

PREPARING STUDENTS TO INCORPORATE STAKEHOLDER REQUIREMENTS IN AEROSPACE VEHICLE DESIGN

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The Academic Faculty

by

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PREPARING STUDENTS TO INCORPORATE STAKEHOLDER REQUIREMENTS IN AEROSPACE VEHICLE DESIGN

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To my parents, my brother, and the amazing Coso and Nodarse clans.

In memory of Dr. Samuel Nodarse.

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SUMMARY

The design of an aerospace vehicle system is a complex integration process driven by technological developments, stakeholder and mission needs, cost, schedule, and the state of the industry. The vehicle then operates in an equally complex context, dependent on many aspects of the environment, the performance of stakeholders and the quality of the design itself. Satisfying the needs of all stakeholders, including both users and non-users, is a complicated challenge for designers and engineers, and stakeholder requirements are, at times, neglected and/or design decisions are made without considering the operational context of the vehicle system. Given the quantity and variety of stakeholders affected by the design and operation of an aerospace vehicle system, it is critical to examine how to better incorporate stakeholder requirements earlier and throughout the design process. The intent of this research is to (1) examine how stakeholder considerations are currently integrated into aerospace vehicle design practice and curricula, (2) design empirically-informed and theoretically-grounded educational interventions for an aerospace design capstone course, and (3) isolate the characteristics of the interventions and learning environment which support students' integration of stakeholder considerations.

The first research phase identified how stakeholder considerations are taken into account within an aerospace vehicle design firm and in current aerospace engineering design curricula. Interviews with aerospace designers revealed six conditions at the group, interaction and individual levels affecting the integration of stakeholder considerations. Examining current curricula, aerospace design education relies on quantitative measures. Thus, many students are not introduced to stakeholder considerations that are challenging to quantify. In addition, at the start of an aerospace engineering senior design capstone course, students were found to have some understanding of the customer and a few contextual considerations, but in general

students did not see the impact of the broader context or of stakeholders outside of the customer.

The second research phase comprised the design and evaluation of a Requirements Lab and Stakeholders in Design Labs, two in-class interventions implemented in a senior aircraft design capstone course. Further, a Stakeholders in Design rubric was developed to evaluate students' design understanding and integration of stakeholder considerations and, as such, can be used as a summative assessment tool.

The two in-class interventions were evaluated using a multi-level framework to examine student capstone design projects, a written evaluation, and observations of students' design team meetings. The findings demonstrated an increase in students' awareness of a diverse group of stakeholders, but also perceptions that students appeared to only integrate stakeholder considerations in cases where interactions with stakeholders were possible and the design requirements had an explicit stakeholder focus. Further, particular aspects within the aircraft design learning environment such as the lack of explicit stakeholder requirements, the differences between the learning environment in the two semesters of the course, and the availability of tools impacted students' integration of stakeholder considerations and overall effectiveness of the active interventions.

This research serves as a starting point for future research in pedagogical techniques and assessment methods for integrating stakeholder requirements into technology-focused design capstone courses. The results can also inform the vehicle design education of students and engineers from other disciplines.

CHAPTER 1 - INTRODUCTION

“Stakeholders are all those affected by the system. They may be users or non-users. They need not be clients or decision-makers. Stakeholders may be major or minor, and the ways in which they interact with a large-scale system are myriad.” (Gibson et al., 2007), p.315)

The design of an aerospace vehicle system is a complex integration process driven by technological developments, stakeholder and mission needs, cost, schedule, and the state of the industry. The vehicle then operates in an equally complex context, dependent on many aspects of the environment, the performance of stakeholders (including pilots, operators, and maintainers) and the quality of the design itself. Thus, vehicle systems design requires an understanding of not only its technical and performance components, but also the needs and limitations of the stakeholders in the operational context. Satisfying the needs of all stakeholders, however, is a complicated challenge for designers and engineers. Unfortunately, stakeholder requirements are at times neglected until the latter stages of the design process and/or design decisions are made without considering operational context (Chua & Feigh, 2011; Feigh & Chua, 2011; Ives, 2007; Proctor & Zandt, 1994; Thronesbery et al., 2006). These decisions can have significant impacts on the overall design, the subsequent life-cycle costs, and the extent that stakeholders’ needs, including safety, are met.

Despite proposals for substantive changes in the field of aerospace systems design, there is a need to better prepare aerospace engineering students to overcome current and future challenges within the field (Chaput, 2010; Haupt, 1977; McMasters, 2003; Nicolai, 1998). To be able to design in what members of the industry call “the modern engineering environment,” graduates of aerospace programs should be able to view design from a systems perspective and understand the societal, environmental, and economic context in which engineering is practiced (McMasters, 2003, p. 16). Within the

aerospace engineering curriculum, students should be exposed to designing across multiple disciplines (Chaput, 2010) and be capable of deriving achievable and measurable requirements that also fulfill those of stakeholders (Tam, 2004). This raises questions about the differences between how design is taught and how design is performed in industry settings and, more specifically, how stakeholder considerations are integrated into the design process within industry. The answers to these questions can then be used to improve the aerospace engineering design curricula and prepare engineers to take into consideration the needs of stakeholders as a part of design in the “modern engineering environment” (McMasters, 2003, p. 16).

1.1 Stakeholders in Complex Systems Design

1.1.1 Complex Systems Design Industry

Stakeholders are critical to the successful design of products in many fields, from providing funding to giving manufacturers a competitive edge (Green & Jordan, 1999; Nelson, 2013). In addition, stakeholder considerations affect the overall success of a design. For example, a survey performed by the Standish Group in the United States showed that the two most common causes of system failure were insufficient effort to establish user requirements and lack of user involvement in the design process (Maguire, 2001). In the case of early McDonnell F-4s, for instance, the tightly packed and “elegant” fuselage design required maintenance workers to remove rear ejection seats completely each time they needed to adjust the communications system, adding significant maintenance hours (Nicolai & Carichner, 2010).

For aviation, space, military and software systems, human-related design criteria are part of certification requirements established by regulators. These different standards and certification procedures enforce a focus on many of the stakeholders of a particular design (EASA, 2007; Federal Aviation Administration, 2005; ISO, 2010; Lockheed Missiles and Space Company, Inc., 1995). However, these standards provide only a

minimum acceptable standard and do not specify a particular design process. Thus, designers can develop a product that achieves the bare minimum of compliance and/or delay taking into consideration the stakeholder perspective until the end of the design process.

In the aviation industry, specifically, ICAO has called for a more integrated consideration of stakeholders, specifically through social sustainability efforts (Hupe, 2011). Social sustainability incorporates considerations of equity, diversity, quality of life, and the impacts of the design on future generations (Watson, 2013). While aviation has focused significantly on environmental sustainability efforts, ICAO notes that the area of social sustainability “remains one area where aviation’s contribution needs to be further enhanced and disseminated” (Hupe, 2011, p. 3).

For these reasons, members of the aerospace engineering vehicle design industry have been exploring a variety of tools and resources for better incorporating stakeholder considerations in a design. This exploration supports not only these sustainability efforts within the industry and vehicle certification processes, but also the safe and successful performance of the vehicle in the operational environment. For instance, participatory design and user involvement design models (Damodaran, 1996; Hussain et al., 2012) are used within some aerospace design processes or have been used previously. In the case of the development of the Boeing 777, for example, the world’s major airlines served as a “working together” group for the company, collaborating on specifications for this new design (McKinzie, 1996; Norris, 1995).

However, more efforts are necessary to overcome design decisions that didn’t consider the operational environment of the system (Chua & Feigh, 2011; Feigh & Chua, 2011; Ives, 2007; Proctor & Zandt, 1994; Thronesbery et al., 2006) or ‘technology pushes,’ where technology developments motivate innovations, rather “than by concerns for users’ needs and preferences” (Steen, 2012, p. 72). Given the quantity and variety of stakeholders affected by the design and operation of an aerospace vehicle system, it is

critical to examine how to better incorporate stakeholder requirements earlier and throughout the design process (Feigh & Chua, 2011; Landsburg et al., 2008; Pew, 2008). Petroski (1994) explained how “understanding how errors are made and can be avoided in the design process can help eliminate them and can illuminate the very process of design” (p. 2).

1.1.2 Engineering Design Education

A recent American Society for Engineering Education (ASEE) and National Science Foundation (NSF) Report on Transforming Undergraduate Education in Engineering (TUEE) describes how industry seeks “a T-shaped engineering graduate who brings broad knowledge across domains and the ability to collaborate within a diverse workforce as well as deep expertise within a single domain” (ASEE, 2013, p. 2). Overall, the findings from the report characterize the importance of particular knowledge and skills for engineering graduates in today’s engineering industry and ten years from now. For example, in a survey of industry representatives, along with a handful of academics, the respondents view the importance of “[synthesizing] engineering, business, and societal perspectives to design systems and processes” as moderately important today (59%), but very important ten years from now (69%) (ASEE, 2013). They view the current ability of engineering education to produce graduates with this ability as fair (66%) (ASEE, 2013). Only 10% viewed the current ability of engineering education to produce graduates with this ability as very good or good, while 24% viewed it as poor or very poor.

The Accreditation Board for Engineering and Technology (ABET) define programs outcomes for engineering graduates that include:

- (c) “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,” and

(h) “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context” (ABET Engineering Accreditation Commission, 2011).

These criteria and the TUEE report results illustrate the importance of supporting students’ understanding of and ability to integrate societal, environmental, economic considerations into design. Yet, the TUEE report suggests that there exists room for improvement in how engineering programs currently prepare engineering graduates.

Studies of design and explorations of engineering students’ pathways in industry support the need to determine how to better prepare students to incorporate stakeholder considerations into design. In an IEEE Spectrum Article titled “What keeps engineers from advancing in their career,” Hinkle (2013) outlines four pieces of advice for early career engineers. One piece of advice is to

“Know your stakeholders. This can be much more difficult than knowing your customers, who are a subset of your stakeholders. The broad definition of a stakeholder is anyone who is affected by your work in any way, or who affects your work in any way. Think about that, and you’ll start to realize the impact you are having on the world. It’s probably much bigger than you realized if you haven’t thought about stakeholders this way. You can’t have relationships with that many people, so at least build rapport with three or four of your most important stakeholders who aren’t customers.” (p. 1)

This perspective aligns with the outcomes of a Harvey Mudd Design Workshop, comprised of engineering design educators and researchers, that illustrate how “design is replete with “people” issues, both personal and social” and instructors need to “give attention to the Humanist Engineer: include culture, values, and the notion of intent in the academic program,” (Dym et al., 2001, p. 293). Self-reports by engineering seniors illustrate a low level of confidence in their ability to understand how broader social contexts impact engineering practice (Ro et al., 2012). These findings align with similar

research about sustainability in engineering design, where students perceive the social aspects of sustainability to be less important when compared with the economic and environmental aspects (Watson et al., 2013).

As a result, there is a movement within some fields of engineering to design learning environments which place a higher value on the needs and limitations of stakeholders (Jordan & Lande, 2012; National Academy of Engineering, 2004; National Academy of Engineering, 2005; Zoltowski, 2010; Zoltowski et al., 2010). At the undergraduate level, the purpose of these approaches and experiences is to allow students to interact with the stakeholders throughout the design process and complete a design that, in many cases, can be delivered to the client for future use (Zoltowski, 2010). Through these experiences, students are gaining valuable insight into the importance of stakeholder considerations within design (Lande & Leifer, 2009; Zoltowski, 2010) and the “impact of engineering solutions in a global, economic, environmental, and societal context” (ABET Engineering Accreditation Commission, 2011, p. 3). Yet, this movement is restricted to fields such as product design, industrial design, and computer science: It does not consider how to integrate these techniques into the design of complex systems, such as aerospace vehicles.

Aerospace engineering education literature calls for students to learn to view design from a systems perspective and to understand the societal, environmental, and economical context in which engineering is practiced (McMasters, 2003). Yet, research is limited in terms of how to improve students’ understanding of the broader context of design and students’ abilities to balance the performance and stakeholder-related considerations within a vehicle design. In addition, the design of an aerospace vehicle is technically complex and costly and, as a result, the extent is limited to which students can experience the entire design process and interact regularly with stakeholders (Mason, 2010). For example, many fixed wing or spacecraft design course instructors have to choose whether to pursue a project that focuses on the conceptual design process, but

does not include design activities like prototyping and building, or a project that includes detailed design and construction, but can be expensive (Mason, 2010). While many studies discuss ways to teach aircraft and space system design (Chaput, 2010; Crawley et al., 2008; Fowler, 2012; Frederick & Frederick, 2007; Guerra & Fowler, 2008; Hall & Cummings, 2007; Livne & Nelson, 2012; Mason, 2010; Schrage et al., 2008), few studies examine the effects of the design experiences on graduates' preparedness for making challenging design decisions in industry (Butler et al., 2012; Goff & Terpenney, 2012). Thus, an examination of the challenges of integrating stakeholder considerations into aerospace vehicle design and aerospace engineering design curricula is necessary to develop methods for preparing students to integrate stakeholder considerations into the design of an aerospace vehicle system.

1.2 Significance of Study

The findings of this doctoral work contribute to the engineering industry, engineering education practice, and engineering design research. By understanding how stakeholder considerations are integrated currently at aerospace engineering design firms, this doctoral work provides empirical evidence of conditions that enhance or inhibit the integration of human factors and stakeholder considerations into the aircraft design process. In addition, the research findings synthesize the experiences of engineering designers at aerospace engineering design firms to isolate challenges students may face upon entering the aerospace engineering industry support improvements to aerospace engineering design education. To prepare students to integrate stakeholder considerations into aerospace vehicle design, this work provides empirically-informed and theoretically-grounded interventions that can be easily integrated into an aircraft design capstone course or adapted for complex systems design course. Furthermore, evaluation instruments, which were designed based on empirical evidence and literature in engineering design and engineering education, provide methods for

- exploring engineering students' perceptions of how stakeholder considerations are integrated into the vehicle design process,
- supporting students' understanding of how to design with stakeholders in mind, and
- assessing students' abilities to consider the impact of complex system design decisions on stakeholders.

Due to the importance of the learning environment in the implementation of any educational intervention, this research contributes empirical evidence of conditions within the learning environment that impact students' integration of stakeholder considerations into a complex systems design process. As a result, this doctoral work serves as a starting point for future research into pedagogical techniques that support students' integration of stakeholder considerations into the design of complex systems. Overall, the discipline-based education research that is presented in this dissertation informs teaching and learning within aerospace engineering and supports continued research into this interdisciplinary field.

1.3 Research Overview

The aim of this doctoral work was to understand how to prepare students to integrate stakeholder requirements early and throughout the design of an aerospace vehicle system. A two-phase research design, illustrated in Figure 1 and discussed in Table 1, was used to support the development, implementation, and evaluation of educational interventions within a senior aircraft design capstone course. The first phase of the research identified how stakeholder considerations are taken into account within an aerospace vehicle design firm and in aerospace engineering design curricula. In addition, this phase included an exploration of incoming aerospace engineering senior design students and their perceptions about design and the role of stakeholders in the design process.

The results of Phase I informed specifications for educational interventions that were used not only in the design of the content and structure of the interventions, but also

in the selection of the learning theory and pedagogical techniques underlying the design. Phase II comprised the design and evaluation of the educational intervention. Following implementation of the interventions, they were evaluated using a multi-level framework to examine student capstone projects, a written evaluation, and observations of students' design team meetings.

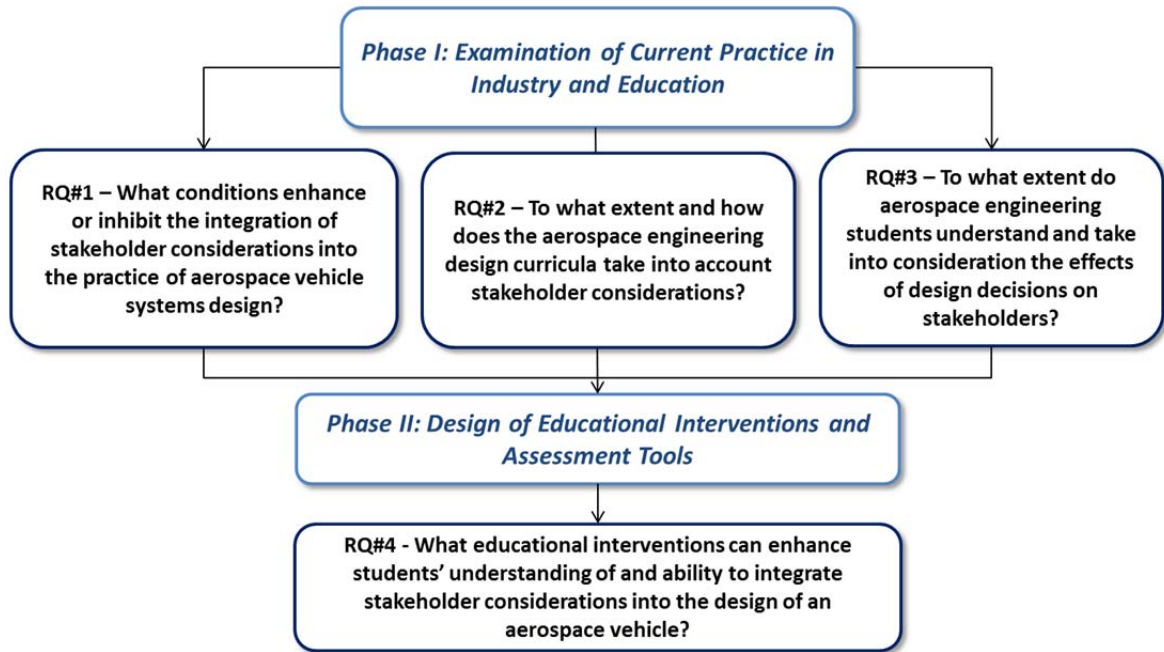


Figure 1: Ph.D. Thesis Research Outline

Table 1: Research Outline

Research Aim(s)	Research Question(s)	Research Tool(s)	Relevant Chapter(s)
Examine how stakeholder considerations are currently integrated into aerospace vehicle systems design	<i>Research Question #1:</i> What conditions enhance or inhibit the integration of stakeholder considerations into the practice of aerospace vehicle systems design?	Case Study of Aerospace Vehicle Design Firm	<i>Chapter 2:</i> Integration of Stakeholder Considerations in Aerospace Design Practice
Examine how stakeholder considerations are currently integrated into aerospace engineering design education	<i>Research Question #2:</i> To what extent and how does the aerospace engineering design curricula take into account stakeholder considerations?	Review of Aerospace Engineering Design Syllabi and Textbooks	<i>Chapter 3:</i> Integration of Stakeholder Considerations in Aircraft Design Curricula and by Aerospace Engineering Students
	<i>Research Question #3.1:</i> What prior knowledge do engineering students bring to a senior design capstone course about design and the role of stakeholder considerations within the design process?	In-Class Evaluation	<i>Chapter 3:</i> Integration of Stakeholder Considerations in Aircraft Design Curricula and by Aerospace Engineering Students
	<i>Research Question #3.2:</i> What factors contribute to students' perceptions of the design process and role of stakeholders in aircraft design?	In-Class Evaluation	<i>Chapter 3:</i> Integration of Stakeholder Considerations in Aircraft Design Curricula and by Aerospace Engineering Students
Design empirically-informed and theoretically-grounded educational interventions	<i>Research Question #4:</i> What educational interventions can enhance students' understanding of and ability to integrate stakeholder considerations into the design of an aerospace vehicle?	N/A	<i>Chapter 4:</i> Design of the Interventions
Isolate the characteristics of the interventions and learning environment which support students' integration of stakeholder considerations	<i>Research Question #4.1:</i> What characteristics of the educational interventions support students' abilities to integrate stakeholder considerations into the design of an aerospace vehicle?	Evaluation of Intervention Artifacts, In-Class Evaluation, Stakeholders-in-Design Rubric, Observations of Design Team Meetings	<i>Chapter 5:</i> Evaluation of Students' Experiences in the Educational Interventions
	<i>Research Question #4.2:</i> To what extent can the interventions help students integrate stakeholder considerations into the design of an aerospace vehicle?	Evaluation of Intervention Artifacts, In-Class Evaluation, Stakeholders-in-Design Rubric, Observations of Design Team Meetings	<i>Chapter 6:</i> Summative Evaluation: Students' Application of Intervention Content and Tools
	<i>Research Question #4.3:</i> What characteristics of the engineering design learning experience and learning environment support or hinder students' integration of stakeholder considerations into the design of an aerospace vehicle?	Observations of Design Team Meetings, Student Focus Groups, Instructor Interviews, Stakeholders-in-Design Rubric	<i>Chapter 7:</i> Impact of the Learning Experiences and the Learning Environment

CHAPTER 2 - Integration of Stakeholder Considerations in the Practice of Aircraft Design

The purpose of the first part of this doctoral work is to understand how stakeholders are incorporated in the current practice of aerospace vehicle design. Research within human factors and related fields has addressed the need to integrate many stakeholder considerations into the design of complex systems such as aircraft (Bainbridge, 1983; Chua & Feigh, 2011) and provided recommendations for how to best integrate these considerations into these designs (Chapanis, 1996; Chua & Feigh, 2011; Elm et al., 2008; Militello et al., 2010; Pew, 2008; Sanders & McCormick, 1993). Within the aircraft design literature, stakeholder considerations have been examined as part of multidisciplinary design and optimization studies (Cheung et al., 2012; Nunez & Guenov, 2013), aerodynamic analyses (Bizinos & Redelinghuys, 2013), and examinations of the operational environment (Kim et al., 2013; Langhans et al., 2013; McDonald, 2013). However, this literature has not empirically studied how stakeholder considerations are integrated into aerospace design through multidisciplinary design teams. As a result, the study described in this chapter seeks to answer Research Question #1 “*What conditions enhance or inhibit the integration of human factors and stakeholder considerations into the practice of aircraft design?*”

The chapter begins by reviewing how stakeholder and human factors considerations are currently examined in the literature on aircraft design. In this chapter, the term ‘human factors’ (HF) will encompass all of the sub-fields which focus on human-systems integration within design, including ergonomics, cognitive engineering, anthropometry, and human engineering (Hollnagel & Woods, 1999; Pew, 2008). As a result, HF considers the physical and cognitive capabilities and limitations of humans who interact with the design as well as the needs and wants of the various stakeholders who impact and are impacted by the design. Following the discussion of related

literature, the context of the case study will be introduced, along with a description of the research design. Conditions fostering (or obstructing) stakeholder integration are then described using evidence from two cases: (1) a design group successfully integrating stakeholder considerations and (2) other design groups.

