams will present their final designs during the workshop and submit their final reports and *individual* logbooks. Winning designs from each workshop will be selected.

Workshop 12 (4/12 -13)

Supplemental Assignment

“Supplementary Advertisement”

Team video *(2 min max)*, poster, or hand- out

Prepare and present an advertisement for your design solution which also promotes the renewable energy topic.

Workshop 12 (4/12 -13)

“Peer Evaluation Form”

Objective: To provide feedback on your team’s performance.

Individual

Each student will complete and turn in a form to evaluate his or her team member’s performance.

Week 13 Date to be Announced

“Design Showcase”

By Invitation Only

A team of judges will select a “Best Design” and two “Honorable Mentions.” The winning teams will be announced.

Appendix C

From: Prof. Lohani Date: September 10, 2007 Subject: Sustainable Energy Design Project

The Dean's Taskforce on Energy and Sustainability was formed in 2006 to coordinate, promote, and position Tech University's educational, research, and outreach efforts to achieve sustainable and secure energy systems. This task force plays a key role in implementing the university's strategic plan which has identified energy as

one of its broad area's of discovery that recognizes Tech University's strengths and its ability to address societal needs. *(http://www.research.vt.edu/energy/index.html)*

As an engineering student and a member of the Tech University community, you will need to develop an awareness of current energy research efforts, both in our country and abroad, as well as the impact these innovations will have on the environment and society. In lecture you were given the following definition of sustainability:

"Sustainable development meets the needs of the present without compromising the ability of future generations to meet human needs and aspirations."

World Commission on Environment and Development (WCED) – 1987

A suitable definition for sustainable energy, then, "*is energy which is replenishable within a human lifetime and which causes no long-term damages to the environment*." As such, sustainable energy promotes sustainability. Sustainability, here, is twofold, as it constitutes self-sustenance and the ability to foster sustainable development. (*http://www.jsdnp.org.jm/susEnergy.htm*)

Assignment:

You have been assigned to work with a team of students on an eight week long design project. The main objectives of the project are to develop: i) your understanding of sustainable energy, ii) a basic understanding of the engineering design process, and iii) team and communication skills.

Your assignment is to develop a "Promotional Innovation" that promotes awareness of a renewable energy source. Your team will be assigned one of five renewable energy topics by your workshop instructor that includes: *Hydropower, Solar, Wind, Geothermal and Biomass*. You can assume your audience is the general public, who may have limited knowledge of renewable energy sources. Please consider the following parameters for your design:

-It should be functional, safe, and interesting. -It must highlight one or more key components of a renewable energy source. For example (*but not limited to)* the collection of solar power, the conversion of hydropower

140to mechanical work, the potential for wind power to create electricity, etc. -It should strive to educate and entertain as well as generate further inquiry and interest in renewable energy sources. -It should aim to have broad appeal, across gender, age, race, and nationality.

Competition and Design Categories:

There are three broad design categories that will compete for prizes at the "Design Showcase" to be held in Torgersen Museum on November 29, 2007 (*further details to follow*). Approximately 20 semi-finalist designs will be selected from the 45 workshop sections by a panel of workshop and lecture instructors. From these semi-finalists, a panel of judges will select 3 finalists and 3 honorable mention award winners based on the following broad categories. These themes should guide your design solution and include:

I. Renewable Energy Systems

Designs in this category include large scale renewable energy systems. Examples from previous semesters include the wave powered lighthouse, the hydropower plant, and a methane plant located in a landfill.

II. Renewable Energy Solutions for the Developing World.

Designs in this category include renewable energy solutions appropriate for communities in the developing world which have limited access to manufactured resources. Examples include the solar powered hearing aid and a portable light reading mat.

III. Consumer Products and Renewable Energy

Designs in this category include a range of consumer products that utilize renewable energy sources. Examples from previous semesters include, the wind powered bike light, the solar powered drink mixer, and the solar water lantern.

Materials:

Your team will be allowed to purchase materials up to $20.00 per team. You must submit receipts for all materials purchased, or proof of "fair market value" for nonpurchased materials (donated, recycled, etc.) with your final design.

Timeline and Grade Distribution:

This project counts as 15% of course grade. It will be carried out over eight weeks and involves a series of individual and team assignments, see Table 1 below. The project will culminate with a competition.