2.1 Background

Stakeholder considerations impact aircraft design decisions within all design groups and at every stage of the design process and the aircraft life cycle. For manufacturers and maintainers, the detailed design and integration of aircraft components can affect their ability to build or maintain the aircraft and its components. For aircraft operators, changes to mission specifications can require atypical design solutions. With the B-2 bomber, for instance, crewmembers installed beach lounge chairs for power naps on long missions (Tirpak, 1999). Non-users can also be affected by design decisions related to noise and/or the operational environment. For example, one potential solution for resolving congestion in the airspace above New York City is a new departure route from La Guardia airport that reduces fuel consumption and emissions (Buckley, 2013). However, the route places aircraft precisely over the same places each day; on one hand, this affects fewer people but, for the affected population, this results in a localized increase in aircraft noise and emissions (Buckley, 2013).

The aircraft design literature recognizes the importance of stakeholders in aircraft design, whether it be the customer (Cheung et al., 2012; McDonald, 2013; Nunez & Guenov, 2013), the passenger (Bizinos & Redelinghuys, 2013), the manufacturer (McDonald, 2013), the airport operators (Kim et al., 2013; Langhans et al., 2013), or the pilot (Forrest et al., 2012; Lampton & Klyde, 2012). For instance, McDonald (2013) indicates that “in the commercial sector, the voice of the customer is critical” (p. 741). A review of *Journal of Aircraft* papers over the past two years identified several categories of research related to stakeholder considerations and aircraft design. The first category

sought to quantify considerations affecting a range of stakeholders, including passengers, airports, and pilots. These studies focused on quantifying stakeholder considerations to further explore potential design solutions or to compare the considerations quantitatively with more traditional design metrics (Bizinos & Redelinghuys, 2013; Forrest et al., 2012; Kim et al., 2013; Lampton & Klyde, 2012). Bizinos and colleagues, for example, compared the drag reduction of formation flight with the impact of formation flight on passenger comfort (Bizinos & Redelinghuys, 2013). Other studies of aircraft handling qualities investigated the effects of different designs on the controllability and maneuverability of the aircraft and associated pilot training (Forrest et al., 2012; Lampton & Klyde, 2012).

The second category of research centered on airport operations and the implications of new operational concepts on the airport operators, the passengers, the airline, and the aircraft manufacturers (Kim et al., 2013; Langhans et al., 2013). Here, researchers focused on issues such as how to respond to unplanned iterations in the design process (Nunez & Guenov, 2013) caused by changes in customer needs or manufacturing constraints.

The third category of studies integrates operational considerations with aircraft design considerations. Value-Driven Design research, for example, supports the integration of stakeholders into the design process by capturing attributes of interest to the stakeholders using quality function deployment and similar methods (Cheung et al., 2012). Other research explored designing based on how the aircraft is used in operation (McDonald, 2013). Mane and colleagues (2012) proposed a coupling between aircraft operations optimization algorithms and aircraft design algorithms: “With this formulation the manufacturer could work more closely with a customer to determine the best new aircraft for the operations” (p. 141).

While the literature does offer approaches for incorporating stakeholder considerations, research is limited on how this incorporation actually occurs within

design teams at aircraft design firms. Researchers within aerospace engineering have examined the dynamics of concurrent engineering teams (Hihn et al., 2011) and teamwork, adjustment to change, and knowledge management among design team members (Baird et al., 2000). However, this and similar research does not specifically address the complexities which arise due to the cross-disciplinary nature of design or how those complexities impact the overall design. This chapter provides a situated perspective of design by examining the integration of human factors and stakeholder considerations into the aircraft design process at an aircraft design firm.

Research in HF and related literature emphasize universal approaches to integrating HF and stakeholder considerations into the design of complex systems at all design stages (Feigh & Chua, 2011). Nevertheless, HF specialists encounter challenges with respect to integration, from misunderstandings of HF to lack of organizational support (Feigh & Chua, 2011; Militello et al., 2010; Pew, 2008). HF specialists describe additional obstacles within organizations, including the lack of awareness and appreciation by the design engineers with no HF background (Feigh & Chua, 2011; Militello et al., 2010). Pew describes a tension between those designers who do (and don't) have an HF background and a mismatch between their design philosophies (Pew, 2008).

To combat the challenges of integration, researchers and practitioners have discussed recommendations for more effective integration of HF into the design process. Commitment and support from management are defined as key components for introducing HF into the design process and for demonstrating the importance of HF and stakeholder considerations to the organization (Feigh & Chua, 2011; Landsburg et al., 2008; McSweeney et al., 2009). The integration of HF specialists needs to come early and remain continuous throughout the design process (Elm et al., 2008; Landsburg et al., 2008; McSweeney et al., 2009), with stakeholder considerations as a part of the organization's design philosophy (Feigh & Chua, 2011; McSweeney et al., 2009). Once

integrated, planning the HF-related efforts alongside the efforts from other engineering disciplines will be essential for maintaining effective integration (Landsburg et al., 2008; McSweeney et al., 2009). Further, HF specialists should attempt to quantify stakeholder considerations into metrics that help designers with or without an HF background understand the contributions of HF (Feigh & Chua, 2011; Landsburg et al., 2008).

Education and training are cited as additional ways to increase awareness about the relationship between HF and design (Feigh & Chua, 2011; Landsburg et al., 2008; McSweeney et al., 2009). Researchers recommend training team members to find a shared language that is more aligned with the design problem than any individual's discipline, and developing models or artifacts to explain human concepts and connections to the entire design team (Feigh & Chua, 2011; Militello et al., 2010; Pew, 2008). Likewise, this training should describe how to involve stakeholders such as the client, the system's users, and the system's non-users within the design process (Feigh & Chua, 2011; Landsburg et al., 2008; Pew, 2008). Each of these recommendations addresses challenges to effectively integrating HF and stakeholder considerations into the design process; however, only one of the studies demonstrates the effectiveness of some of these recommendations. As a result, additional research is necessary to determine if these training recommendations are sufficient.

Conceptual frameworks for integrating human-systems principles and stakeholder-related considerations into design have also been published. Pew describes an Incremental Commitment Model based on system definition and stakeholder commitment (Pew, 2008). Elm and colleagues incorporate HF practices into a Department of Defense system-life cycle and systems engineering design model (Elm et al., 2008). Militello and colleagues depart from the use of a sequential design process and develop a more iterative approach to the integration of HF (Militello et al., 2010). Each of these frameworks provides an option for organizations seeking to integrate HF and stakeholder considerations more firmly into their design process. Nevertheless, these

and other similar frameworks (Chapanis, 1996; Sanders & McCormick, 1993) may not capture all the complexities of the design process in practice. To determine the potential effectiveness of these and similar frameworks and their potential for use in design education, it is necessary to explore aircraft design practice and understand how HF and stakeholder considerations are integrated into the overall design process at the level of design teams.

2.2 Methods

2.2.1 Site and Sample

This research was conducted over three months at an aircraft design firm where designers are organized into different functional groups (e.g., Pilot Compartment, Avionics, Safety, Systems Engineering). Within the last decade, the firm moved to have each of the functional groups include at least one subject matter expert (SME) who focuses on the needs and limitations of one or more stakeholders. These SMEs have a background in HF, psychology, or a related discipline and, for consistency, they will be referred to as HF specialists.

Fourteen HF specialists and eleven design engineers without an HF background were invited to participate in the study, as shown in Table 2. The sampling technique used in this study was affected by the accessibility of different groups and individuals. Thus, the final sample attempted capture the perspectives of both design engineers and human factors specialists by inviting individuals with varying years of experience and individuals who had previous experience in more than one functional group within the firm. Approval for the study from both the firm's human subject protection program and the Georgia Tech Institutional Review Board was obtained prior to the start of data collection (See Appendix A.1 for a copy of approved consent form).

Table 2: Breakdown of Sample by Disciplinary Background

	HF Specialists	Design Engineers	Total
Pilot Compartment Group	3	11	14
Other groups within the organization	11	0	11
Total	14	11	25

2.2.2 Data Collection

An embedded, multiple case study method was employed using two rounds of semi-structured interviews. A case study, in this context, is a research method that examines a single setting or, in this case, multiple settings holistically to better understand a particular phenomenon (Eisenhardt, 1989a; Yin, 1989). Case studies have been used to research a variety of phenomena in different fields, from the effect of high velocity environments on rapid decision-making (Eisenhardt, 1989b) to the impact of military base closures on local communities (Bradshaw, 1999).

The use of multiple cases permitted a more comprehensive examination of the integration of stakeholder considerations into the design process (Yin, 1989). Specifically, the participants in this study included individuals from different functional groups, including, but not limited to, Pilot Compartment, Safety, and Systems Engineering. The study of multiple cases (functional groups) also allowed for replication logic to be utilized; in other words, each case could confirm or reject the generalizability of results found in other cases (Yin, 1989). The embedded design enabled multiple units of analysis, i.e., individuals, groups of individuals from a particular disciplinary background, and functional groups of individuals from multiple backgrounds.

2.2.2.1 First Round of Semi-Structured Interviews

Nineteen HF specialists and design engineers participated in the first round of interviews. Each interview lasted between forty-five minutes and one hour, and I conducted all of the interviews. Following the interviews, my notes were expanded into detailed accounts and the participants reviewed these accounts as part of the validation

procedure. The semi-structured interview protocol (see Appendix B) included questions about the following topics:

- 1) the design process within the firm;
- 2) the participant's experiences with regards to the integration of stakeholder considerations;
- 3) challenges to the integration of stakeholder considerations into the design process within design teams, their group, and the firm as a whole; and
- 4) interventions previously used within the firm to improve integration.

Afterwards, the different ways stakeholders are considered (or not considered) within the design process and the types of challenges faced by the members of the functional groups were categorized (see Section 2.2.3 - *Data Analysis* for more details). In addition, the results informed development of the questions for the second round of interviews.

2.2.2.2 Second Round of Semi-Structured Interviews

I applied theoretical sampling to select six additional participants from different functional groups for a second round of semi-structured interviews. This type of sampling identifies participants who could provide answers to questions remaining after the first round of interviews (Eisenhardt, 1989a). Thus, these interviews sought to clarify issues described by the previous participants and the interactions among the participants and the different functional groups.

2.2.3 Data Analysis

To capture emerging themes, all of the interview accounts were read and reread to develop high-level categorizations of the content. The next step was a within-case analysis, i.e., an in-depth examination of each interview as a “stand-alone entity” (Eisenhardt, 1989a, p. 540). Case reports were written to capture more detailed information about the experiences of each of the participants. To look for patterns across

the cases, I used the categories from the within-case reports to describe and compare the cases within each functional group (Pilot Compartment, Safety, etc.) and within each disciplinary background (HF specialist and design engineer with no formal HF background) (Eisenhardt, 1989a; Meyer, 2001; Yin, 1989). At each stage, I used a peer debriefing procedure where a peer, unaffiliated with the study, was asked to challenge the research design, data analysis, and conclusions (TheNguyin, 2008).

Differences emerged from the cross-case analysis based on whether the participant was from the Pilot Compartment (PC) group or from any other group. At this stage, I reviewed the relevant literature regarding cross-disciplinary teamwork to further understand the results and to identify additional categories relevant to this effect (Adams et al., 2010; Adams et al., 2009; Collins et al., 2007; Galison, 1997; Gorman, 2004; Jenkins, 2010; Kellogg et al., 2006). Again, peer debriefing was used to discuss possible researcher bias within the results and any competing hypotheses. Case reports were written for (1) cases within the PC group and (2) all cases of HF specialists who were not members of the PC group. Finally, the results were organized based on the six conditions which emerged from the analysis and the relationships among those conditions.

2.3 Results

2.3.1 Overview

Several conditions were found to impact the integration of HF and stakeholder considerations into the aircraft design process, spanning several levels of analysis, as illustrated in Figure 2. The first two relate to the structure of a design team or functional group in terms of the benefit of (1) the existence of a common goal addressing HF and/or stakeholder considerations and (2) a group structure which supports addressing stakeholder needs. The ability of group members from different disciplines to form a ‘trading zone’ for their design was affected by (3) the use of ‘boundary objects’ (e.g., storyboards, prototypes) among the group members and (4) the existence (or lack of

existence) of a shared language to support the exchange of ideas. Individual characteristics of group members also influenced the integration of stakeholder considerations, specifically in regards to (5) each individual's perspective about how to work on cross-disciplinary teams. Finally, group members' (6) training and learning experiences regarding approaches to working on cross-disciplinary teams emerged as important.

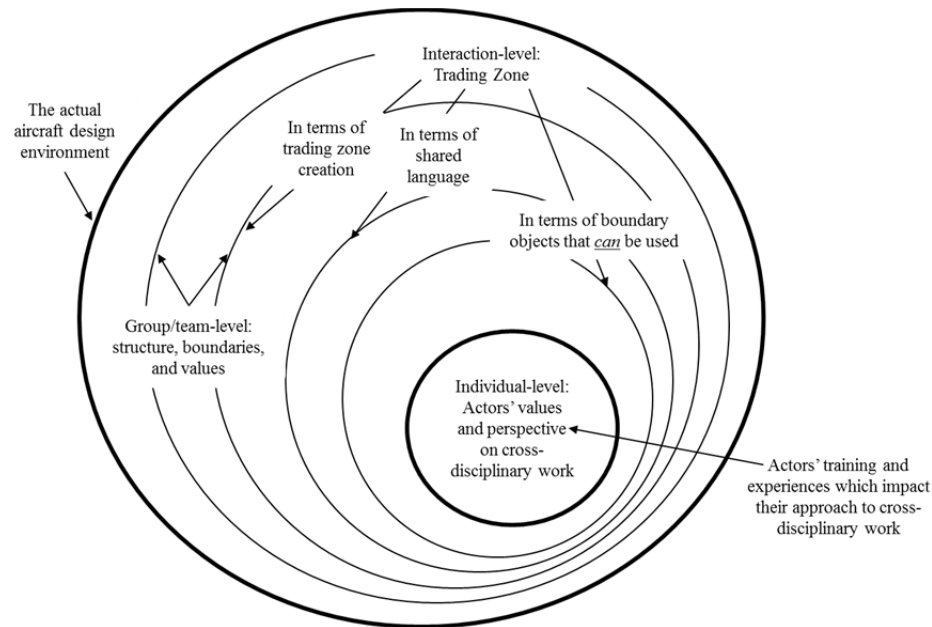


Figure 2: Levels of Analysis for Understanding Stakeholder Integration within the Aircraft Design Environment [NOTE: This representation applies the framework for analysis of work activities created by Pejtersen and Rasmussen (1997, p. 1520).]

The subsequent sections discuss each of these six conditions at the group/team-level (conditions 1 and 2), interaction-level (conditions 3 and 4), and individual-level (conditions 5 and 6). Each discussion reflects on the differences between the two cases: the PC group where the group structure and composition were found to support the integration of HF and stakeholder considerations, and groups with embedded HF specialists. Figure 3 illustrates each case, reflecting the practice at this aircraft design firm of embedding HF specialists into the different functional groups, rather than forming a separate HF group. In Case 1, the Pilot Compartment (PC) functional group has several

HF specialists and their role is recognized as being central to the purpose of the group. In Case 2, on the other hand, functional groups may have fewer HF specialists with tasks less-central to the group's purpose. Thus, the following sections explore the impact of embedding HF specialists at the group/team-level, individual-level, and interaction-level.

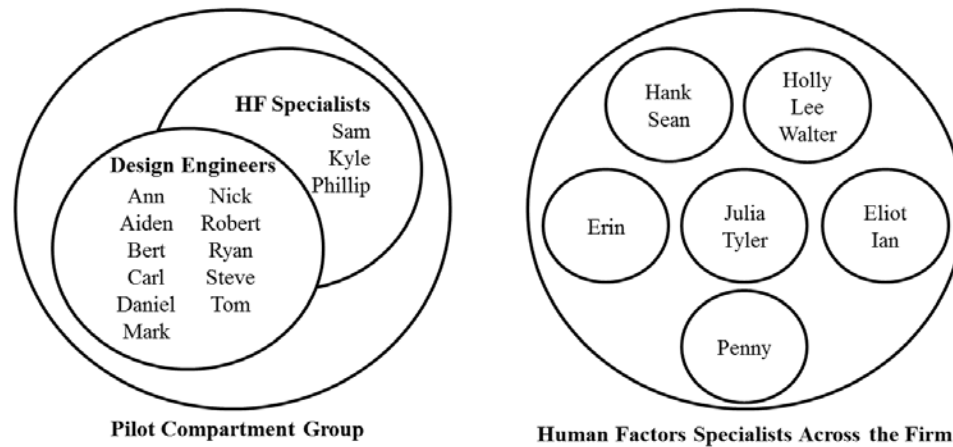


Figure 3: Functional Groups and Disciplinary Affiliations of Participants (All names have been replaced by pseudonyms.)

2.3.2 Group/Team-Level Conditions: Structure and Values

2.3.2.1 Case #1: The Pilot Compartment Group

The interviews suggest that the PC group finds embedding HF specialists is a useful team structure. Nick, a design engineer within the PC group, explained,

“The HF community [within the firm] has relied on making HF an integral part of the design process from square one. Within PC that has been a success, because HF can own part of the design with PC. In the rest of the groups, the HF community has seen varied success.”

Further proponents such as Kyle, an HF specialist, expressed that it is better for HF specialists to sit with the individuals from other disciplines to prevent the development of “too much of a barrier” and to achieve a good integrated design. For Nick, embedding HF into the different functional groups is the “only way it works.”

Of the factors contributing to this success, the structure and collective values of the functional group emerged as critical to the successful integration of stakeholder considerations into their design work. Within PC, pilot safety, satisfaction, and performance serve as common goals. Both Ryan and Tom, design engineers within PC, view the pilots as critical to their design decisions. Ryan discussed how he brings in pilots at different phases of design to gather their feedback. Tom focused on how he tries to understand pilots' knowledge about different systems: "Pilots will have been trained on other systems (i.e., it wasn't going to be possible to "untrain" the pilots), so the design would need to incorporate pilots' knowledge about the current system." The structure of the PC group also inherently values stakeholder needs. The PC group is unique in that it has a group of pilots to consult with during the design process, a Chief Pilot who represents the pilots at the design reviews, and a Pilot Operations subgroup. This structure provides for a high frequency of interactions among group members and the group's key stakeholder. Kyle, an HF specialist within the group, discussed his interactions with customers, pilots, and other groups and how he viewed the presence of the in-house pilots as a mechanism for reducing the risk of large changes late in the design process: "These individuals are in-house in PC which helps decrease the likelihood churn will happen."

Some challenges were noted, however. Aiden, for example, noted a challenge that arises because there are no HF specialists in his sub-group of the PC group: "The subject-matter-experts (SMEs) are there if you actively seek them out, but on another level, engineers won't ask if they don't know the SMEs exist or the studies exist." Phillip, an HF specialist, further discussed the existence of competition among HF specialists embedded in the same functional group and a lack of awareness of other HF individuals outside of the functional group.

2.3.2.2 Case #2 – Outside of the Pilot Compartment Group

In the other functional groups, there were some proponents of team structures that embed HF specialists. For example, Penny, an HF specialist, explained that, from her experience, the embedded solution can cause issues initially, but works well over time as team members begin to trust and respect each other.

On the other hand, about half of the HF specialists interviewed perceived that the embedded team structure creates more challenges than benefits. Hank, an HF specialist, explained how the collocation of HF specialists in the various functional groups makes the HF specialists “the minority within their groups.” Sean, an HF specialist, described his experience as “very lonely. There is no unified movement, no head, no banner carrier.” Erin, another HF specialist, expressed how HF specialists who are alone in a group are in “the wild west.” She felt that it was not enough to embed HF specialists in these groups: “There is a need for a community (‘for friends’) and like-minded co-workers who can cover each other in times of need and provide visibility of potential work within the organization.” Looking across the different functional groups, Walter, an HF specialist, commented that HF is currently integrated unevenly: “Within the PC group, HF gets lots of attention, but the rest of the vehicle is uneven at best.”

The success of the embedded team structure appears to depend on whether the groups have common goals that directly relate to particular stakeholder considerations. For many of the HF specialists in this study, the first challenge to integrating HF and stakeholder considerations into design is creating awareness within their groups about how design decisions affect the stakeholder. Eliot explained that, for areas outside of PC, those individuals with a background in aerospace and other engineering fields tend to not have been exposed to HF until they meet HF people within the organization. Hank and Sean discussed how every month they find themselves educating someone(s) about what HF is, why it is important, and how “it isn’t just common sense.”

One implication is that many design engineers can be unaware of how to design for the various stakeholders. Julia discussed how many design engineers have the perceptions that the design is fine “as long as it works for them and their experience.” She labeled this perception as the “n of 1” problem: “I am human. Therefore I understand everything about humans.” Walter and Sam, from PC, also discussed the “n of 1” problem. Ian felt that individuals without an HF background don’t appreciate some of the human performance issues: “Among some design engineers, there exists an attitude of ‘if the pilot would just do their job, they wouldn’t have made this mistake.’” Eliot described this as the result of systems-centered design: Engineers “love to know how often will a human fail. Humans aren’t like that and the certification process isn’t like that. You can’t treat a human component of a system the same as a hydraulic component.”

Julia explained that the aircraft design firm is technology-driven and “we sell to specific customers.” Most of the engineers “don’t view passengers and crew as end users.” She described that the focus is on making “beautiful vehicles” and there is a lack of focus “on people riding on them.” For the PC group, the focus on pilots is rooted in the group structure where the goals and mission of the group also focus on the pilot. In contrast, other groups may resist the integration of HF and stakeholder considerations within the design process. In some cases, there are engineers who may not see the value-added in certain design decisions that may benefit a particular stakeholder, such as a mechanic or maintenance personnel, or that may impact passenger comfort. HF specialists, according to Julia, need to ensure that “we have our story straight” and remind management that “we bring value.” She discussed how HF-related research and groups are the first to have funding cut when it comes to the budget, which she attributed to the fact that, without HF, the design groups can still pass the various design reviews. Yet, Julia noted, there may be problems two years later in manufacturing which could have been prevented if the HF specialists had been involved at the beginning of the process.

Penny, Eliot, Sean, and Hank all discussed the driving factors which HF specialists must be mindful of during the design process – weight, cost, and schedule. Ian has advocated in the past for human performance to be included among these factors, so that designers include them within important trade-offs. Yet, as Sean and Hank noted, one challenge is developing a quantitative cost value for the human performance impact of a design. Tyler emphasized that there is “not always a clear cut answer with human-related problems” due to human variability and the amount of judgment involved in resolving HF issues. Thus, developing a quantitative cost value, or simply responding to an HF-related issue, may require a significant amount of time or may rely on qualitative judgments about a given situation. Holly mentioned motivation as another important consideration: She explained how many of the engineers may not get rewarded for going the extra mile, thus, “why should they take the time to learn more about HF?”

In summary, whether created by design drivers, human variability, or a lack of a reward structure, the groups outside of PC may not have collective values that include stakeholder considerations for the reasons described here. While having HF specialists embedded in the groups was sufficient in some cases, in others the HF specialists felt isolated. Further, without stakeholders embedded into the group structure, many of these groups may remain unaware of critical stakeholder considerations.

2.3.3 Individual-Level Conditions: Perspectives on Cross-Disciplinary Work

The perspective each individual brings to cross-disciplinary work also impacts the success of the overall design team. The participants were found to possess differing perspectives about their collaborations with individuals from other disciplines. To further understand these different perspectives, the authors applied the Cross-Disciplinary Practice (CDP) framework developed by Adams and colleagues (2010) as a lens through which to examine how individual engineers within a design team experience the complexities of aerospace engineering design. The framework captures four hierarchical

categories for experiences of cross-disciplinary work: (1) *working together*, (2) *intentional learning*, (3) *strategic leadership*, and (4) *challenging and transforming practice*. The higher-number categories describe team members' experiences that are more reflective in how he or she approaches other disciplinary perspectives and more critical in how he or she views disciplinary boundaries (Adams et al., 2010). The following two sections examine each case study using this framework.

2.3.3.1 Case #1 – The Pilot Compartment Group

Within PC, Tom, Nick, Daniel and Mark (design engineers), and Sam (an HF specialist), exhibited *strategic leadership*, a category 3 perspective. Such individuals apply what they know about collaboration and communication (category 1) and their previous successes and failures (category 2) to select team members who will facilitate strong cross-disciplinary solutions, to build trust among team members from the start of the project, and to emphasize system connections during the problem formulation/definition stage (Adams et al., 2010). Adams and colleagues (2010) refer to an individual in this category as the “interface,” the “connector,” or “communication specialist” (p. 4). Tom, for example, while having no formal HF education, described consciously choosing to use what he has learned through collaboration and communication with HF specialists and through previous successes and failures when he approaches a cross-disciplinary design process. Due in part to his experiences with HF specialists, he understands the main issues enough to wear the “HF hat” when necessary. Throughout Tom’s interview, he also emphasized how you “bring people in,” not only in regards to the pilots, but also in regards to other groups, such as avionics: “Give them a say early. Right from Day 1.” He further noted that that one of the best ways to prevent late minute changes is to get all the shareholders involved, including suppliers.

Nick, like Tom, has had to wear an HF hat over his time at the company. During the interview, he described his role as serving as an “interface” between the HF

specialists and the rest of the design team. For instance, when discussing how he explains sizing to new hires, he integrated HF concepts within the sizing-related concepts in his descriptions of pilot compartment components. Nick described how “pilot tasks” are drivers for the size of the pilot compartment. Specifically, Nick explained,

“Sizing can create both limitations and opportunities for the practice of HF as part of the design process....Other than the volume necessary to enclose pilots, the size of the pilot compartment can be driven by numerous considerations, including tasks, which drive information requirements, which size the display suite.”

Tom and Nick, along with the other strategic leaders within PC, support the development of the trading zone between HF specialists and the rest of the PC group by building trust among the team members and demonstrating the importance of the connections among the disciplines.

The approach of others (specifically Kyle, an HF specialist, and Aiden, a design engineer) aligns with category 2, *intentional learners*. This approach includes a focus on social learning and on collaboration and communication (Adams et al., 2010). The overarching goal of cross-disciplinary practice for individuals in this category is for everyone to gain: the individual, the team, and the stakeholders (Adams et al., 2010). Individuals with this approach create opportunities to educate one another on the different perspectives of team members and, through this education, develop a group-wide systems perspective on the problem (Adams et al., 2010). Learning also occurs as team members develop ways to investigate the problem using multiple disciplinary perspectives and as team members reflect on successes and failures in the integration of disciplines (Adams et al., 2010). Kyle strives to understand the roles of everyone in his group and to gather knowledge about their areas. He described how, in one of his first display design projects, he would only interface with the display engineer. However, he learned that he needed to understand how the sensor worked, what data it recorded, and how that data propagated

to the display. Kyle explained that “The more you understand about the roles of everyone in your group, the better the design.” Overall, he cited standards, domain knowledge gathered from computer-based training, and people as valuable resources during the design process.

Aiden has an engineering background with no formal training in HF, but his work spans both disciplines. He learned about HF and user safety by attending meetings, reading about HF in aviation, and examining similar work in other fields. For one project, Aiden had to balance marketing requirements with pilot comfort, speed (in developing a design) and price. He administered surveys to the flight crew and researched related studies from the automotive industry and the medical field. Aiden ran tests to learn how a representative group of users would interact with the design. In addition, he constructed mock-ups and interviewed flight crew to understand complaints. Thus, even though Aiden is in a sub-group that doesn’t have any HF specialists, he has developed a process for integrating HF and stakeholder considerations into his design.

Of the remaining interview participants within the PC group (design engineers: Bert, Robert, Ryan, Ann, Carl, and Steve and HF specialist, Phillip), each described experiences which aligned with the *working together* perspective, category 1. Individuals in this category seek to develop a stronger solution through an iterative communication process of asking questions, listening, and being aware of how to communicate with individuals who have different training (Adams et al., 2010). *Working together* also describes understanding the possible contributions of different team members and learning how to move past one’s disciplinary mindset to take personal responsibility for facilitating effective collaboration (Adams et al., 2010). As one example, when Ryan, a design engineer, talked about working with other groups, he noted how he makes a point to attend meetings in those other groups. He described how it allows you to recognize the value of other groups and allows the other groups to understand your role on a given project. Ryan also discussed the importance of the face-to-face interactions in PC,

explaining how you get the answer faster by getting up and walking over to someone. Finally, Ryan suggested understanding the constraints that other individuals operate within during the design process and the overall operational infrastructure of the aircraft.

When discussing HF specifically, Robert talked about the integration of HF into design as a learning process, where designers sit in on meeting, talk to experts, and figure out what to look for and what's important. Carl, a new engineering hire, explained that he has learned about HF from feedback he received during design presentations and HF-related readings he found on his own. Overall, all of the individuals interviewed within the PC group viewed collaboration with individuals from other disciplines and groups as valuable to the overall design and as a method for reducing the risk of late and costly changes to an aircraft design.

In terms of awareness of HF, however, Ann discussed how some of her colleagues may have an "idea" about HF concepts, but may not correlate their design concerns to the domain of HF or may be unaware of the relevant HF specialists. Ann explained that it "definitely wouldn't hurt to realize that [HF] is what they are doing and [then they] would be more conscious about it." Aiden noted that there isn't an awareness of on-going HF-related studies or previous findings and recommendations, and as a result, he suggested a broader integration of HF within the organization. Daniel explained how some teams won't inquire about HF because teams don't know there is a need to do so. Later in the interview, he described a challenge for some design engineers is that they "don't know what they don't know." He also gave an example of many design engineers not being able to see beyond technical aspects of a design. Robert and Ann, for example, associated many HF concepts with "common sense" which, on one hand, may make them more likely to consider HF principles within the design process. Ann, for example, is a former pilot and she noted that her experiences as a pilot and her height have made her more considerate of HF and individual differences among pilots; note, however, this perspective could also discredit the work of HF specialists. Likewise, Bert perceived that

many HF skills could be acquired as needed, and it probably would be easier to take a systems and software engineer and teach them HF skills than to teach an HF person how to program.

Still, Daniel explained that while many engineers have not been educated in HF, the field is becoming increasingly well known. He reiterated, “We are getting better at it,” even though there are still aerospace and electrical engineers who will wonder “why you need to look at that.”

2.3.3.2 Case #2 – Outside of the Pilot Compartment Group

In all the functional groups, the use of the more reflective perspectives of cross-disciplinary work, such as *strategic leadership* and *intentional learning*, can support the integration of HF and stakeholder considerations into the design process. In the interviews, several HF specialists described the need for embedded HF specialists to adopt these perspectives. For example, Hank mentioned that HF specialists have to be in the driver’s seat and be prepared to re-educate every new manager about the importance of HF. Julia uses her own pro-active approach to get buy-in from other functional groups for her research projects. Specifically, Julia recruits representatives from other functional groups, such as Payloads or Controls, to serve as members of her research team. These representatives provide the team with knowledge from their area of expertise and serve as “connectors” between the HF research team and their functional groups. The representatives are each responsible for presenting the results of the research to their own functional group. Through this approach, Julia helps engineers without an HF background gain exposure to HF-related design considerations and facilitates the integration of HF research results into the overall design by building relationships with other functional groups. From investing time to learn more about the aircraft design industry to engaging in a pro-active approach to collaborative work, it was evident from

the interviews that the other HF specialists also strive to be intentional learners and strategic leaders.

However, not all of the engineering members of the different functional groups participate in these aspects of cross-disciplinary practice. Further, the HF specialists noted additional challenges. Walter explained that, due to the small number of HF embedded within some groups, HF lacks the apprenticeship model of training used by much of the rest of the organization. Thus, embedded HF specialists may not be receiving the necessary training and professional development to become strategic leaders or intentional learners within their groups. Hank also indicated that there are gaps in the pipeline for HF specialists: As HF specialists retire, there may be no one knowledgeable enough to replace them, which could result in the loss of critical knowledge and experience. Beyond the challenges of training new HF specialists, Penny, Tyler, and Julia all discussed how, in general, there are a small number of HF specialists within the organization. Tyler spoke optimistically that, as more HF-related issues become integrated into the design process, HF specialists would obtain a larger voice. Yet, the small number of HF specialists requires that the community determine how to sustain this larger, strategic leader, voice and increase their overall visibility, so that functional groups and design teams can effectively address both technology and stakeholder considerations.

2.3.4 Interaction-Level Conditions: Trading Zone Development

This embedding approach, in addition to its impact on team structure, also facilitates what is known in the literature as a *trading zone* to encourage ‘trades’ and integration among different disciplines (Galison, 1997). A trading zone, in this case, exists when individuals from distinct disciplines (e.g., HF) can communicate and coordinate with other designers despite differences in the norms, values, methods, and performance metrics (Galison, 1997). Galison (1997) describes it as “local coordination

despite vast global differences” (p. 783). Trading zones originated with Galison’s descriptions of interactions among subcultures of physicists and engineers (Galison, 1997) and have since been used to examine engineering teams within NASA (Kellogg et al., 2006), the development of Earth Systems Science Management (Gorman, 2004), and the evolution of coordination among diverse stakeholder groups (Jenkins, 2010). Thus, the embedded solution may serve to create trading zones within each functional group based on a merged culture of several disciplines, including HF specialists (Collins et al., 2007).

A trading zone facilitates interactions using boundary objects and a shared language in interactions between different disciplines or groups to help span knowledge boundaries and serve as a means of translation (Collins et al., 2007; Star & Griesemer, 1989). The following discussions of the two cases studies will examine the interactions within the functional groups, particularly noting the extent to which a trading zone exists and applies boundary objects and a shared language.

2.3.4.1 Case #1: The Pilot Compartment Group

The more reflective perspectives of collaboration exhibited across disciplines within the group illustrate the degree to which trading zone is being created within PC. Individuals within this functional group have developed the ability to speak a shared language among the disciplines by learning as much as they can about the other domain and seeing value in working with one another despite disciplinary differences.

For Sam and Kyle, both HF specialists, boundary objects have been a successful aspect of their work thus far: Kyle uses storyboards and prototypes to communicate with customers and pilots, while Sam uses low-fidelity prototypes and safety-incident reports. Sam discussed, for example, how he uses lower fidelity software tools to get feedback from pilots. He is able to send the files via email and run the experiments over the phone, if necessary. “If you can do a little desktop study, you can get performance data and

timing information in the course of a few days.” His most recent desktop study not only validated the organizational structure of a new design, but also gave him valuable information about a potential training impact. Through the use of boundary objects, these HF specialists were able to communicate more effectively with other design engineers and pilots about their work.

However, while the trading zone within PC is successful overall, some of the members of PC requested additional support to improve the integration of stakeholder and HF considerations into the design process. For instance, Robert asked for a solution to help engineers without a background in HF determine what requirements are necessary to satisfy HF concerns and how to implement them. Ann noted how it would be helpful to have five “whys” related to HF to prevent engineers from saying “how did we miss asking that question” or to “keep us from making small mistakes, when we could have corrected them at the start.” She noted how, without these considerations, “we end up paying more to fix it later.” Mark and Phillip, an HF specialist, both saw the need for boundary objects and, respectively, worked on a guidance framework and a checklist of HF principles. Ryan and Aiden each expressed how it would be helpful to have HF information more available, whether an overview of HF principles or a checklist of HF concepts to consider.

Thus, further challenges exist in fully creating and consistently benefiting from a trading zone. Mark discussed a lack of awareness by both HF specialists and those design engineers without an HF background about how to communicate and work with one another, suggesting the need for a more prominent shared language. Ryan discussed one of the challenges of integrating HF into a team’s collective design process is finding a concrete thing to design or consider designing. Ryan gave examples of some of the designs created from an HF standpoint that he perceived as too vague for him or another design engineer to implement. Ryan explained that “we have to write code and develop

pieces of hardware.” As a result, further development of appropriate boundary objects and a shared language may be required to support a successful trading zone.

2.3.4.2 Case #2: Outside of the Pilot Compartment Group

The interviews, as mentioned, identified cases where HF specialists are embedded within groups that, in general, have neither a group structure nor a core mission that explicitly calls out stakeholder considerations. In addition, many members in these groups do not use a more reflective approach to cross-disciplinary work. With this in mind, this section describes the boundary objects and approaches used by these HF specialists to strengthen the interactions (and the overall development of a trading zone) under these conditions. Penny explained “you need to be aware of your design” and need to know what compromises are needed. Hank agreed and recommended that HF specialists become familiar with the company, the customer, and “figure out how you want to compromise between HF principles and design.” The compromises, in this case, become how the HF specialists can trade with members of a team or a functional group during the design process.

In terms of boundary objects, Penny and Walter emphasized the importance of the business case as an abstract boundary object connecting the costs of an HF- or stakeholder-related design change to its benefits. Walter provided an example of a design solution with a long-term benefit, i.e., decrease in maintenance costs, which may not be implemented due to a short-term cost, i.e., additional pilot training. Penny noted the first questions from management are “what’s it going to cost me?” and “what’s it going to get me?” She suggested that HF specialists learn to create a business case which maps potential costs and savings to stakeholder requirements.

Requirements serve as another boundary object for engineers and HF specialists. The process of designing a complex system typically generates progressively lower-level requirements for components or aspects of a design. Penny and Sean both noted the

significance of requirements when it comes to specifically integrating stakeholder and HF considerations. Sean explained how lower level requirements may reflect trade-offs within the design and someone else, usually not an HF specialist, has the authority to remove or change them. “We need to stay constantly involved....If the requirements don’t say it, your statement has no teeth.” Walter further noted that requirements serve as an agreed-upon definition of what the system is and how good it has to be once completed.

Over the course of the interviews, the HF specialists discussed many potential or attempted boundary objects as integration solutions, including introductory HF courses, pilot or mechanics training, new design metrics or design drivers, guidebooks, and process documents. Many of the attempted solutions were not sustainable or disappeared over time. Nonetheless, two of the HF specialists, Holly and Lee, noted the reinstatement of a multidisciplinary training course for their group, which introduces all of the disciplines within the group including human performance. In addition, prior to one of the more recent aircraft designs, checklists were developed by a group of HF specialists. One purpose of these checklists was to raise awareness and encourage design engineers to inquire about how their design affected the different stakeholders. Hank explained how the checklists were given to the heads of the different functional groups, and each group was provided with an HF specialist point-of-contact to consult in case of any problems or questions. Julia described these checklists as a way of “alerting” those engineers without an HF background to specific HF principles and design considerations, while Tyler mentioned them as a way for HF specialists to “build something into the design process.” Overall, Julia, Hank, and Tyler spoke highly of the checklists and mentioned that in the future they should be incorporated earlier in the design process.

Beyond the use of boundary objects, the development of a shared language aids in the evolution of a trading zone into the merged culture, as discussed earlier in the results section. Design engineers, as described by Ian and Sean, work in a world of

technical constraints, requirements, metrics, and numbers. Walter explained how HF specialists need to translate their work into mission goals and demonstrate how their proposed design solution improves the overall system. Hank and Sean agreed and added that HF specialists need to consider how their work relates to the technical performance requirements and metrics for the project. Sean also emphasized the critical need for quantitative HF-related requirements against which the design can be verified. Eliot noted many new HF specialists believe that people should accept their wisdom that HF is good, but the HF specialists who succeed in the organization translate theory to real world concepts and applications when interacting with other designers, pilots, and management. He provided one example about presenting a situation awareness framework at a meeting: Eliot started with “there is a widely accepted definition for situation awareness” but, instead of diving into the theory, he showed how the definition fit the circumstances and what it meant for the vehicle. Eliot advised that new HF specialists should let actual results or operational experience speak for the HF discipline rather than laboratory studies.

Even with a shared language and boundary objects, a trading zone still requires people from both disciplines to take part in the trade. The HF specialists, Lee, Walter, Eliot, and Julia, discussed the importance of getting buy-in from several stakeholders at different phases of the design process. Eliot noted that the conceptual phase of design requires buy-in from many groups, including senior subject-matter experts, the user community, pilots, training personnel and members of the safety group. Julia mentioned that she works with design teams to understand their schedules and when certain information will be necessary. Many times she has to be her own advocate and “push her way in.” Further, the HF specialists highlighted the need to “bring people in.” To improve the potential for later buy-in, Eliot recommended getting early involvement from a subset of user populations, while Julia utilized her diverse, multidisciplinary research team to gather information from different groups. Walter warned about the increased risk

for late and costly changes to design caused by excluding or overlooking key stakeholders. Penny suggested bringing users to weekly design meetings, as there is a benefit to having “everyone in the room together,” even though the process might take longer. She also noted that HF specialists need to be “jacks of all trades, masters of none.” Penny views the role of the HF specialist as bringing people together to distinguish what is necessary to know from what is unnecessary to know. Thus, from Penny’s perspectives, it is the HF specialists who develop the trading zone by bringing people together and helping them, through boundary objects and a shared language, to achieve a well-designed end product.

2.4 Summary

This chapter examined the conditions that enhance or inhibit the integration of human factors and stakeholder considerations in the practice of aircraft design. A case study of design engineers and human factors specialists at an aircraft design firm explored the integration of stakeholder considerations through the perspectives of individuals within functional groups and on aircraft design teams. Twenty-five interviews were conducted and the accounts from those interviews were analyzed using qualitative data analysis techniques. The results demonstrated differences between the integration of human factors and stakeholder considerations within the Pilot Compartment group and the other functional groups. These differences were expressed through six conditions related to group structure and goals, individuals’ expertise and approaches to cross-disciplinary work, and shared language and boundary objects to support exchange among disciplines. The conditions reflect existing literature about the integration of stakeholder considerations into design and cross-disciplinary collaborations, while adding to the current understanding of methods for improving that integration. The resulting implications, which are discussed in detail in Chapter 8, reflect how, at least at one large aircraft design firm, design problems and teams can be structured to support stakeholder

integration and design team members can be educated to effectively engage in cross-disciplinary work. As an example, Table 3 illustrates the educational intervention specifications derived from these results, which are aimed at supporting student understanding of and ability to integrate stakeholder considerations into the aerospace vehicle design process (see Chapter 4).

Given the importance of stakeholder considerations to an aircraft’s overall mission and life cycle performance, it is necessary to look beyond the development of a single new guidebook or training course or the addition of one new person on a team. This work highlights how the individuals, their tools, their language, their functional groups, and the connections among them are critical to furthering the integration of these considerations across design firms and the aircraft design industry.

Table 3: Educational Intervention Specifications Based on Case Study Findings

#	Educational Intervention Specifications	Derived from:
ID1	Shall create a stakeholder-centric learning environment with activities structured to encourage students to appropriately value stakeholder considerations in their design activities.	Industry Case Study <i>Group/Team-level</i>
ID2	Shall introduce a language and vocabulary for discussing stakeholder considerations and the role of stakeholders in design.	Industry Case Study <i>Interaction-level</i>
ID3	Shall provide students with tools and resources that can bridge their current approach to aircraft design with an approach that incorporates stakeholder considerations explicitly.	Industry Case Study <i>Interaction-level</i>
ID4	Shall provide students with experiences and training in cross-disciplinary problem-solving	Industry Case Study <i>Individual-level</i>
ID5	Shall demonstrate to students the value of cross-disciplinary work and examinations of designs from multiple perspectives .	Industry Case Study <i>Individual-level</i>

CHAPTER 3 - Integration of Stakeholder Considerations in Aircraft Design Curricula and by Aerospace Engineering Students

Chapter 2 investigated the integration of stakeholder considerations in the aircraft design industry. This chapter examines how the undergraduate aerospace engineering design curricula and aerospace engineering senior design students to answer the following research questions:

- RQ2: To what extent and how does the aerospace engineering design curricula take into account stakeholder considerations?
- RQ3: To what extent do aerospace engineering students understand and take into consideration the effects of design decisions on stakeholders?
 - RQ3.1: What prior knowledge do engineering students bring to a senior design course about design and the role of stakeholder considerations within the design process?
 - RQ3.2. What factors contribute to students' perceptions of the design process and role of stakeholders in aircraft design?

This chapter begins with a review of perspectives on stakeholders within other related design fields (e.g., mechanical engineering, software development, and architecture) to compare with the aerospace vehicle design curricula. This review is followed by an exploration of aerospace engineering design curricula, highlighting the design paradigm common to aerospace programs and examples of stakeholder considerations presented within some aerospace design courses. Then, the particular context of this study, an aircraft design senior capstone course, is described and compared with other aircraft design capstone courses across the country. To capture the understanding and perceptions of incoming aerospace engineering senior design students, data collection and analysis methods included an in-class evaluation and in-class

observations. Following a description of these methods, the prior knowledge of these students and the factors affecting that prior knowledge are presented.