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Table 1: Project Assignments

Peer Evaluation:

Please download and review the peer evaluation form from class Web site. It is important that you make an effective contribution in completing this group project. All students will be requested to evaluate their group members' contribution using this form. The results from this peer evaluation will affect the final grade you receive on the team components of the project.

Team Log:

Your team is required to meet at least six times during the span of this design project. A record of these meetings should be created in OneNOTE according to the guidelines provided.

Assignment Details:

Assignments

Grade

Due Date

Individual/Team

Research Questions

5%

Workshop 5 *(9/19-21)*

Individual

Research Answers

5%

Workshop 6 *(9/26-28)*

Individual

Brainstorming Inventory

10 %

Workshop 7 *(10/3-5)*

Team

Sketch

10%

Workshop 9 *(10/17-19)*

Individual

Prototype

10%

Workshop 10 *(10/24-26)*

Team

Team Log

10%

Workshop 12 *(11/7-9)*

Individual

Team Demo & Presentation

30%

Workshop 12 *(11/7-9)*

Team

Design Brief

20%

Workshop 12 *(11/7-9)*

Team

Due Date

Assignment

Requirements

Details

Workshop 5 (9/17-9/19)

"Research Questions"

Objective: To increase general knowledge of a renewable energy source through an inquiry based methodology.

Individual Font size12 pt. Times New Roman

2 Copies

-Submit at least 5 questions that you feel are relevant and important concerning the renewable energy source your team has been assigned. These questions may be general, technical, or concern social perspectives on a renewable energy topic. (Further details will be provided in Workshop 4)

Workshop 6 (9/26-9/28)

"Research Answers"

Objective: To increase general knowledge of a renewable energy source and to facilitate a meaningful dialogue with your team concerning renewable energy.

Individual Font size12 pt. Times New Roman Single Spaced

Cite all References

-Submit a one to two page response to **3** *of the 5* research questions you have been assigned. In this document you need to include the 3 questions you chose and your response to these questions, **in your own words**, including citations if necessary. (Further details will be provided in Workshop 5)

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Workshop 7 (10/3**-**10/5)

"Brainstorming Inventory"

Objective: To facilitate the idea generation process in your teams search for solutions.

Team Form provided on the course BB site

-Record your team's potential solutions, a brief description, and team member's initials on the form provided. There is no "right" or "wrong" answer, nor an upper limit to the number of ideas. Your team should provide at least 5 ideas per person.

"The best way to have a good idea is to have a lot of ideas." Linus Pauling

Workshop 9 (10/17 – 10/19)

"Sketch"

Objective: To communicate a detailed design solution that emerged from the preliminary design phase. To improve hand sketching skills.

Individual On Green Engineering Paper, use pencil

- Submit a hand sketch communicating your team's design solution. Each group member will sketch the same design solution, independently. This sketch may be isometric or orthographic, properly formatted, titled, clearly label all parts, and include a brief description of its function. This sketch should strive to effectively communicate your teams design solution to someone unfamiliar with the project.

Workshop 10 (3/29-3/30)

"Prototype"

Objectives: To construct the design solution. To receive feedback from peers that will inform improvements to the final design. To provide meaningful feedback on other design team's prototypes.

Team

Your team will bring a prototype of your design to your workshop session and will receive feedback from classmates.

Workshop 12 (11/7-11/9)

"Team Demo and Presentation"

Team

All teams will present their final designs and give a brief (5-10) minutes presentation discussing their teams design process (i.e. research questions, brainstorming ideas, sketch, prototype, team meetings, etc.) Winning designs from each workshop will be selected.

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Workshop 12 (11/7-11/9)

“Design Brief”

Team 1 page document

(8.5” x 11”) A template will be provided

2 copies

Each team will submit 2 copies of a ‘design brief” which will capture the essence of their final design and include the following information: design title, description of design solution, photo of final design, pertinent information concerning renewable energy topic, team member’s names. A template will be provided.

Workshop 12 (11/7-11/9)

“Team Log”

Individual

Refer to the OneNOTE document posted on the Main BB site. Your team is expected to meet at least 6 times during the design project.

Workshop 12 (11/7-11/9)

“Peer Evaluation Form”

Objective: To provide feedback on your team’s performance.

Individual

Each student will complete and turn in a form to evaluate his or her team member’s performance.

Week 13 November 29, 2007 Torgerson Museum

“Design Showcase”

By Invitation Only

A team of judges will select 3 finalists and 3 honorable mentions from the 3 categories detailed in this document (see “Competition and Design Categories”) Prizes will be awarded.