By providing a clear illustration of how stakeholders are considered within aerospace engineering design education, this chapter

- (1) distinguishes the role of stakeholders within aerospace vehicle design curricula, as compared with other design disciplines,
- (2) defines a baseline for students' understanding about design and the role of stakeholders in the design process based only on their previous academic experiences, and
- (3) identifies factors which impact students' perceptions of the importance of and methods to integrate stakeholder considerations in design when they start a senior design capstone course.

3.1 Stakeholders in Design Curricula

3.1.1 Perspectives from Other Fields

User. Client. Customer. Stakeholder. There are a variety of words used to describe individuals who are impacted by the design of a system and/or whose needs impact the design of a system. Buede's system's engineering textbook (Buede, 2000) describes multiple categories of stakeholders where each stakeholder has a different perspective on the system and its requirements. Yet, it is clear from Visser's work that "some views of design focus strongly on people, others do not" (Visser, 2006, p. 31). Some of these different perspectives on stakeholders may be more important to the designer than others; some designers may not find any of these perspectives important. This section outlines three different representations of "stakeholder" that appear in design-related courses outside of aerospace engineering.

3.1.1.1 Stakeholders as Clients/Customers

In the product development world, an understanding of customer needs can be critical to the successful launch of a new product. As a result, the education of students in this area begins with an examination of customer and market needs. Otto and Wood (2001) and Pugh (1991) emphasize the importance of market and competitor analysis to determine consumer acceptance of a design (Otto & Wood, 2001; Pugh, 1991). “Many new technology-development initiatives are undertaken with no basis for market acceptance other than management belief” (Otto & Wood, 2001, p. 112). To prevent this approach to design, Ulrich and Eppinger (2011), authors of the textbook *Product Design and Development*, describe the first activity within the design process as the identification of customer needs with weightings of importance. Later in the process, the authors incorporate customer feedback into the prototyping and testing activities to ensure that customer needs have been met by the product (Ulrich & Eppinger, 2011). These processes, however, only briefly discuss stakeholders outside of the customer and client, and society as a whole is only considered from the perspective of the environmental impacts of the product (Ulrich & Eppinger, 2011).

3.1.1.2 Stakeholders as End-Users

In the fields of human computer interaction, software, and product design education, faculty also focus on the concepts of user research and user testing (Widmann et al., 2011). At Illinois Institute of Technology, the first phase of the design process introduced to students is research to know the user and know the context (Dubberly, 2004). Within Carnegie Mellon’s School of Design, user testing is taught as a form of evaluation within the design process (Dubberly, 2004). Buchanan, a faculty member in the program, emphasizes three lines of reasoning which he states are necessary in the design of products: (1) “the ideas of designers and manufacturers about their products,” (2) “the internal operation logic” of the products, and (3) “the desire and ability of human

beings to use the products in everyday life” (Buchanan, 1992, p. 20). This model relates product experience with the various elements of the product and focuses on the community of users and the expectation of how the user will interact with the product (Buchanan, 1992). These concepts reinforce the emphasis on not only the importance of considering users as stakeholders, but also incorporating their perspectives into the overall design of the product.

3.1.1.3 Stakeholders at the Center

In the education community, human-centered design approaches have begun to materialize in a variety of courses, including environmental design, service learning and electrical and computer engineering courses (Dubberly, 2004; Jordan & Lande, 2012; Oehlberg et al., 2011; Titus et al., 2011). Additionally, engineering education researchers have begun to examine student experiences, assessment methods, and interventions related to human-centered design (Melton et al., 2010; Newman et al., 2004; Oehlberg & Agogino, 2011; Zoltowski, 2010). At the University of Colorado, Boulder, faculty members in the environmental design group describe the role of an environmental designer as solving human environmental problems (Dubberly, 2004). Their corresponding design process considers the human as a critical component in developing the problem statement, completing background research, developing hypotheses to the “environmental malfunction,” and ultimately evaluating the solution (Dubberly, 2004, p. 37).

In a product development course at the University of California-Berkeley, the faculty has combined human-centered design and product development approaches (Newman et al., 2004; Oehlberg & Agogino, 2011; Oehlberg et al., 2011). The perspective of the stakeholder at the center of the design process provides students with an opportunity to view all of the critical stakeholders in a project, including the customer, the end user, and the non-user. The students revisit the stakeholder requirements and

limitations throughout the design process and participate in requirement definition and user testing (Oehlberg et al., 2011; Titus et al., 2011). An evaluation of students within this product development course specifically demonstrated that “students developed a strong belief that ‘good design dictates that technology can and should serve all members of the potential user population’” (Dym et al., 2005, p. 108). Most importantly, the use of a human centered design process in this course has helped broaden students’ perspectives of design, better preparing them to collaborate with other engineers and designers during their careers (Oehlberg & Agogino, 2011).

3.1.2 Aerospace Engineering Design Curricula

In the final year of most undergraduate aerospace engineering curriculum, students participate in a senior design capstone course focused on aircraft, spacecraft, or another technical component (e.g., engine design). For many students, this course is their first opportunity to experience design. While courses vary from program to program, these design experiences generally include a large-scale team project accompanied by instruction on the aerospace design process. Within this structure, the most variability among the courses and programs results from different required texts and different requirements for the large-scale project. To understand the perspectives of stakeholders used within aerospace design curricula, the subsequent sections describe a review of (1) publicly-available aerospace engineering senior design capstone course syllabi from several universities, including MIT, Georgia Tech, Virginia Tech, University of Texas-Austin, Iowa State University, and Purdue University, and (2) published works from aerospace and engineering education conferences and relevant journals.

3.1.2.1 Isolated Courses

Both MIT’s Department of Aeronautics and Astronautics and Georgia Tech’s School of Aerospace Engineering offer elective courses covering some aspects of human

performance within an aerospace system. These courses introduce students to factors which affect a human's performance, such as perception, attention, decision-making, and ergonomic considerations (Pritchett, 2011; Young & Yeh, 2001). Students also begin to examine the effect of interactions between the human and automation on total system performance (Pritchett, 2011; Young & Yeh, 2001). These issues can be critical in the design of the cockpit and its displays, alerting systems, and other systems requiring human monitoring or action. These courses, however, are taught in isolation from the required courses in aerospace engineering fundamentals and technology design. Thus, they may be insufficient in training students to integrate these topics into the design of aerospace systems in their capstone courses and, in the future, as professional engineers (Peet & Mulder, 2004). At the time of a student's senior design capstone course, he or she may be unaware of the connections between their human performance-related elective and aerospace design.

Courses in Systems Engineering concepts have also been incorporated into some aerospace curricula (Guerra et al., 2011; Marais, 2009). These courses focus on introducing students to the processes and tools used in the systems engineering process prior to their capstone courses. Specifically, students are required to consider the needs and wants of the customer and the necessary trade studies for balancing those requirements with cost, risk, and performance requirements (Guerra et al., 2011; Marais, 2009). While capturing the view of stakeholders as customers and introducing students to a broader perspective of design, these isolated courses are also not integrated into the capstone design experience. As a result, students may not see how and when to apply these concepts. In addition, the view of stakeholders as customers and clients is just one perspective. Students are not necessarily asked to consider the importance of the operational context and other critical stakeholders such as pilots, ground personnel, and non-users.

3.1.2.2 Design Textbooks

The review of aerospace design syllabi demonstrated how many instructors require one of four classic texts: *Aircraft Design* by Roskam (1990), *Fundamentals of Aircraft and Airship Design* by Nicolai and Carichner (2010), *Aircraft Design – A Conceptual Approach* by Raymer (2006), and *Space Mission Analysis and Design* by Wertz and Larson (1999). These texts place a large emphasis on aircraft and spacecraft sizing, in which competing quantitative performance metrics, such as weight, cost and fuel economy, are traded in pursuit of an ‘optimal’ design concept (Nicolai & Carichner, 2010; Raymer, 2006; Roskam, 1990; Wertz & Larson, 1999). Where stakeholder-related metrics are included, they represent stakeholders via surrogates, allowing for quantitative approximations of different stakeholder characteristics to be traded with measures such as weight and cost. For example, when examining life-cycle costs of an aircraft, the experiences of maintainers and manufacturers are incorporated using metrics such as “maintenance-man-hours per flying hour” and “tooling hours” respectively (Nicolai & Carichner, 2010). Pilot limitations and needs are captured in trade studies regarding fuselage and cabin size along with metrics such as “training costs” and “training hours” (Nicolai & Carichner, 2010). When sizing a spacecraft, astronauts are represented by their body weight and the weight of their required food rations and equipment (Wertz & Larson, 1999). Some stakeholder concerns may also be presented as constraints on the design, such as the physiological effects of space travel and human safety in the spacecraft design text (Wertz & Larson, 1999) and aircraft handling qualities in the aircraft design texts (Nicolai & Carichner, 2010; Raymer, 2006; Roskam, 1990).

The core components of the Roskam design process, which also align at a high-level with the design processes in Raymer and in Nicolai and Carichner, are shown in Table 4: (1) mission specification, (2) preliminary sizing, (3) configuration layout determination, (4) subsystem sizing, and (5) additional analyses (e.g., cost and stability).

Additionally, students may need to integrate new technologies into their designs; this integration is explicitly incorporated into the design processes from Raymer and from Nicolai and Carichner. Each of these components of the design process are detailed in the following sections.

Table 4: Stakeholder Integration in the Aircraft Design Process

Design Phase	Roskam (1990)	Raymer (2006, 4th edition)	Nicolai & Carichner (2010)	Stakeholder Integration
Mission Specifications/ Design Requirements	Specifications derived from market analysis or needs identification and initial trade studies. (Part I)	Requirements established by prospective customer or market analysis. (Ch. 2)	Customer is at the start of the design process and design guidelines are negotiated with the customer based on initial specifications and concept of operations. (Ch. 1)	Specifications for student project could consider stakeholders but are very dependent on instructor or other sources of project specifications and whether students have access to the customer.
Preliminary Sizing	Based on historical data, mission requirements (e.g., payload, mission profile), and regulatory requirements. (Part I)	Based on historical data, mission requirements, and regulatory requirements. (Ch. 3)	Based on historical data and mission requirements. (Ch. 5)	Dependent on whether stakeholder requirements will affect sizing.
Configuration Layout Determination	The layout is based on the requirements, a review of previous aircraft configurations (historical perspective) and additional justifications (e.g., trade studies). (Part II)	The layout is based on the requirements, previous designs (if applicable), and technology availability. (Ch. 2)	The layout is based on the requirements, new technologies, and the Measures of Merit for the design. (Ch. 1)	Dependent on the mission specifications and selection of appropriate Measures of Merit or trade study parameters to account for stakeholder considerations.
Sizing the Aircraft	Step-by-step process for fuselage/cockpit design and sizing includes anthropometric information, regulatory data, and historical data. Process includes how to determine pilot visibility angle. (Parts II & III)	Process for cockpit and fuselage sizing from anthropometric information, regulatory data, and historical data. Process includes how to determine the pilot visibility angle. (Ch. 9)	Process for designing fuselage and cockpit from anthropometric information, regulatory data, and historical data. (Ch. 8)	Quantitative measures for size and weight only. Impact of sizing on passengers, flight crew, and maintenance not discussed at this point.
Refinement of the Design	Cost-estimation methods for RDT&E, manufacturing, acquisition, operation & support costs. Includes economic perspectives of multiple stakeholders and impact of design phases on LCC costs (Part VIII); Stability and control analyses include a ride & comfort characteristics analysis and analysis of flying qualities (Part VII); Subsystems layout design process includes cockpit instrumentation and escape system design (Part IV); Recommends high level overview of what to consider when designing for survivability. (Part IV)	Cost-estimation methods for RDT&E, production, operations and maintenance costs. Presents airliner & military economic perspectives (Ch. 18); Stability and control analyses include connections to handling qualities and Cooper-Harper Ratings. (Ch. 26)	Methodologies for RDT&E, acquisition, operations & maintenance costs. Discusses impact of design engineer on LCC costs, along with ways to reduce production costs. (Ch. 24); Describes ways to design for survivability based on two quantitative parameters. (Ch. 12) Design process explicitly includes a step to “share trade results with customer.” (Ch. 1)	Stakeholders considered via surrogates within cost-analysis. Discussions of stakeholder perspectives of cost. Stability and control analyses address pilot concerns with handling qualities. Survivability discussed at high level or quantitatively. Sharing trade results with customer is dependent on student access to customer.
Technology Integration	Not explicitly discussed.	Technology availability discussed, in terms of impact on aircraft design schedule. (Ch. 2)	Technology trades are completed later in the design process to select technologies to invest in based on the potential benefits and risks. (Ch. 25)	Explicit connection to stakeholders not included in these discussions, especially in regards to the impact of technologies on, for example, aircraft maintenance and pilot training.

3.1.2.2.1 Mission Specifications

The design processes of each text begin with mission specifications or design requirements. The specifications may include parameters critical to the customer and other stakeholders, such as cost, schedule, and mission requirements. Roskam describes how specifications are derived from market analysis or need identification and the results of initial design and trade studies (Roskam, 1990). A market analysis is based on what a design company researches in terms of public's needs or wants in the near future, and a need identification can be based on a customer request or an operational requirement from the military (Nicolai & Carichner, 2010; Raymer, 2006; Roskam, 1990). Throughout all three of the design processes, the authors return to the mission specifications (or the associated design guidelines) to improve their understanding of the customer and to verify that the requirements have been met by the design. With this in mind, there exists the potential for requirements that are stakeholder-centric, especially if based on a market analysis or a stakeholder-driven mission. In Nicolai and Carichner, the authors also present the concept of operations document that defines how the aircraft will be deployed, operated, maintained, and supported (Nicolai & Carichner, 2010). This document serves as another mechanism for introducing stakeholder considerations into the design. One difference among the texts is the explicit inclusion of the customer by Nicolai and Carichner. Specifically, the customer is placed at the start of the design process and the process includes a step for *negotiating with customer* (Nicolai & Carichner, 2010). This step follows an evaluation of the requirements and concept of operations by the design engineers. Overall, the mission specifications and concept of operations in all of the design processes introduce the potential for stakeholder considerations to be included; however, it is dependent on the developers of the specifications and the concept of operations.

3.1.2.2.2 Preliminary Sizing

In the three design processes, the initial sizing is based on a historical data and the payload requirements for the mission (Nicolai & Carichner, 2010; Raymer, 2006; Roskam, 1990). The incorporation of stakeholder requirements in this step (and the sizing steps in the other design processes) is contingent on the requirements (for instance, if there is a rate of climb or lengthy loiter requirement due to the mission needs of the military aircraft) and regulatory requirements associated with the design.

3.1.2.2.3 Configuration Layout Determination

Once the initial weight sizing is complete, the preliminary configuration layout is selected and other key components (i.e., propulsion system, tail, landing gear, wing, and fuselage) are integrated. Roskam recommends a historical perspective that reviews diverse established aircraft configurations to determine the configuration layout and justify design decisions (Roskam, 1990). If allowable, he promotes having multiple sub-teams completing trade studies of each candidate configuration to inform the designs (Roskam, 1990). Thus, stakeholder considerations can be integrated into these phases of the design process through the trade studies and justification for the configuration layout decisions. One form of justification discussed in Nicolai and Carichner is the use of Measures of Merit (MOMs or Figures of Merit) assessing the customer's desires for the design (Nicolai & Carichner, 2010). Raymer discusses the critical nature of these MOMs with a military aircraft design example of (Raymer, 2006). With military aircraft, cost MOMs can be the driving factors in the design, even at the expense of performance and range (Raymer, 2006).

As with the previous components of the design process, the integration of stakeholders in the configuration layout determination is dependent on the mission requirements. While trade study parameters and MOMs can contribute, students must rely on the instructors and mission requirements to determine the MOMs or other

important parameters to consider, particularly in courses where there is limited or no access to the customer or other stakeholders.

3.1.2.2.4 Sizing the Aircraft

With the preliminary sizing complete and a configuration selected, the different components of the aircraft, such as the wing and fuselage, are sized. For the fuselage, each of the textbooks presents anthropometric information guiding the design of the cockpit to fit most pilots and incorporate information to help design the interior of the fuselage (whether for a commercial or military application) (Nicolai & Carichner, 2010; Raymer, 2006; Roskam, 1990). Roskam provides a step-by-step process for determining seat pitch, aisle and galley size, and seating provisions for cabin crew, and both Raymer and Roskam present a process for determining the pilot visibility (or over-nose viewing) angle (Raymer, 2006; Roskam, 1990). In general, each of the design processes presents quantitative criteria for the fuselage and cockpit size. However, the sizing criteria here often consider only basic aspects of pilot and passenger physical fit and do not address other stakeholders, such as maintenance personnel or airport operators.

3.1.2.2.5 Refinement of the Design

In the refinement of the preliminary configuration, subsystems are further developed and additional analyses are completed, including, but not limited to, cost assessments and stability and control analysis. Depending upon the project requirements, a preliminary structural layout may need to be developed. Nicolai and Carichner (2010) provide structural design rules of thumb which explicitly connect the impact of load paths with manufacturing and assembly. In addition, the authors recommend considering subsystem requirements at this early stage, such as location of doors and windows on the aircraft.

All three design processes include cost analyses and each textbook presents methods for estimating Research, Development, Test, & Evaluation (RDT&E),

production, acquisition, operating and support costs. In Roskam and in Nicolai and Carichner, the authors emphasize “the conceptual and preliminary design phases are responsible for locking in most of the life cycle cost of an airplane” (pg. 11, part VIII) (Roskam, 1990). Roskam introduces the different economic perspectives of an airplane manufacturer, a commercial airplane operator, a personal or corporate airplane operator, a government or military airplane operator, and a consumer and/or taxpayer. With these perspectives, he isolates which cost terms are the most critical to a given stakeholder. He also discusses the difference between social, psychological, and environmental costs which can be related to the economic, noise, and environmental impacts on users and non-users. When discussing operations and maintenance costs, Nicolai and Carichner acknowledge the impact of the human element on these costs, as direct personnel costs account for more than one-third of the total costs (Nicolai & Carichner, 2010). The authors also discuss various approaches to reduce production and maintenance costs. In general, the cost-estimating methods presented within these design processes consider stakeholders via surrogates such as “maintenance-man-hours per flying hour” and “tooling hours,” and highlight different stakeholder perspectives on the cost and price of an airplane and how to reduce costs.

This design stage must also consider the aircraft’s stability and control characteristics of their design. Beyond the static and dynamic stability analyses assessing pilot concerns with handling qualities, Roskam also provides guidelines and a methodology for determining the ride and comfort characteristics of the aircraft. He describes them as important for the following two reasons:

“(1) if the ride and comfort level are not acceptable to passengers, they are unlikely to return for another flight. This hurts the commercial viability of the airplane!

(2) If the ride and comfort are not acceptable to the crew members, they may not be able to carry out their duties thus negatively affected safety and/or mission effectiveness” (Roskam, 1990, pg. 104, part VII).

Roskam also notes which factors impact ride and comfort to support student understanding of the explicit connection between their design decisions and the experience of the passengers and crew members. Finally, he points out “the airplane sizing process described in Part I results in a choice of wing-loading without even considering ride characteristics” (Roskam, 1990, pg. 105, part VII). Thus, the students must be prepared to iterate through the design process if they need to make changes to the design due to this ride and comfort characteristics analysis. Overall, the inclusion of this methodology demonstrates evidence of more subjective, qualitative stakeholder considerations (i.e., passenger comfort, crew member comfort) being included within the process in a quantitative manner.

The concept of Design for Survivability is included in Roskam and in Nicolai and Carichner. In Roskam, the author recommends that design engineers regularly read accident reports and provides high-level overview of things to consider when designing for survivability within military and commercial aircraft (Roskam, 1990). Nicolai and Carichner, on the other hand, decompose survivability into two quantifiable parameters, susceptibility and vulnerability, to facilitate the use of these parameters in trade studies or other analyses (Nicolai & Carichner, 2010). With Design for Survivability, the stakeholders are considered directly, but from two different perspectives, one quantitative and one more qualitative and high-level.

Finally, as with the beginning of the design process, Nicolai and Carichner explicitly incorporate the customer into the later stages of the design process through the *share trade results with customer* step (Nicolai & Carichner, 2010). This explicit inclusion of stakeholders would again depend on access to a customer (or someone acting as a customer).

3.1.2.2.6 *Technology Integration*

With technology integration, the relationship to the stakeholder requirements appears in two areas: the types of technologies considered and the discussion of the benefits and consequences of using those particular technologies. Roskam does not explicitly discuss technology integration from this perspective. Within Raymer's design process, it is necessary to consider what technologies will be incorporated based on whether they are currently available or will be available in the future (Raymer, 2006). Like Raymer, Nicolai and Carichner connect the technologies with the design guidelines at the beginning of the design process. Later in the Nicolai and Carichner's design process, technology trades are used to select technologies and the benefits and potential consequences of those technologies (Nicolai & Carichner, 2010). None of the texts explicitly discusses how stakeholders can be considered through the integration of current and new technologies into the design or how stakeholders can be impacted by the integration of these technologies (e.g., maintainability, pilot training).

3.1.2.2.7 *Summary*

In general, all of the texts utilize surrogates to represent stakeholder requirements in trade studies and the sizing process, such as "maintenance-man-hours per flying hour" and "training costs" (Nicolai & Carichner, 2010). However, there is little explicit information about where or how to incorporate stakeholder requirements and concerns which are novel or qualitative in nature and thus difficult to quantify. In addition, the texts do not describe how to consider the purpose of the design as viewed by the stakeholders in the operational context. Thus, stakeholders may be seen as the source of constraints and costs, limiting the design's ability to achieve the maximum technical performance highlighted in the text. While within some aerospace design curricula instructors have created opportunities for students to interact with specific clients and/or end-users, such as the case of human-powered aircraft (Kamp, 2012; Mason, 2010;

Phillips et al., 2010; Smith et al., 2011; Young et al., 2003; Young et al., 2005), there still exists a need to support student understanding of a broad range of stakeholders.

3.1.2.3 Design Project

An important aspect of the capstone course is the design project. In contrast to product design or other capstone courses, the scope and complexity of aerospace vehicles imposes constraints on the extent to which students can experience the entire design cycle within a year or semester long course. Each year NASA and the American Institute of Aeronautics and Astronautics (AIAA), along with industry and other organizations, publish design competitions for undergraduates to design an assortment of aerospace systems. Some competitions, such as Design-Build-Fly (DBF), provide students with opportunities to explore the effects of their design on manufacturing, maintaining or operating a system (AIAA, 2012b). The testing phases of the design process provide students with critical hands-on experiences, which can emphasize the importance of understanding the operational context of the design and the stakeholders who are affected by the design (Young et al., 2003).

Other competitions or industry projects are exclusively focused on the conceptual and preliminary phases of design (AIAA, 2012c; NASA, 2012). These design tasks include unmanned aircraft systems, air racers, or deep space habitation modules (AIAA, 2012c; NASA, 2012). In the design of such aerospace vehicle systems, the user testing of the entire vehicle system required to assess handling qualities, passenger comfort, or crew systems (e.g., displays, alerting systems) is extremely expensive and time-consuming. Paradoxically, in industry, this cost motivates the better inclusion of stakeholder concerns early in design to prevent expensive testing-redesign cycles later in the design process. However, the cost of even applying high fidelity simulators or full size mock-ups of the aircraft to demonstrate and test the design typically prevents testing directly in senior design experiences.

Each design competition or industry project provides students with a Request for Proposals (RFP) that dictates the requirements for the aerospace system they will design. Some past design competitions and projects have included an array of human-related design requirements, from cargo handling system with time constraints for loading and unloading to the environmental effect of the reduction of the number of pilots in the cockpit (AIAA, 2012c; NASA, 2011; NASA, 2012).

As noted previously, in many product design capstone courses, students have the opportunity to work with companies and clients closely throughout the design process (Newman et al., 2004; Todd & Magleby, 2004) and need to consider the marketing aspects of the design and understand the importance of satisfying the customer (Marais, 2009). The importance of the customer can also be implicit in aerospace capstone courses where the students are responding to an RFP or similar document (Hall & Cummings, 2007). Yet, the extent to which the students must account for the stakeholder is highly dependent on the wording of the RFP. Depending on the RFP requirements, students may choose not to prioritize stakeholder-related requirements or may not make critical connections between these requirements and the overall performance of the vehicle system. In addition, without certain systems engineering tools it may be challenging for students to determine how diverse considerations can be prioritized or integrated. Thus, the RFP may need to explicitly state stakeholder considerations as critical requirements to the design, or otherwise frame the projects so that students must take into account stakeholder and context concerns to accomplish the performance and technical feasibility goals of the project (Eccles & Wigfield, 2002).

Some aerospace programs have organized actual customers for their capstone projects (Kamp, 2012; Smith et al., 2011). In these cases, as with the product design courses, students interact with the customers throughout the capstone experience (Davis et al., 2006; Jordan & Lande, 2012; Newman et al., 2004; Zoltowski et al., 2010). A recent study in design education emphasized that immersive experiences with clients or

customers provide students with an opportunity to experience the importance of considering context and stakeholders in design, counter-balancing a tendency by students who lack design experience with customer/user interactions to view design as entirely technology-centered (Zoltowski, 2010).

3.1.3 Summary

In response to Research Question # 2, stakeholder and operational context considerations can be incorporated into an aerospace curriculum through a variety of mechanisms. Within an isolated course, students can begin to perceive the critical nature of humans in aerospace design. However, if it is not integrated into the capstone design curriculum, an isolated course may not be sufficient for providing students with a broader perspective of design. The classical aerospace design textbooks represent stakeholder needs and limitations via surrogates, addressing a limited set of concerns. While some of the texts discuss passenger safety, stakeholder- and context-related regulations, and handling qualities, the emphasis is pre-dominantly on the technology and technical components of the aerospace vehicle. Finally, the large-scale design project may incorporate human- or context-related requirements, but, unless satisfying these requirements is clearly part of an assessment rubric or graded assignment, students may assume these requirements are not important. Additionally, in a course focused on conceptual design, students may not see what effects will later manifest in manufacturing, maintenance, and operational performance.

Overall, within aerospace design education, stakeholder considerations are commonly limited to the viewpoint of stakeholders as surrogates. Thus, there is a high reliance on quantitative measures for stakeholder needs and limitations. Many students, then, are not introduced to stakeholder considerations that are challenging to quantify, such as metrics for maintainer's performance or pilot fatigue. Aerospace capstone courses with a broader focus on design provide students opportunities to consider the customer

and the end-user more directly, but cannot consider other stakeholders due to the constraints on the design project (e.g., conceptual design-focused capstones, inability to perform field testing). This differs from courses in service learning or product design that require students to focus on usability from the start.

3.2 Aerospace Engineering Students' Perceptions of Stakeholders in Design

The aim of these methods is to respond to Research Questions #3.1 and #3.2 by (1) capturing the prior knowledge engineering students bring to a senior design capstone course about design and the role of stakeholder considerations within the design process and (2) identifying factors which contribute to students' prior knowledge.

3.2.1 Background

Throughout this study, students' integration of stakeholder considerations and students' design understanding were examined in parallel. The application of this strategy to the methods is based on the results of a phenomenographic study of the ways students experience human-centered design. In that study, students were found to experience human-centered design in two dimensions (Zoltowski, 2010). The first dimension describes how the students experience the design process and integration, ranging from a non-existent process to an empathic process. The second dimension describes how students understand the user, ranging from lack of appreciation of the user to including the user in the design process (Zoltowski, 2010). The outcome space (see Figure 4) illustrates the breadth of the two dimensions and the intersections students' experiences were found to inhabit (Zoltowski, 2010). This doctoral work also sought to categorize students' prior knowledge, students' experiences, and students' integration of stakeholder considerations into this two dimensional space.

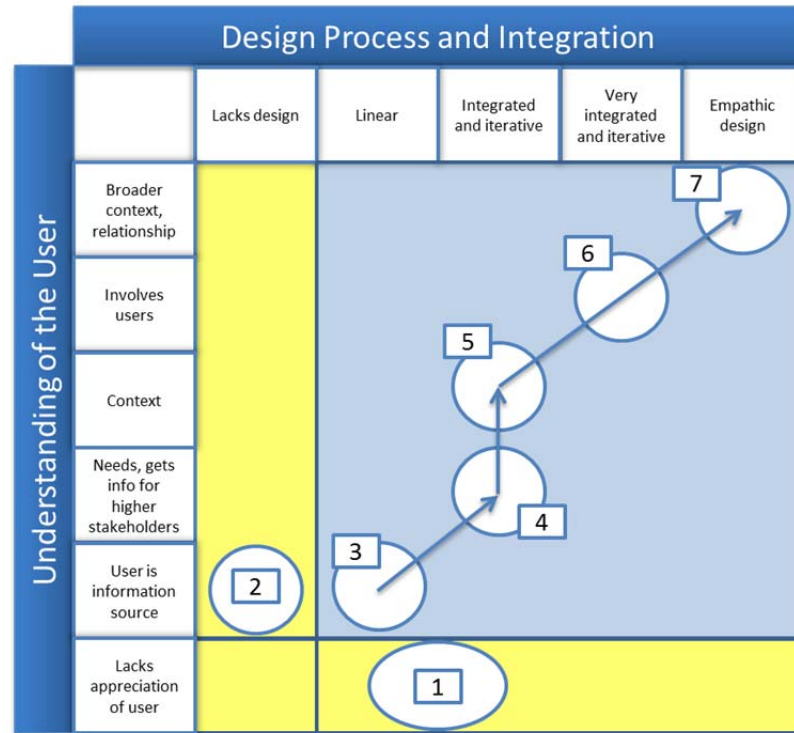


Figure 4: Students' Ways of Experiencing Human-Centered Design Outcome Space (Zoltowski, 2010)

3.2.2 Context of the Study: Site and Sample

The research site for this study is a large public, research institution with an undergraduate enrollment of over 10,000 students. Prior to senior design, aerospace engineering students must complete coursework focused in six technical areas: aerodynamics, propulsion, structures and materials, structural dynamics and aeroelasticity, fluid mechanics and control, and performance and design. A human performance elective course is offered by the department, but only on alternating years. When the students reach senior design, they are also typically enrolled concurrently in departmental laboratory courses.

The aircraft design sequence is comprised of two courses, one in the fall and one in the spring. Their purpose, as defined in the syllabus, is to give students experience with a conceptual design methodology that integrates methods for vehicle sizing,

configuration selection and layout determination, propulsion system design, vehicle performance analysis, and cost analysis. During the fall semester, lectures introduce students to the design process and methods such as weight sizing and constraint sizing. The instructors follow Roskam's aircraft design methodology and require the students to purchase the associated textbooks. For the fall semester, students complete four individual projects and a final design report which account for 90% of their grade. The final 10% is comprised of in-class quizzes about aircraft and aircraft design. The projects provide students with practice completing all of the components of the design process individually. In the spring semester, students separate into teams to develop a solution to a Request-for-Proposals (RFP) selected by the course instructors. For the 2012-2013 academic year, the instructors selected the AIAA Undergraduate Aircraft Design Competition RFP. In both the spring and fall semesters, the course is taught using lecture sessions (two 50 minute lectures each week) and lab sessions (2 three hour lab sessions each week). During the spring semester, the instructors use the lab sessions for 30 minute design team meetings with the individual teams.

Considering the conceptual design courses discussed earlier in the chapter, the type of project, the scope of the courses, and the design textbook required are very similar to the senior design capstone courses at other programs. Generally, 20 universities have competed each year in the NASA design competition (Barnstorff, 2011) and 20 in the AIAA aircraft design competition (Andino, 2013). In terms of scope, the courses at this research site do not include an outside customer or client that the students interact with regularly. Instead, the instructors serve as mentors throughout the spring semester and provide the perspective of a customer as necessary. In addition, as a conceptual design course, the scope of the course requires the students to complete the preliminary design phase, but does not require any prototyping or testing of a physical design. By examining courses similar to those conducted within other universities, it is possible to

discuss the generalizability of these results and the unique aspects of the learning environment in this study.

3.2.3 Methods

3.2.3.1 In-Class Evaluation

To explore students' current level of understanding about design and the role of stakeholders in the design process, an evaluation was developed based on instruments previously used in the literature and an additional instrument designed for this study. The evaluation includes two scales, a design conceptions task, and a two-part scenario-based design task (see Appendix C.1). Students' design understanding and self-efficacy are examined using a Design Self-Efficacy Scale (Carberry et al., 2010) and a widely-used Design Ranking Test (Adams & Fralick, 2010). Students' competence and perceptions about context are evaluated using a Contextual Competence Scale (Ro et al., 2012) and an open-ended follow-up question. Finally, students' understanding and perceptions of the role of stakeholders in design are explored using a two-part submarine design task, designed particularly for this doctoral study. The evaluation was piloted and refined in the summer of 2012 using aerospace engineering graduate students. The final evaluation design is detailed in the subsequent sections and in Table 5. Demographic information along with information about students' experiences in other design courses, internships, or co-ops was solicited at the end of the survey. The evaluation was administered at the start of the senior aircraft design capstone course via pencil and paper during the Week 1 lab sessions. Approval of the evaluation was received from the institution's IRB prior to its distribution (see Appendix A.2 and Appendix A.3).

Table 5: Overview of In-Class Evaluation Components

Section of Evaluation	Purpose	Associated Reference	# of Questions	Format of Responses
Design Self-Efficacy Scale	Assess students' confidence in their design skills	(Carberry et al., 2010)	9	Quantitative Ratings
Design Ranking Test	Explore students' perceptions about the design process (Responses can be compared with similar studies.)	(Adams & Fralick, 2010)	3	Ranked List of Items, Open-Ended Response
Contextual Competence Scale	Assess students' belief in their ability to integrate contextual considerations into a design solution	(Ro et al., 2012)	4	Quantitative Ratings
Context in Design Question	Explore students' perspective of how context can affect fixed wing design		1	Open-Ended Response
Submarine Design Scenario	Capture students' connections between design requirements and the stakeholders who can be affected by the design		2	Open-Ended Responses

3.2.3.2 Students' Design Understanding and Self-Efficacy

3.2.3.2.1 *Design-Self Efficacy Instrument*

The first scale assessed students' design self-efficacy (Carberry et al., 2010). Self-efficacy describes the belief an individual has in his or her own ability to perform a particular activity or activities successfully (Tsenn et al., 2013). Students rate their confidence in their ability to perform nine tasks within the design process (e.g., *develop design solutions*), each on a scale ranging from 0, "cannot do at all," to 100, "highly certain can do" (see Table 6). Appendix C.3 details the reliability and validity checks for this particular scale.

Table 6: Design Self-Efficacy Items

#	Item
1	Conduct engineering design
2	Identify a design need
3	Research a design need
4	Develop design solutions
5	Select the best possible design
6	Construct a prototype
7	Evaluate and test a design
8	Communicate a design
9	Redesign

The scale provides an opportunity to examine students' design self-efficacy as a single score. Specifically, items 2-8 are reduced to a single design self-efficacy item through the use of factor analysis. The correlations among the items are examined and used to develop a factor score, which is a single regressed continuous variable scaled to the original 0 to 100 point range, that illustrates students' design self-efficacy (Distefano et al., 2009; Starkweather, 2012).

3.2.3.2.2 Design Ranking Test

The Design Ranking Test focuses on the conceptual models students have developed about design by asking students to select the six most important and the six least important design activities from a provided list of activities (Bailey et al., 2012) (see Figure 5). The purpose of this widely used test was to gain an understanding of students' perceptions about the design process and to compare the results with similar studies (Adams & Fralick, 2010; Atman et al., 2008; Butler, 2012; Hohner et al., 2012; Mosborg et al., 2005; Oehlberg & Agogino, 2011). The activities provided to students use terminology viewed as accessible to students; however, the results may be limited based on students' interpretation of this terminology. This evaluation also utilized a variation of the test that also prompted students to explain why they chose one of the highest and the lowest ranked aspects (Adams & Fralick, 2010).

Abstracting	Identifying constraints	Seeking information
Brainstorming	Imagining	Sketching
Building	Iterating	Synthesizing
Communicating	Making decisions	Testing
Decomposing	Making trade-offs	Understanding the problem
Evaluating	Modeling	Using creativity
Generating alternatives	Planning	Visualizing
Goal setting	Prototyping	

Figure 5: Design Ranking Test - List of Design Activities

Descriptive statistics were used to evaluate which design activities are considered the most important and least important to the students. Kendall's Tau, a non-parametric

rank correlation statistic, was used to compare this student population to senior aircraft design students at Virginia Tech and professional aerospace engineers (Butler et al., 2012). The Kendall's Tau statistic is used when comparing ranked scores, many of which may have the same rank (Field, 2012). The design activities were ranked according to the number of students or professionals within a given population who selected that activity as most important and then a second ranking was created for the least important activities. A weak correlation among the populations was defined as one with a Kendall's Tau of 0.2, while a moderate correlation had a Kendall's Tau of 0.5 (Butler et al., 2012). Correlation values larger than 0.7 were defined as strong correlations among the populations (Butler et al., 2012). The results of this test were also compared qualitatively to other studies where the Design Ranking test was used.

3.2.3.3 Students' Competence and Perceptions about Context

The second scale captured information about the students' contextual competence or the "ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions" (Ro et al., 2012, p. 1). This four-item scale requested that students indicate their knowledge or ability on a five point scale ("Little or none" to "Very high") as it related to the integration of contextual considerations within the design process. Again, this scale can be reduced to a single score of contextual competence through factor analysis and transformed back to the original 1 to 5 point scale. As with the design self-efficacy scale, analysis was necessary to examine the reliability and validity of the contextual competence scale for this context (see Appendix C.3). Overall, the reliability, factor, and correlation analyses illustrate the validity of the items in this scale, allowing the resulting factor scores to be used with confidence in the remainder of the analysis.

A qualitative follow-up question, after the second scale, asked students to consider how context affects fixed wing design. Specifically, students were asked to

describe how “the ability to recognize how different contexts could change a solution” might relate to fixed wing aircraft design. To analyze students’ responses to this open-ended question, students’ responses were transcribed and thematic analysis was applied to the 70 open-ended question responses (10 students left this question blank) (Miles & Huberman, 1994). Two researchers read and reread through the first half of the responses (in opposite orders) and classified the responses based on emerging patterns within the data. The researchers met to discuss the patterns and develop series of categories (a.k.a. a coding scheme) capable of describing the major themes found within the responses. The resulting four themes were used by one researcher to code the remaining responses. Two categories were added to the scheme based on the ABET criteria and relevant literature on contextual competence (Ro et al., 2012), specifically scope of influence and types of considerations (i.e., historical, social, economic, environmental, political, cultural, ethical, stakeholder-related). Two rounds of peer debriefing were used to establish trustworthiness and decrease researcher bias with the coding scheme. During the first peer debriefing session, categories were modified to capture emerging trends in the data. In the second peer debriefing session, twenty percent of the responses (n = 24) were discussed in depth by the two researchers to confirm the findings of the analysis. Following this session, the trends within the data were examined by looking at both the frequency of certain categories as well as the nature of the categories themselves. Statistical analysis was used to determine if there were any relationships between students’ previous experiences or gender and students’ responses.

3.2.3.4 Stakeholders in Design

The final portion of the evaluation presented students with the following scenario:
For this problem, imagine you are an employee at AeroAquatics, Inc, a submarine design firm. Based on a recent design challenge, upper management has tasked you with

heading up the conceptual design of a new personal submarine. The submarine will be used by researchers (and other customers) to perform solo deep dives in the ocean.

The purpose of the scenario-based design task was to capture students' connections between design requirements and the stakeholders who can be affected by the design (e.g., operators, maintainers, users, non-users, etc.). In addition, the task provided information about students' understanding of requirements and cross-disciplinary projects at the start of their senior design capstone experience. Previously, human-centered design tasks have been used to assess students' conceptions of human-centered design, but the tasks documented in the literature are intended to be performed in a team (Melton et al., 2010).

To evaluate individual students' understanding, this evaluation asked students to select the necessary expertise and disciplines to design a personal submarine from a predefined list:

Your first task is to put together a team to begin the design process. Please select a team of 6 individuals from the list below and briefly explain why you chose each individual.

The students were then asked to list the high-level requirements for this submarine design:

Prior to the first team meeting, upper management asked you to prepare a list of requirements for the project. Please list the requirements you would bring to the meeting.

The fluid dynamic qualities of a submarine aligned with the aerospace backgrounds of the students and the necessity to include life-support and control systems for the operator of the submarine allowed for potential human-related requirements.

Students' responses were transcribed with care to reproduce students' responses as handwritten. To analyze the data, a coding scheme was developed based on the coding scheme used to evaluate solutions to the Midwest Floods Problem, a well-known design task (Kilgore et al., 2007). The purpose of this scheme was to categorize the reasons for selecting certain team members for the submarine design and the types of requirements

the students included. Once the scheme was adapted for the submarine design scenario, it was tested using the results of the evaluation pilot study and reviewed by subject-matter experts. The resulting scheme was comprised of a frame of reference dimension, which aligns closely with the frame of reference dimension from Kilgore and colleagues work (2007) and a design consideration dimension, which is similar to the physical locations dimension used within Kilgore and colleagues (2007) (see Table 7 and Table 8). The final coding scheme is included in Appendix C.2. For any portion of a student's response which could not be categorized using these categories, the portion was placed in the "No Code" category; typically, these discussions were irrelevant to the submarine scenario.

Table 7: Frame of Reference Categories

Frame of Reference	Description
Technical	Technical or engineering vocabulary, design issues, decisions about having the submarine
Logistical	Cost, funding, construction process, maintainability issues, resources needed
Natural	Water, topography, animals, plants, weather, weather predications, damage caused by sub on environment
Social	People, safety, concerning people, towns, living areas, fields of engineering and education

Table 8: Design Consideration Categories

Design Considerations	Description
Submarine	The submarine itself, but specifically the non-user focused systems, the technology which could be used, and the locations where the submarine might operate
Surroundings	The environment surrounding the submarine, which includes aquatic life, the ocean ecosystem, etc.
Stakeholders	These focus on the various stakeholders, ranging from the design of the submarine controls (operator) to market research (potential customer) to considerations affecting maintainers and competitors.

Two researchers each coded 10 of the responses to acclimate themselves to the coding scheme. To assess the variability among the two researchers, interrater reliability was calculated using Cohen's Kappa for both the frames of reference and the design considerations (Kilgore et al., 2007). For this round of coding, Kappa was 0.66 for the frames of reference and 0.765 for the design considerations, where an acceptable Cohen's

Kappa is defined as 0.5 (Multon, 2010). The team met to resolve differences in the coding choices and modify the coding scheme as necessary. Following this meeting, one researcher coded all of the responses and the second researcher coded 20 randomly selected responses (which did not include the first 10). Interrater reliability was again calculated for those 20. For the frames of reference, Cohen's Kappa was 0.726 and for design considerations, Kappa was 0.835. These values represent substantial agreement for both coding dimensions, and as a result, the team then met only to discuss differences in coding and resolve those differences to consensus.

Visual representations were used to examine the distribution of the discussions within students' responses. Descriptive statistics were also used to more closely examine the distribution of disciplines students selected for their teams and the diversity of the topics included in their responses. To analyze the diversity of each team the students selected, a scoring rubric was adapted from Richter and colleagues' (2009) study of student perspectives of interdisciplinary collaborations. Based on the coding scheme, team members could be classified as one of four combinations of design considerations and frame of references: (1) *submarine and technical*, (2) *submarine and logistical*, (3) *surroundings and logistical*, and (4) *stakeholder and logistical*. If students included team members from all four categories, they received a score of four. A score of three represented selecting members from three of the four categories and the scores continued in that fashion.

To further examine the breadth of discussions within students' responses, the categories were grouped based on their focus on design details, context, and stakeholders (see Figure 6). For example, if all of the discussions within the responses were classified as *submarine*, *technical* and *submarine*, *logistical* categories, the response was considered to describe a technology-focused vehicle. Finally, to determine the effects of the demographic variables, the students' previous experiences, the design self-efficacy

scores, and the contextual competence scores on the students’ response to the submarine scenario, multiple regression analysis was used.

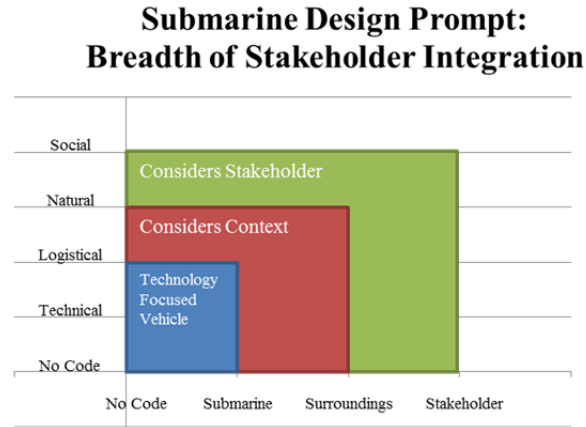


Figure 6: Categories for Analyzing Breadth of Discussion within Submarine Design Scenario

3.2.3.5 In-Class Observations and Document Analysis

To better understand the context of the course, observations were conducted during the first week of the course and the documents used during class (i.e., lecture slides) were examined. Approval from the institution’s IRB was received and student consent was sought prior to beginning classroom observations and document analysis (see Appendix A.2). The documents and observations were analyzed qualitatively and compared with the results of the evaluation to isolate potential areas of the learning experiences and environment that could impact the students’ design understanding and their understanding of the role of stakeholders in the design process. Peer debriefing was used to decrease researcher bias and establish trustworthiness (TheNguyen, 2008).

3.2.4 Results

Of the 83 students who filled out the evaluation as a requirement for their participation grade within the course, 80 consented to participate in this research study. The sample was comprised of 8 women (~10%) and 5 international students (~6.3%).

Thirty students (~38%) noted having completed a design course at another point in their college curriculum and 52 students (65%) described having industry experience, either through a co-op or internship. Finally, in the prior academic year, 50 of the students (~63.3%) had taken in a problem-based learning course within the department.

3.2.4.1 Students' Understanding and Perceptions

2.4.1.1.1 *Students' Design Understanding and Self-Efficacy*

For the design self-efficacy scale, missing data was resolved by replacing the two missing responses with the mean value for that particular survey item.

Aircraft design students reported the highest self-efficacy for problem-scoping and communication activities on a scale ranging from 0 to 100: *researching a design need*, *communicating a design*, and *identifying a design need* (see Table 9). The students reported the lowest level of self-efficacy for *constructing a prototype*. The resulting factor scores illustrate students' perceptions about their overall design skills (Mean: 68.33, SD: 12.90) (see Figure 7). The histogram indicates students are fairly confident in their abilities to design, with the highest frequency of scores between 70 and 80. However, only a few students reported extremely high levels of confidence in their design skills: only ten students had scores above 80.

Table 9: Description of Raw Scores of the Design Self-Efficacy Items [NOTE: Confidence levels were rated from 0 - "Cannot do at all" to 50 - "Moderately" to 100 - "highly certain can do"]

#	Item	Min	Max	Median
3	Research a design need	30	100	80
8	Communicate a design	20	100	70
2	Identify a design need	30	100	70
9	Redesign	30	100	70
4	Develop design solutions	10	100	70
7	Evaluate and test a design	10	100	70
5	Select the best possible design	10	100	70
6	Construct a prototype	0	100	60

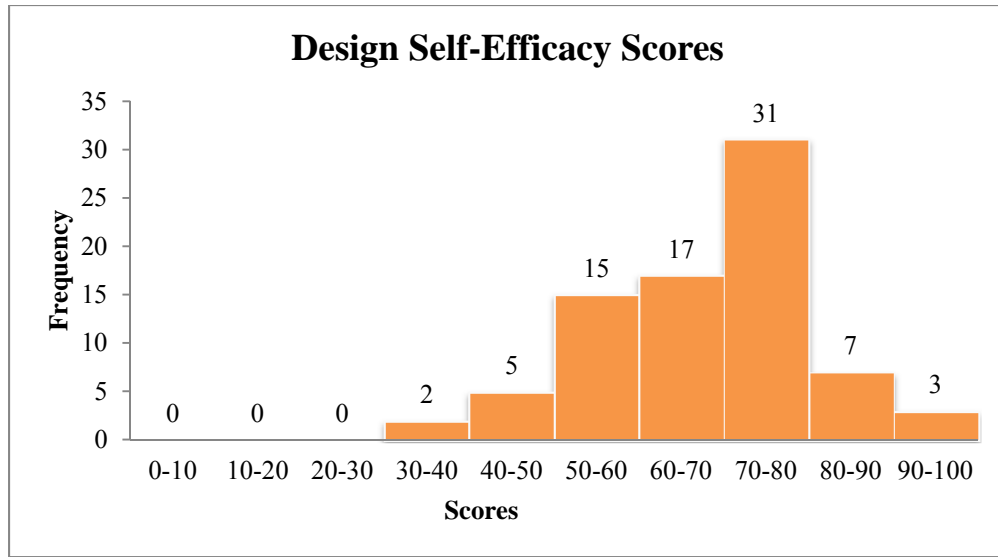


Figure 7: Histogram of Design Self-Efficacy Factor Scores

The Design Ranking Test has been used in many studies of engineering design education (see Table 10). The aircraft design students in this study responded consistently with those of students and professional engineers in other studies. The most important design activities were related to problem-scoping (e.g., *identifying constraints* and *understanding the problem*) and *communicating* (see Figure 8). The least important design activities included *decomposing*, *abstracting*, and *building*, which is consistent with the viewpoints of the professional engineers in the study by Mosburg and colleagues (2005).

Table 10: Selected Results of Design Ranking Test within Engineering Design Education

Citation	Use of Design Ranking Test	Sample	Major Findings
Mosborg, Adams, Kim, Atman, Turns, and Cardella 2005	Ranking of 6 most and 6 least important of the 23 design activities	19 Professional Engineers (no aerospace engineers in sample)	<ul style="list-style-type: none"> • Most important design activities were <i>problem scoping</i> and <i>communicating</i> activities. • The least important included <i>decomposing</i>, <i>building</i>, <i>abstracting</i>, and <i>synthesizing</i>.
Atman, Yasuhara, Adams, Barker, Turns, and Rhone 2008	Ranking of 6 most and 6 least important of the 23 design activities	89 engineering students surveyed in the 1 st and 4 th years of college. 19 Professional Engineers (no aerospace engineers in sample)	<ul style="list-style-type: none"> • Students' rankings became more aligned with those of the professional engineers by their 4th year of college. • Most important design activities were <i>problem scoping</i> and <i>communicating</i> activities.
Adams and Fralick 2010	Ranking of 6 most and 6 least important of the 23 design activities with qualitative follow-up questions	Pre- and post-tests of first year engineering students	<ul style="list-style-type: none"> • Post-test responses align with findings from Atman, et al. (2008) and Mosborg, et al. (2005). • Iteration and generating alternatives became significantly more important between the pre and the post tests
Oehlberg and Agogino 2011	Ranking of 6 most and 6 least important of the 23 design activities	Pre- and post-tests of mechanical engineering students in upper-division human-centered design course	<ul style="list-style-type: none"> • Most important design activities included <i>understanding the problem</i> and <i>communicating</i>, but also <i>prototyping</i> and <i>brainstorming</i>.
Hohner, Daly, Wegner, Lee, and Goldstein 2012	Ranking of 6 most and 6 least important of the 23 design activities	Pre- and post-tests of first year engineering students	<ul style="list-style-type: none"> • Most important design activities included <i>understanding the problem</i>, <i>testing</i>, <i>prototyping</i>, <i>communicating</i>, <i>brainstorming</i> and <i>building</i>. • Most significant change came from the increase in the importance of <i>iteration</i> over the course of their first year.
Butler 2012	Ranking of 6 most and 6 least important of the 23 design activities	Pre- and post-tests of 53 senior aerospace engineering students 20 Professional Aerospace Engineers	<ul style="list-style-type: none"> • Students' rankings became more aligned with those of the professional engineers over the course of senior design. • Professional engineering findings consistent with Mosborg, et al. (2005) except for "<i>making trade-offs</i>," which was considered one of the most important design activities.

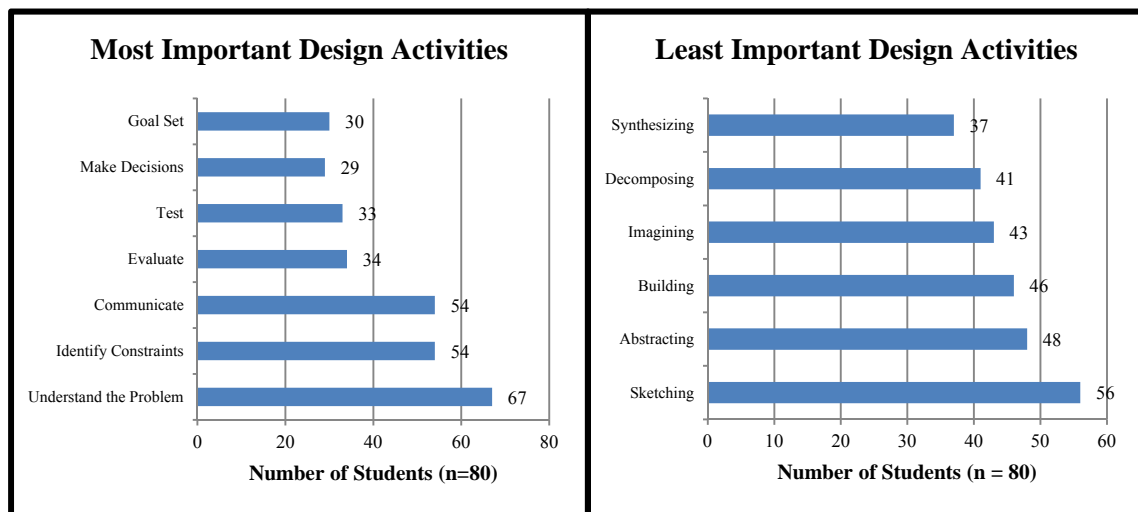


Figure 8: Students' Perceptions of the Most and Least Important Design Activities in this Study

To more closely examine the similarities among the aerospace engineering populations, Kendall's Tau rank statistic was used to compare the students in this study to the aerospace engineering population directly (see Table 11). A weak correlation among the populations was defined as one with a Kendall's Tau of 0.2, while a moderate correlation had a Kendall's Tau of 0.5 (Butler et al., 2012). A correlation value larger than 0.7 illustrated a strong correlation among the populations (Butler et al., 2012). All of the correlations were found to be statistically significant. For the most important design activities, the ranks of the students in this study were moderately correlated with the rankings provided by the AE professionals, $\tau = .467$, $p < .01$, and strongly correlated with the VT students, $\tau = .781$, $p < .001$. Figure 9 illustrates the most important design activities within each of the populations. It should be noted that the biggest difference among the populations is the classification of *making trade-offs*. Over 70% of the AE professionals sampled viewed *making trade-offs* as one of the most important design activities, while less than 40% of both student groups included *making trade-offs* on their lists.

Table 11: Kendall's Tau Rank Comparison Values among Populations (p-values are included in parenthesis) Results for AE Professionals and VT students from Butler (2012)

	Survey Sampling	Professional/ Study Students	Professional/ VT students	Study Students/ VT students
Most Important Activities	Pre-Test	.467 (.003)	.433 (.005)	.781 (.000)
Least Important Activities	Pre-Test	.603 (.000)	.560 (.000)	.788 (.000)

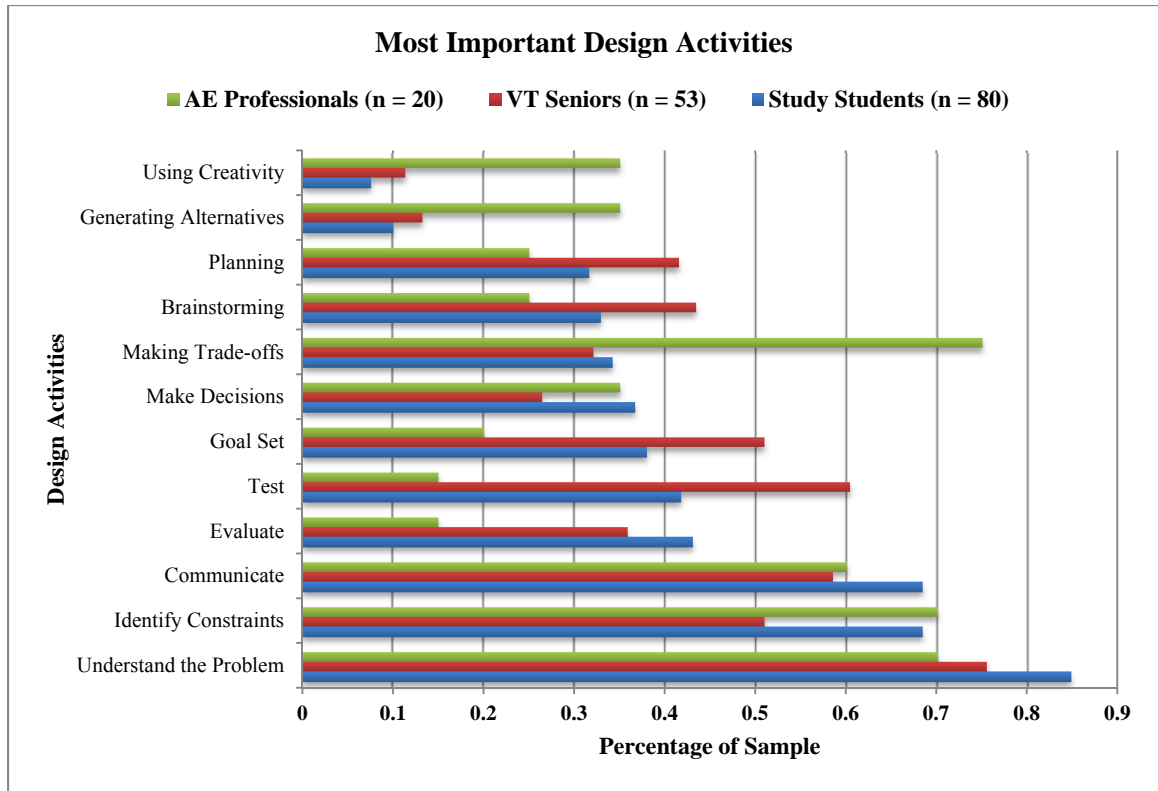


Figure 9: Most Important Design Activities for Aerospace Engineering Students and Professionals

With the least important design activities, the ranks of the students in this study were found to have a moderate to strong correlation with the rankings of the AE professionals, $\tau = .603$, $p < .001$ and a strong correlation with the rankings of the VT students, $\tau = .788$, $p < .001$. When comparing the choices of each population, it is interesting to note how few (less than 10%) of the professionals listed *iterating* as one of the least important design activities, but over 30% of the student populations included it as one of the least important (see Figure 10).

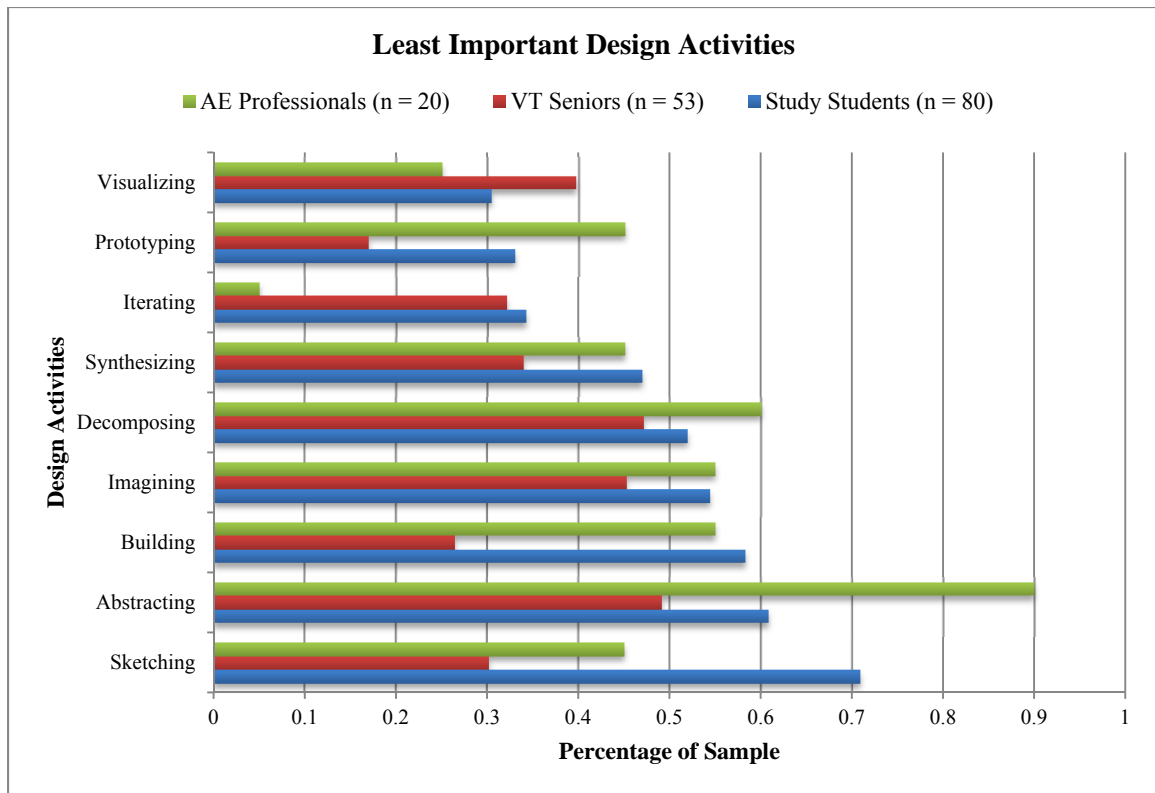


Figure 10: Least Important Design Activities for Aerospace Engineering Students and Professionals

Thus, the design understanding of the students in this study appears consistent with aircraft design students from other aerospace engineering departments. *Iteration* is viewed by 34% of the students in this study as one of the least important design activities, which is consistent with the pre-tests in related studies. *Making trade-offs* is not one of the six most important design activities for either student sample. Yet, *making trade-offs* is the most important design activity as selected by the AE professionals. *Understanding the problem* resulted as the most important design activity for more than eighty percent of the students. This phase of the design process is also the phase that students in this study report the highest level of self-efficacy. This pattern also emerged for other problem-scoping and communication activities.

3.2.4.1.1 Students' Competence and Perceptions about Context

Overall, students reported an adequate level of knowledge or ability as it relates to the role of context within engineering design, with mean values for all four items around

a 3 (see Table 12). The rating scale for these items went from 1 (little or no knowledge/ability) to 5 (very high knowledge/ability) with a 3 representing “adequate” knowledge or ability. The *ability to recognize how different contexts can change a solution* was associated with the highest level of ability by the students. The factor score for contextual competence reiterates students’ perceptions that they have an adequate level of contextual competence, with a few students reporting a much lower level and many students reporting between an adequate and a high level of competence. (Mean: 3.187, SD: 0.563) (see Figure 11).

Table 12: Description of Raw Scores of Contextual Competence Items

#	Item	Min	Max	Median
1	Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem.	1	5	3
2	Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	2	5	3
3	Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	1	5	3
4	Ability to recognize how different contexts can change a solution	1	5	3

Contextual Competence Scores

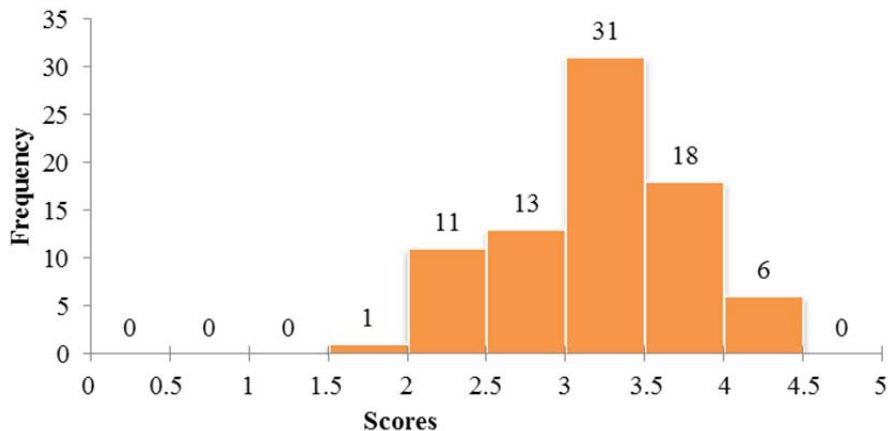


Figure 11: Histogram of Contextual Competence Factor Scores

By asking students to consider different contexts, it was possible to categorize students' understanding of the effect of context on design and their perceptions of its importance. Specific quotes are attributed to pseudonyms to protect confidentiality in the student's responses. Within their responses, most students provided examples of how context can affect design and many mentioned how it affected the design. A few students noted potential solutions that could incorporate the contextual factor discussed.

These responses could be further categorized to showcase whether students had a microscopic, or local, perspective on design or a macroscopic, or global, perspective. Overall, a higher percentage of students (60%) discussed the impact of changing contexts from a microscopic or local perspective about the design and the impact of context, as opposed to a global perspective (see Table 13). A local perspective was defined as "design in isolation." The discussions with a local scope focused on the impacts of context on the designer, their design firm, and/or their customers (or how the designer, design firm or customer impact the design). Adam, for example, explained that "one context might include the mission for your aircraft. Different mission types (reconnaissance, air-to-ground, air-to-air, transport, etc.) would definitely have an influence on your design." Discussions with a global scope incorporated issues related to the aircraft operating environment, noise, pollution, stakeholders (besides the customer), the market, or regulatory groups. For instance, Natalie noted how,

"Economic constraints are always a huge factor when it comes to design. I think an interesting problem right now is also fuel usage and a need for alternative sources. Intellectual property issues may also play a factor when considering how large corporations go about designing and executing new aircraft."

Adrien considered the impact of material choices for an aircraft and different economies. "Location of primary assembly – most corporate subsystems are manufactured in Asia – jobs can be effected in the us by choosing composite wing spars for instance."

Table 13: Frequency of Different Scopes of Influence within Students' Responses

Design Scope of Influence		
	Count	%
Local	42	60.0%
Global	25	35.7%
Neither	3	4.3%
Total Sample	70	100%

Thirty-three of the students (48%) discussed various types of contextual considerations, including cultural, political, and social (see Table 14). The most common types discussed were economic and environmental considerations. This result is consistent with studies of students' conceptual understanding of sustainability considerations (which include context and stakeholder considerations) (Watson et al., 2013). Finally, just over 30% of the students who responded to the question discussed stakeholders or stakeholder-related considerations (see Table 15). Of those 22 students, the most common stakeholders discussed were customers (81%).

Table 14: Frequency of Different Types of Contextual Considerations in Students' Responses

Types of Contextual Considerations		
	Count	%
Economic	15	21.4%
Environmental	14	20.0%
Political	11	15.7%
Cultural	3	4.3%
Social	3	4.3%
Ethical	2	2.9%
Historical	1	1.4%
Total Sample	70	

Table 15: Frequency of Different Stakeholder-Related Discussions within Students' Responses

Stakeholder-related Considerations		
	Count	%
Stakeholders	22	31.4%
Sample	70	
By Stakeholder Type		
	Count	%
Customer	18	81.8%
Countries/Societies	2	9.1%
User	2	9.1%
Manufacturers/Corporations	1	4.5%
Pilot	1	4.5%
Sample	22	

3.2.4.1.2 Stakeholders in Design

When asked to select members of a submarine design team, the majority of students included an aerospace engineer on their team (76.3%) (see Table 16). Almost half (46.3%) of the students selected a participatory design team by adding a user or customer to their team.

Table 16: Most Commonly Selected Disciplines for the Submarine Design Team

Team Members	Count	%
Aerospace Engineer	61	76.3%
Mechanical Engineer	55	68.8%
Electrical Engineer	53	66.3%
Materials Science Engineer	48	60.0%
Systems Engineer	47	58.8%
Project Manager	35	43.8%
User	29	36.3%
Financial Analyst	24	30.0%
Customer	10	12.5%
Total Sample	80	
Participatory Design	Count	%
User or Customer	37	46.3%
Total Sample	80	

Most of the teams included members from three or more sectors (78%) (see Table 17). Thus, each of the teams included at least one team member focused on context or stakeholders.

Table 17: Diversity of Disciplines within the Submarine Design Teams

Score Frequency	Count	%
1 Category Only	1	1%
2 Categories	17	21%
3 Categories	44	55%
All 4 Categories	18	23%
Total Sample	80	

When discussing the design considerations for the submarine, the students included considerations ranging from the vehicle performance to the context to the stakeholder (see Table 18). The majority of considerations, however, were focused on the vehicle design and performance, disconnected from the contextual and stakeholder considerations (69%). Twenty-one percent of the considerations incorporated stakeholder-related concerns and systems, while only eleven percent related to the operational context of the design. Nonetheless, a majority of the students included at least one consideration from all three of these areas (61%), demonstrating some understanding of the impact of context and stakeholders on design. Figure 12 illustrates the aggregation of all of the students' considerations.

Table 18: Breadth of Design Discussion Results by Category and Across Categories

Design Analysis	%	Design Analysis	Count	%
Design Details for Technology Focused Vehicle	67%	1 Category Only	5	6%
Considers Context	11%	2 Categories	26	33%
Considers Stakeholders	21%	All 3 Categories	49	61%
Total Sample	100%	Total Sample	80	100%

Submarine Design Scenario: Aggregation of all of Students' Responses

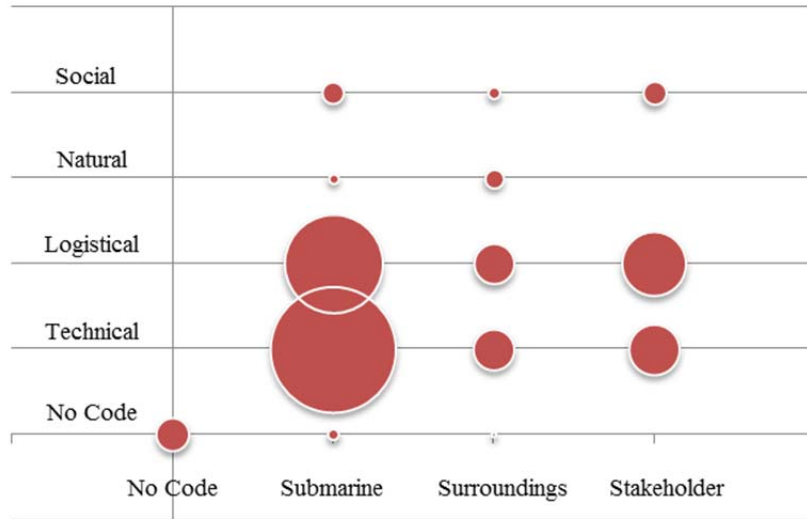


Figure 12: Categorizations of the Design Considerations for the Entire Sample (n = 80)

Even though the student sample in the aggregate considers both context and stakeholders within their designs, there are still individual differences within the sample that should be noted. Table 19 and Figure 13 include Zachary’s and Mason’s responses to the submarine scenario. Zachary’s response provides an example of a more technology-focused design with little stakeholder and context considerations, while Mason’s response illustrates a response with greater breadth in terms of considerations.

Table 19: Content of Example Responses to Submarine Design Scenario

Zachary's Response	Mason's Response
<p><i>Team Selected:</i></p> <ul style="list-style-type: none"> • <i>Aerospace Engineer</i> – aerospace engineer is needed to understand the fluid mechanics along with engine design knowledge • <i>Computer Engineer</i> – knowledge of computer systems and applications are needed • <i>Financial Analyst</i> – needed to understand the costs involved • <i>Mechanical Engineer</i> – required for design of engines and other components • <i>Project Manager</i> – give focus to the team and can compile data • <i>Systems Engineer</i> – required for various system involved in submarines <p><i>Requirements:</i></p> <ul style="list-style-type: none"> • Model of submarine • Cost analysis • List of all parts needed • Conceptual design spreadsheets/report • Error analysis report 	<p><i>Team Selected:</i></p> <ul style="list-style-type: none"> • <i>Aerospace Engineer</i> – good with fluid flow, aerodynamics are also important under water, general engineering knowledge base, plus systems knowledge, will be useful. • <i>Cognitive Engineer</i> – It will be manned by 1 person, complex machine, the control layout must be intuitive and easy for one person to do and still focus on the research task. • <i>Electrical Engineer</i> – Large amounts of circuitry, electronic water proofing and computer systems will be in use -> hopefully 1 EE could handle it. • <i>Materials Science Engineer</i> – deep sea diving requires special/strong material, if they can help reduce weight, improve safety, then the cost of operation will be much less • <i>Mechanical Engineer</i> – A general engineer to help with the design and manufacturing of the product will be useful. • <i>Project Manager</i> - Engineers don't always work well together, guidance to meet all constraints will reduce cost, and make the design process more efficient. <p><i>Requirements:</i></p> <ul style="list-style-type: none"> • Must submerge to desired depth (let's say 1000 ft?) operate for 60 minutes and then return safely with 1 hour of extra life support available • Must be able to see 15ft in direction of travel at darkest depths (no light) • Should have small bay with extendable arm to take small <100lb samples • Ejection pod for controller must get to surface in 5 minutes or less (worry about bends later – cockpit should be able to eject) • Must have cameras mounted above & below & in all 4 directions giving pilot live feed & recording • Must be able to maintain radio and live feed contact with topside crew at 100 feet below max operation depth.

Submarine Design Scenario - Example Responses

● Technology-Focused Vehicle (Zachary) ● Breadth of Considerations (Mason)

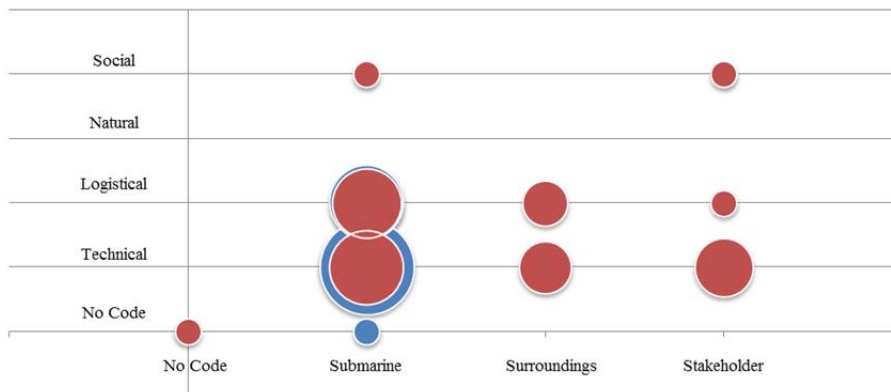


Figure 13: Example Responses for the Submarine Design Scenario

3.2.4.1.3 Summary

The results presented here describe the typical senior design student within this sample. The student has a moderate to high confidence in their abilities to do design. He or she is most confident in their ability to complete problem-scoping activities (e.g., identifying a design need and researching a design need) and to communicate a design solution. These activities align with the student's beliefs as to which design activities are most important. At this stage within their curriculum, the student most likely does not view iteration and making trade-offs as critically important design activities.

The student perceives his or her ability to consider context within a design as adequate. The student's understanding of context considers the effects of the customer, the type of aircraft being designed, the mission, and/or the economic constraints on the mission. The student, however, does not see the impact of the broader context, such as political and ethical considerations, or of stakeholders outside of the customer, such as maintenance personnel or non-users. When asked to develop a design team and requirements for a single manned submarine, the student may include a customer or user, but mostly selects engineers who will be able to focus on the technical and logistical considerations of the submarine. The majority of their design considerations focus on the technical aspects of the design, with a few contextual or stakeholder-related considerations.

3.2.4.2 Contributing Factors from the Learning Experience and Learning Environment

Having defined the perspectives of students at the start of their senior design capstone course, it is necessary to consider the impact of their previous experiences and the learning environment on their perceptions. Thus, this section will incorporate statistical analysis of the impact of students' previous industry and design experiences as well as qualitative analysis of classroom observations and course documents, such as the syllabus, for the first week of the term.

Throughout the data analysis, statistical analysis was completed to examine the effect of independent variables (specifically demographic variables and students' previous design, industry and problem-based learning experiences) on the dependent variables, such as design self-efficacy or percentage of stakeholder considerations in the submarine design scenario. Specifically, the effect of independent variables was calculated using a multivariate analysis of covariance (MANCOVA) with the lab section as a covariate. The use of a MANCOVA allowed the researcher to establish whether there were any relationships between the dependent variables.

Industry experience was found to have a statistically significant positive effect ($F(1,79) = 8.719$; $P < 0.01$; partial $\eta^2 = .105$) on students' contextual competence score. The interaction term, industry experience and enrollment in a problem-based learning (PBL) course, on the other hand, had a statistically significant effect on design self-efficacy ($F(1,79) = 5.736$; $P < 0.05$; partial $\eta^2 = 0.072$). Students who didn't have industry experience or PBL experience reported a higher self-efficacy than students with PBL experience or industry experience.

There was a significant association found between the inclusion of stakeholder-related considerations in students' responses to the context in design question and whether or not the student had industry experience ($\chi^2(1) = 5.373$, $p < .05$). Students who had industry experience were more likely to discuss stakeholders within their context question response. There was also a significant association found between discussing a global consideration and whether or not the student had industry experience ($\chi^2(1) = 5.142$, $p < .05$). Based on the odds ratio, the odds of a student discussing a global consideration were 10.15 times more likely if they did not have industry experience than if they did. Finally, when the submarine design scenario responses were compared with the independent variables, the design self-efficacy scores, and the contextual competence scores, no correlations or statistically significant relationships were found between these

variables and the students' considerations of stakeholders within the submarine design scenario.

Through the use of in-class observations and document analysis, it was possible to examine characteristics of the learning environment which may have an impact on students' design understanding and their understanding of stakeholders over the course of the semester. Two characteristics emerged in this initial assessment of the learning environment: *instructor emphasis* and *task characteristics*. In the opening lecture, the instructors discussed specific characteristics of design:

- Design starts with a need (and is constrained by that need).
- Design includes non-unique solutions (“The final accepted solution will always involve compromise and judgment”)
- It is necessary to use a systematic method “to identify the ‘best’ solution”
- The design process is iterative
- “Designers must have more than a basic understanding of all of the disciplines involved and understand how they interact”

If the instructors emphasize these characteristics during the term, students' perceptions of the importance of certain design tasks may change. For example, the basic drivers of the conceptual design process, as presented during the first week, were aerodynamics, propulsion, and performance. It is possible that, since stakeholder considerations aren't included among these design drivers, students will not think to consider or take the time to account for within their designs.

3.3 Summary

In this chapter, the review of the literature and design curricula, the development and administration of students' responses to an in-class evaluation, and the completion of in-class observations and document analysis were used to respond to the following research questions:

- RQ2: To what extent and how does the aerospace engineering design curricula take into account stakeholder considerations?
- RQ3: To what extent do aerospace engineering students understand and take into consideration the effects of design decisions on stakeholders?
 - RQ3.1: What prior knowledge do engineering students bring to a senior design capstone course about design and the role of stakeholder considerations within the design process?
 - RQ3.2: What factors contribute to students' perceptions of the design process and role of stakeholders in aircraft design?

By providing a clear illustration of the context of this study, this chapter (1) distinguishes the role of stakeholders within aerospace vehicle design curricula, as compared with other design disciplines, (2) defines a baseline for students' understanding about design and the role of stakeholders in the design process based only on their previous academic experiences, and (3) identifies factors which impact (or may impact) students' perceptions. The review of design curricula illustrated different perspectives about stakeholders and demonstrated the impact of different learning environment structures on these perspectives. Based on the context of this study, a conceptual aircraft design capstone course, it may be difficult for students to take certain perspectives of stakeholders since they will not interact with clients or other stakeholders during the design process. The examination of stakeholder integration within the aerospace engineering design curricula provided initial considerations for the design of educational interventions and for analysis of the impact of the learning environment.

The examination of students' perceptions not only contributed a baseline for comparison following the implementation of stakeholder-related interventions, but also supported the generalizability of the results from this study to other aerospace programs. Finally, the isolation of potentially influential characteristics of the learning environment

and previous experiences will aid in the future phases of this study, specifically the development of educational interventions and the analysis of the impact of the learning environment on how students consider stakeholders in their final design project.

CHAPTER 4 - Design of the Interventions

Up to this point, this dissertation has explored current practices in integrating stakeholder considerations in the aerospace industry and within aerospace engineering design education. Using the findings from Chapters 2 and 3, three interventions were designed to support student understanding of stakeholder integration in aerospace vehicle design, as described in Research Question #4. *What educational interventions can enhance students' understanding of and ability to integrate stakeholder considerations into the design of an aerospace vehicle?* This chapter introduces these three educational interventions, the constraints and contextual factors influencing their design, and the learning theories used to frame their design. In addition, this chapter describes my role within the course as a fourth “passive” intervention: Ever-present from the perspective of the students, I may have affected student development during the design sequence.

The chapter opens by revisiting the findings from Chapters 2 and 3 to define “educational intervention specifications” used in the design of two of the “active” interventions: a “requirements” lab and “stakeholders in design” labs. Then, the overarching design principles and learning theory used to design these “active” interventions are detailed, along with the resulting instructional and learning activities. Next, the role of the researcher as a “passive” intervention is discussed. Finally, this chapter also examines the development of three rubrics used to evaluate student understanding of stakeholder integration in aerospace vehicle design. These rubrics are considered future interventions, as they can also serve as teaching tools to illustrate to students the type of performance necessary for a particular grade.

4.1 Educational Intervention Specifications

The industry case study in Chapter 2 demonstrated how, at one large aircraft design firm, the characteristics of the individual designers, design teams, and their environment impact the integration of stakeholder considerations. Specifically, six factors

were identified within the study that could contribute to the design of a learning environment that supports the integration of stakeholder considerations into a complex system design process. The first two relate to the structure of a design team or group in terms of the benefit of a common goal addressing stakeholder considerations and a group structure that supports addressing this goal. These team/group-level factors are reflected in a classroom setting by viewing a class as a community of learners. Just as management is the starting point in setting a team's or group's goals in industry, instructors set the goals of the learning community. As a result, the educational interventions shall (ID1) create a stakeholder-centric learning environment with activities structured to encourage students to appropriately value stakeholder considerations in their design activities (see Table 20 for summary of all specifications).

The ability of individual designers from different disciplines to form a 'trading zone' for their design was affected by the third and fourth contributing factors: the use of 'boundary objects' (e.g., storyboards, prototypes, etc.) among the group members and the existence (or lack of existence) of a shared language to support the exchange of ideas. These interaction-level factors relate to the knowledge, tools, and resources available to the students to help them address stakeholder considerations within the context of the course. Thus, the resulting education intervention shall: (ID2) introduce a language and vocabulary for discussing stakeholder considerations and the role of stakeholders in design; and (ID3) provide students with tools and resources that can serve as a bridge from their current approach to aircraft design to an approach that incorporates stakeholder considerations explicitly.

Individual characteristics of designers also influence the integration of stakeholder considerations, specifically in regards to each individual's perspective on cross-disciplinary teams and the previous academic and industry experiences that influenced that perspective. Therefore, an educational intervention shall: (ID4) provide students with experiences and training in cross-disciplinary problem-solving; and (ID5)

demonstrate to students the value of cross-disciplinary work and designs created from multiple perspectives.

From the review of aerospace engineering design education and the examination of students' perceptions at the start of their senior design capstone course in Chapter 3, five intervention considerations arose (see Table 20). The evaluation of incoming senior aerospace engineering design students' perceptions highlights that students appear to have some appreciation for stakeholders but, in general, students focus on technical and logistical considerations when breakdown a design problem. These results suggest a need to increase overall student awareness of stakeholders and stakeholder-related considerations in the context of aircraft design. In addition, while some students are aware of the customer and contextual consideration such as economic constraints, most students are unaware of the impact of the broader context and of stakeholders outside of the customer. As a result, an educational interventional shall: (ED1) increase students' awareness of contextual and stakeholder-related considerations; and (ED2) highlight the importance of considering context and a variety of stakeholders beyond simply the economic context and the customer.

The aerospace engineering design textbooks and curricula illustrate a heavy reliance on quantitative values to incorporate design considerations and a focus on vehicle performance requirements, which can lead to the exclusion of more qualitative operational or stakeholder-related requirements. With this in mind, an educational intervention shall (ED3) introduce students to methods for explicitly incorporating stakeholder considerations which are novel or qualitative in nature and may be difficult to quantify. Students within in a conceptual design course also may not have access to a client or customer, due to resources and time constraints on the course. Thus, an educational intervention shall (ED4) provide students with opportunities to learn from interactions with clients or other stakeholders during the design process. Finally, class observations reveal an emphasis on trade-offs by the instructors, which contrasts

students' perceptions of the importance of trade-offs. While the students view problem-scoping activities as important in the in-class evaluation, the students did not view making trade-offs or iteration among some of the most important design activities. An educational intervention, as a result, shall (ED5) promote the importance of iteration and trade-offs within the design process.

Table 20: Educational Intervention Specifications Based Findings from First Phase of Study

#	Educational Intervention Specifications	Derived from:	Used in the Design of:
<i>Based on Industry Case Study Results (Chapter 2)</i>			
ID1	Shall create a stakeholder-centric learning environment with activities structured to encourage students to appropriately value stakeholder considerations in their design activities.	<i>Group/Team-level</i>	Framing Both Interventions
ID2	Shall introduce a language and vocabulary for discussing stakeholder considerations and the role of stakeholders in design.	<i>Interaction-level</i>	<i>Requirements Lab</i> Introduction to "Stakeholders" <i>Stakeholders in Design Labs</i> Human-Centered Design (HCD) Methods
ID3	Shall provide students with tools and resources that can serve as a bridge from their current approach to aircraft design to an approach that incorporates stakeholder considerations explicitly.	<i>Interaction-level</i>	<i>Requirements Lab</i> Stakeholder Identification <i>Stakeholders in Design Labs</i> Stakeholder Mapping & HCD Methods
ID4	Shall provide students with experiences and training in cross-disciplinary problem-solving	<i>Individual-level</i>	<i>Stakeholder in Design Labs</i> Case Studies
ID5	Shall demonstrate to students the value of cross-disciplinary work and designs created from multiple perspectives.	<i>Individual-level</i>	<i>Stakeholder in Design Labs</i> Case Studies, Design Process Negotiations & HCD Methods
<i>Based on Evaluation of Current Aerospace Engineering Design Education (Chapter 3)</i>			
ED1	Shall increase students' awareness of contextual and stakeholder-related considerations.	In-Class Evaluation	<i>Requirements Lab</i> and <i>Stakeholders in Design Labs</i> Definition of Learning Objectives & Design of All Activities
ED2	Shall highlight the importance of considering context and a variety of stakeholders beyond simply the economic context and the customer.	In-Class Evaluation	<i>Stakeholders in Design Labs</i> Definition of Learning Objectives & Case Studies
ED3	Shall introduce students to methods for explicitly incorporating stakeholder considerations which are novel or qualitative in nature and may be difficult to quantify.	Review of AE Design Textbooks	<i>Requirements Lab</i> Design Case <i>Stakeholders in Design Labs</i> Stakeholder Mapping & HCD Methods
ED4	Shall provide students with opportunities to learn from interactions with clients or other stakeholders during the design process.	Review of Design Curricula in AE and in other fields	<i>Requirements Lab</i> Interactions with Stakeholders
ED5	Shall promote the importance of iteration and trade-offs within the design process.	In-Class Evaluation	<i>Stakeholders in Design Labs</i> Design Process Negotiation & Case Studies

4.2 Active Interventions: Dedicated Lab Sessions

4.2.1 Requirements Lab

The first “active” intervention is designed to bring stakeholders to the students’ attention at the start of the design process through the development and evaluation of requirements. Here the term “active” is used to signify an intervention that involves dedicated course time and requires student engagement. The overall goal of this Requirements Lab is to introduce students to requirements, their importance, and how and why stakeholder-requirements should be incorporated into the requirements definition phase of the design process. To support the implementation of the lab into an existing aircraft design course, the lab design integrates discussions of stakeholder-related requirements into a broader lesson about design requirements. The broader lesson includes the following topics: the relationship between requirements and aircraft performance, the importance of verification and validation, and the relationship between requirements definition and the rest of the design process.

The final lesson plan (presented in Appendix D.1) is the result of an iterative design process that allowed for feedback from subject-matter experts and experienced educators prior to implementation. The following subsections emphasize the “backwards design” technique applied to develop this requirements lab (Fink, 2003), beginning with a discussion of situational factors and the definition of learning goals or objectives. From these, the feedback and assessment procedures are determined. Finally, the learning theory used to frame and design the learning activities is introduced, along with the learning activities themselves.

4.2.1.1 Situational Factors

The design of the Requirements Lab balances the specific course context and student characteristics with the need to create an intervention which could be utilized in

other aerospace courses and departments. The lab is designed for implementation during the first few weeks of a design course when students are not yet accustomed to any particular learning environment. At this point in the semester, there is a lower risk of student resistance to pedagogical techniques that may not align with those used at other points in the semester. In addition, by conducting the intervention so early in the semester, it is necessary to take into account the wide spectrum of design knowledge among the students. Important student characteristics include that most of the students are in their 4th or 5th year of their college experience and many have previous design or relevant industry experience.

The course structure also plays a role in the design of the Requirements Lab instructional activities. In the first semester of this course, the students meet with the instructors twice a week for a 50-minute lecture as an entire class of 80 students. Following the first lecture of the week, half of the students meet for an additional three-hour lab session; the other half attend the same lab after the second lecture of the week. While this structure allows for extended time with the students, it also creates the opportunity for students within the first lab session to discuss the content of the lab sessions with the students in the second lab session. Students attending the second lab session also receive an additional lecture prior to their lab session. As a result, the lab is designed for multiple contexts such that it could be implemented in either multiple 50-minute class periods or one longer lab period.

4.2.1.2 Learning Objectives

The learning objectives for the Requirements Lab account for the situational factors discussed above, the intervention specifications defined earlier, and the content of a typical requirements lesson. Each of the six learning objectives for the lab is categorized using Bloom's taxonomy as follows (Forehand, 2012):

1. Students will be able to describe the purpose of writing requirements and recognize characteristics of well-written requirements (*Understanding*),
2. Students will be able to explain why validation and verification are critical in the requirements definition process and give examples of different validation and verification techniques (*Understanding*),
3. Students will be able to identify different stakeholders affected by a design problem (*Understanding*),
4. Students will be able to discuss how requirements affect design and the design process (*Understanding*),
5. Students will be able to formulate well-constructed high level requirements and 2nd level requirements (*Applying*), and
6. Students will be able to breakdown a problem and write requirements for performance and stakeholder considerations (*Applying & Analyzing*).

Learning Objectives #1, #2, #5 are aligned with the learning objectives for a typical requirements lesson, while Learning Objective #3 supports the educational intervention specifications ID3 and ED3 (i.e., tools and resources for incorporating stakeholders). Learning Objective #6 aims to form a learning environment where stakeholder requirements are valued alongside performance requirements, similar to the learning environment specified in educational intervention specification ID1. Learning Objective #4 serves as a bridge from students' current awareness of requirements and stakeholders to the level of awareness and understanding necessary to incorporate stakeholder considerations into a design in support of ED1.

4.2.1.3 Feedback and Assessment Procedures

During the lab session, class-wide discussions serve as formative assessments of students' understanding and their experiences during the lab. Specifically, these discussions capture information about whether students achieved LOs #1, #2, #3, and #4 and provide a venue for direct feedback from the instructor to the students. A design case activity functions as the check for understanding of LOs #2, #3, #5, and #6. In this design case, students apply what they have discussed about characteristics of well-written requirements and verification and validation procedures to a design-related problem. The

instructor can collect the results of the design case for further evaluation and to provide the students with more directed feedback.

Anonymous student feedback forms in this implementation further assessed students' understanding of the purpose of the lab, the aspects students liked and disliked, and students' perceptions of the importance of the lab content for their team design project. While not directly tied to a particular learning objective, these feedback forms provided a tool for determining if, for example, the students understood the purpose of the lab as helping students meet any or all of these objectives. Additional insights from the feedback forms are discussed in Chapter 5 to further understand students' experiences during and after the lab session.

4.2.1.4 Kolb's Learning Cycle

The structure of the lesson is based on experiential learning theory, specifically the components defined within Kolb's Learning Cycle (Kolb & Kolb, 2009). Kolb's Learning Cycle originated in management education, but has been applied to courses and lessons within other fields including engineering (Howard et al., 1996; Stice, 1987; Watson et al., 2012). In this model as shown in Figure 14, learning is decomposed into four learning modes that support the construction of knowledge through experience (Kolb & Kolb, 2009): concrete experience, reflective observation, abstract conceptualization, and active experimentation. Each of these modes is related to one another, and it is through these relationships that students begin to realize different concepts (Kolb & Kolb, 2009). For example, a classroom experience designed using this learning cycle may ask students to observe and reflect on an in-class activity centered on specific course content. From these reflections, the student will begin to develop an understanding of that content, which can be more closely examined, or tested, through experimentation. As with all learning theories, Kolb's Learning Cycle is comprised of key propositions about learning. These propositions include how learning is conceived "as a process, not in

terms of outcomes” (p. 43), how learning involves the total person (e.g., their thoughts as well as their feelings and behavior), and how learning is a process of creating knowledge (Kolb & Kolb, 2009). By selecting Kolb’s Learning Cycle, this active intervention is designed such that students will create knowledge about stakeholders and requirements through activities that require them to experience and reflect on the relationships between stakeholders, requirements, and design.

The decision to utilize a learning theory where experience plays a central role is based in part on the role of requirements within the aircraft design curriculum. When the students begin their team design project later in the academic year, they will be given an RFP with explicit requirements for the design. Instead of being asked to define their own requirements, they will need to understand the implications of the given requirements and to identify additional requirements from standards and regulations. As a result, this lab session may be one of the few opportunities students have prior to their team design project to practice defining requirements and explicitly discuss the relationship between the stakeholders, the requirements, and the final design. Thus, the use of an experiential learning theory permits students to learn from the experience of defining requirements within different contexts.

4.2.1.5 Main Activities

The major components of the lab session include an introduction to the lab, a mode of transportation example, a discussion and reflection portion, and a design case (see Figure 14 and Appendix D.1 for the complete lesson plan and handouts). Embedded within these components are also opportunities for students to learn from interactions with clients or other stakeholders, as specified in ED4. A presentation, based on existing slides used within the course, is also made available to students as a reference (see Appendix D.2).

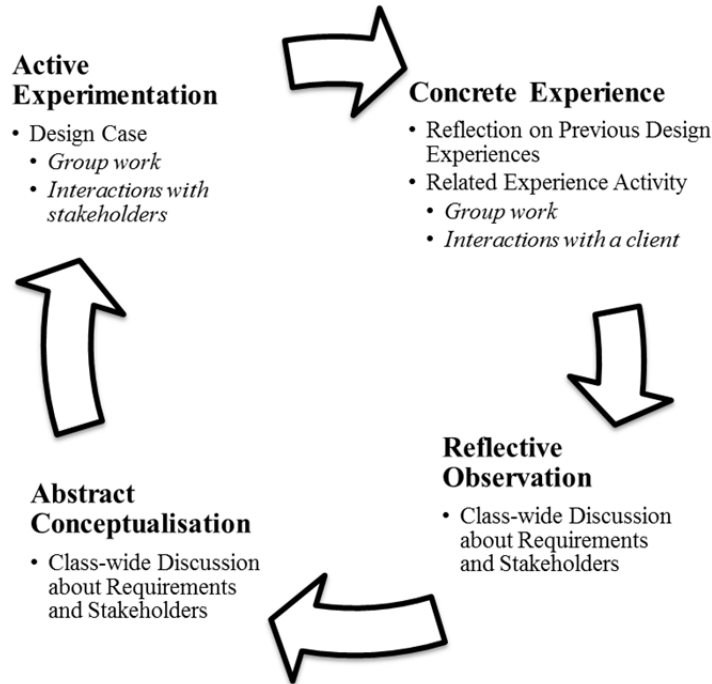


Figure 14: Kolb's Learning Cycle Applied to Requirements Lab Design

In the first part of the Requirements Lab, students start with a relatable experience as an opportunity for the students to reflect on previous “concrete experiences” related to design and requirements development for different stakeholders. This relatable experience is necessarily outside of the context of aerospace engineering since many of the students may have little or no prior aerospace engineering design experience. The concept of *context dependence* defines how students may be unable to accurately and appropriately transfer, or apply, knowledge learned within one context to another context (Ambrose et al., 2010). Thus, these initial experiences serve as a bridge from students’ prior knowledge and experiences to the knowledge necessary to appropriately define requirements in an aerospace setting. Specifically, students are asked to write down an experience where they designed something and the steps they went through. One to two volunteers then discuss their examples with the rest of the class, introducing additional concrete experiences upon which all of the students can reflect on within the later portions of the lab session.

Then, a *learning by experience* activity (Kolb & Kolb, 2009) introduces students to a potential client who is in need of a mode of transportation between campus and home:

I am a graduate student and I am moving out to a new area farther from campus. It will now take too long for me to arrive to campus by walking. I need your help determining what mode of transportation will get me to campus quickly and safely.

The students are asked to write down particular requirements for this client's mode of transportation and to discuss those requirements with a partner. The activity evolves from this point as the client decides to pursue a bicycle as a preferred mode of transportation. As a result, the students develop a list of requirements for the bicycle in small groups and have the opportunity to interact with the client during a short question-and-answer session. Finally, the students review requirements for a bicycle design created by a fake company. They compare their requirements with those developed by this company and discuss as a class whether the requirements by the company were well written or need improvement. Overall, these opening activities are structured to be stakeholder-centric (ID1), giving students an opportunity to learn from interactions with a stakeholder (ED4). Additionally, the class-wide discussions permit the instructor to provide immediate feedback to students.

The Discussion and Reflection portion is used to provide students with a *learn by reflection* activity (Kolb & Kolb, 2009). A class-wide discussion is facilitated to address specific questions about why writing requirements is necessary, who the requirements impact, and where the information comes from to develop requirements. In addition, the students are introduced to the idea of verification and validation and to stakeholder identification. During the discussion, the students also have an opportunity to define characteristics of well-written requirements. This portion of the intervention explicitly addresses many of the learning objectives, specifically #1, #2, and #3. Students are also

introduced to the term “stakeholder” (ID2) and practice identifying stakeholders for the design of a commercial aircraft (ID3). Finally, the class-wide discussions again allow for immediate feedback and quick checks for understanding.

The design case serves as the *learning by experimentation* portion of the lab session (Kolb & Kolb, 2009). This final part of the lesson gives students time to experiment with what they have just learned about requirements. An example of a prompt for this activity is defined for this example as follows:

Prompt: *EliteFlights, Inc. has just received a unique opportunity to design a business jet for a niche market of international business travelers. The company has completed a market analysis, which demonstrated the need for a jet for this passenger group. The design must meet the preferences of the international business traveler, which include locations for sleeping over long night flights, smooth travel so as not to disturb working/sleeping conditions, room for staff & baggage, and a high level of comfort and service. In addition, many of the business travelers prefer to hold business meetings in the air. The jet must be able to fly in all weather conditions both during the day and at night. The jet must also be able to leave at least one engine running for a reasonable amount of time at an airport, so to expedite leaving a particular city or country. An example of a common trip for this class of business traveler is Los Angeles, CA to Abu Dhabi, UAE. Yet, these travelers also are known to use the jets to go to remote locations with smaller airports and landing strips.*

The prompt is intended to be stakeholder-centric, providing students with quantitative and qualitative stakeholder requirements that can be restricting or conflicting. Additionally, a prompt for this design case activity should require students to think about how to balance performance and stakeholder requirements and how to quantify the qualitative stakeholder considerations (ED3).

The structure requires the students to first consider the prompt individually, then to get back into groups of four and negotiate the requirements, the stakeholders, and the necessary verification and validation techniques. The output of the discussion is a write-up due at the end of the lab which includes (1) a list of stakeholders, (2) proposed requirements, and (3) a verification and validation plan. The write-up serves as a tangible outcome of the lab and can be used to check for understanding of LOs #2, #3, #5, and #6 and as a graded assignment.

After about 10 minutes of discussion in groups, three types of stakeholders/characters are made available for questions for 30 minutes: (1) marketing study person(s), (2) future pilot(s) for the jet, and (3) the company's manager(s)/mentor(s) with 20 years of experience in business jet design. There is an opportunity after the stakeholder interaction period for reporting out the different groups' particular requirements. This report-out period provides time for the instructor to reiterate important points and to highlight the importance of well-written requirements. Then the students are given additional time to revisit their requirements and make changes before submitting them. Depending upon the context of the course, this activity allows instructors to alter the particular story (e.g., business jet v. regional jetliner v. military transport), while maintaining the prompts for students to answer in the write-up and the stakeholder interaction period. The design case focuses on LOs #2, #3 (which supports ED3), #5, and #6. It also provides students with another opportunity to interact with stakeholders (ED4) and to brainstorm ways to manage qualitative, and possibly conflicting, stakeholder requirements (ED3). Additionally, the design case encourages valuing stakeholder needs and realizing how stakeholders impact (and are impacted by) a design solution (ID1).

4.2.2 Stakeholders in Design Labs

The intention of the Stakeholders in Design Labs is to provide students with the opportunity to consider how stakeholder requirements and concerns can be integrated throughout the aircraft design process midway through the first semester (see Lesson Plans in Appendix E.1). These lab sessions focus on the characteristics of engineering design and cross-disciplinary practice that were observed in the industry case study and review of aerospace engineering design curricula, specifically collaboration, negotiation, and communication (as described by specifications ID4, ID5, and ED5). As a result, the labs are designed to engage students in reflective activities such as considering what design activities they have been utilizing up to that point in the semester. The students are also introduced to tools and methods for integrating stakeholder requirements and concerns that they can incorporate into their understanding of the aircraft design process (as described by specifications ID3 and ED3). The overall goal is to have students define how stakeholder requirements will be incorporated into the design process they will follow on their team design project.

The remainder of this section follows the “backwards design” technique (Fink, 2003), with the first subsections describing the important situational factors affecting the design and the learning objectives for the labs. With these objectives in mind, the feedback and assessment procedures are described. Finally, the learning theory used to design the learning activities is introduced, along with the learning activities themselves.

4.2.2.1 Situational Factors

The design of the Stakeholders in Design Labs integrates the situational factors (e.g., student characteristics, course characteristics, and the nature of the content) with the findings from the industry case study and student feedback from the Requirements Lab. As with the Requirements Lab, the design of these labs strives to balance the situational

factors with the need to develop an intervention which can be integrated into different aerospace and aircraft design courses.

From the results described in Chapter 3, less than 40% of the students in this study have completed a design course in a previous semester, while 65% have some industry experience through a co-op or internship. Thus, not all of the students have design and industry experiences that they can reflect on as they attempt to overcome different design challenges. Considering the students' academic experiences, 60% of the students have previously taken a problem-based learning course within the department, but the majority of their coursework within the department is delivered in an instructor-centered format. Similarly, the lectures and lab sessions following the Requirements Lab in the second week of this course are mostly instructor- and tool-centered with the instructors lecturing from PowerPoint presentations and demonstrating how to develop and implement design trade-offs within Excel. While student feedback and additional analysis of students' experiences in the Requirements Lab are discussed in detail in Chapter 5, it did illustrate how students appeared to like the student-centered format and pedagogical techniques used. Thus, in utilizing the well-received student-centered format, pedagogical transparency is again necessary here with the transition in teaching styles between the design lectures and active interventions.

Results from the industry case study in Chapter 2 demonstrate key needs for the integration of stakeholder considerations into the design process, including communication skills, collaboration skills, and the values and structure of a group or team. Additionally, the industry case study outlines the need for tools to support the integration of stakeholders into the design process. In the absence of a design process for integrating stakeholder considerations early and throughout the aerospace vehicle design process, it is critical that this intervention appropriately frame these issues and provide useful tools and methods. Thus, the labs are designed to continue to support the team/group level educational intervention specification (ID1) as well as to improve

students' awareness of how designs are developed through cross-disciplinary collaboration (ID4 and ID5). The activities also aim to provide students with tangible tools and language relevant to incorporating stakeholders, as specified in ID2, ID3, and ED3.

To support the integration of these design considerations in the lesson plan for the Stakeholders in Design Labs, the lesson plan is the result of an iterative design process, including reviews by Subject-Matter Experts and experienced educators and a pilot implementation of the activities with aerospace engineering graduate students.

4.2.2.2 Learning Objectives

The learning objectives for the Stakeholders in Design Lab account for the design considerations discussed previously and the educational intervention specifications. Each of the following learning objectives for the lab is categorized using Bloom's taxonomy (Forehand, 2012):

1. Students will be able to identify relevant stakeholders of a fixed wing design and explain how their concerns affect (or affected) the design solution (*Comprehension & Application*), and
2. Students will be able to assess methods for integrating stakeholder considerations into the design process (*Analysis*).

Both objectives are based on specification ID1, which focuses on the creation of a stakeholder-centric learning environment. The first learning objective aligns with the educational intervention specification ED1 and ED2, while the second learning objective incorporates specifications ID3 and ED3.

4.2.2.3 Feedback and Assessment Procedures

The design processes generated by students in the lab enable immediate formative assessment of students' perceptions of the design process and stakeholder integration.

Feedback can be provided by instructors during the lab sessions, while the processes are being developed, and after the lab sessions to give more targeted individual feedback.

The assessment of whether students achieve the learning objectives is based on class discussions about methods for integrating stakeholder considerations, students' evaluations of design case studies, and reflection questions. At the end of the lab's two sessions, the students respond to short reflections questions about their experience within the course so far and their perceptions of the Stakeholders in Design Labs. These reflections include explicit questions about whether students had already, and would now, consider stakeholders in their design projects. Anonymous feedback was also solicited from the students in this implementation to examine students' perceptions of the overall importance of the content of these lab sessions for their team design project.

4.2.2.4 Social Constructivist Theory

This active intervention needs to incorporate communication, collaboration, and negotiation. As a result, the labs are designed with a social constructivist perspective which contends that knowledge is constructed through social interaction (Kim, 2001; Vygotsky, 1978). This theoretical perspective has four main implications. The first is the necessity for social interaction and thus collaborative activities to help students build knowledge (Kim, 2001), aligning with the collaboration and communication skills necessary to support stakeholder integration within the cross-disciplinary industry work environment (ID4 and ID5). The second implication is that collaborative learning should be mediated by a "more knowledgeable other" (Kim, 2001); the focus in these lab sessions is thus less on direct instruction and more on facilitation. The third implication is the importance of scaffolding, which comes from Vygotsky's theory known as the Zone of Proximal Development, which is defined as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving with a more

knowledgeable other” (Kim, 2001). Many of these students do not have previous design or industry experiences; therefore, it is necessary to bridge from students’ current understanding of the design process to encourage them to see how they can integrate stakeholder considerations into the design process. The final implication is that learning activities should be grounded in authentic, real-world contexts (Kim, 2001), aligning with the course instructors’ emphasis on realism within the lectures. Thus, these labs are designed to provide students with the opportunity to work collaboratively on real-world cases, with the instructor serving as a facilitator who is scaffolding the lesson appropriately.

Along with social constructivist theory, the labs are designed considering a view of design as reflective practice. Bucciarelli (1988) describes design as a cognitive process, requiring negotiation among disciplines and perspectives. Based on differences between the perspectives of designers who do and don’t incorporate stakeholder considerations into complex systems design, this theory supports the use of activities which have students reflect on the differences in design perspectives to define their own perspective. Integrated with the social constructivist theory, the design as reflective practice viewpoint allows for additional activities with a focus on reflection, providing students with the opportunity to document and consider more explicitly the lessons learned from the lab sessions.

4.2.2.5 Main Activities

The main activities within each lab are highlighted in Figure 15 and the lesson plan and activity details are included in Appendix E.1. As with the Requirements Lab, a presentation is used to introduce students to stakeholder mapping and can be given to the students to use as a reference later in the course (see Appendix E.2). Each lab session begins the instructor framing the activities. In Lab #1, the framing portion includes the first set of reflection questions (see Appendix E.3). These questions prompt students to

consider what challenges they have faced in the design course up to this point and to describe how they have integrated pilot-related considerations into their aircraft design during the first few projects. In addition, the students are asked to describe the design process they have utilized so far using 23 design activities. These activities are based on those presented in the in-class evaluation, described in Chapter 3 and are included in Figure 16. The following directions are read aloud to the students:

*Think about the process you have been following in this course so far, use the activities above to describe the different steps in that process. Provide explicit examples where possible: if you write **GENERATING ALTERNATIVES** as step 3 – add, for example, **Search on NACA for different airfoil design alternatives**. Feel free to draw, write, and use the sticky notes to describe the design process on the piece of paper distributed.*

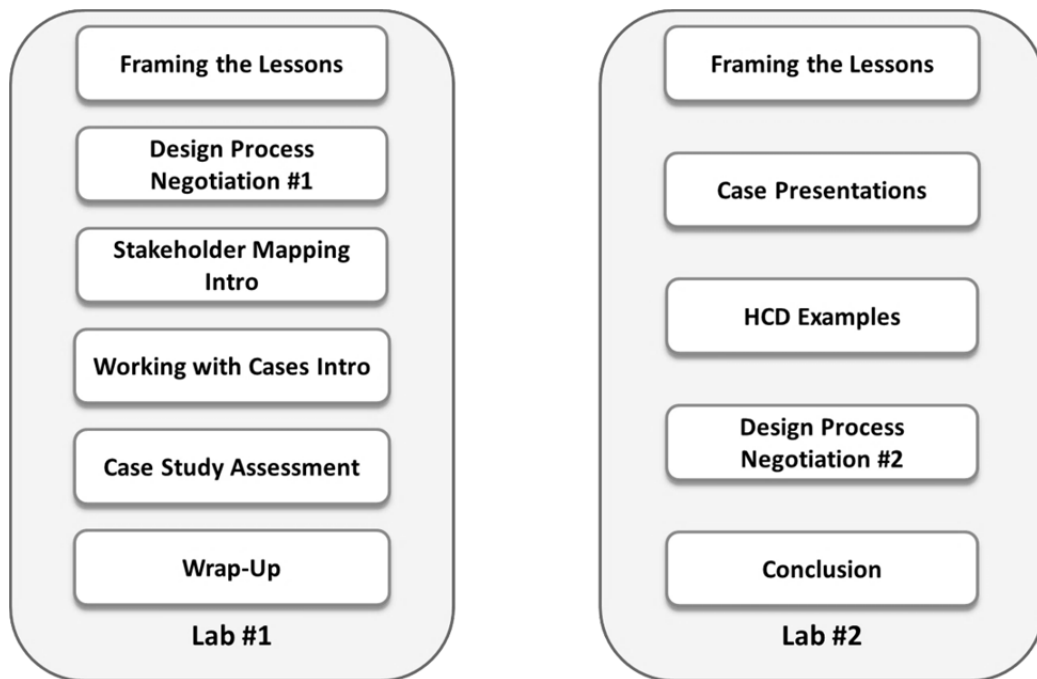


Figure 15: Overview of Lab Activities and Structure

Design Activities

Abstracting	Identifying Constraints	Seeking Information
Brainstorming	Imagining	Sketching
Building	Iterating	Synthesizing
Communicating	Making Decisions	Testing
Decomposing	Making Trade-Offs	Understanding the Problem
Evaluating	Modeling	Using Creativity
Generating Alternatives	Planning	Visualizing
Goal setting	Prototyping	

Figure 16: List of Design Activities (Bailey et al., 2012)

The next activity asks students to work in small, randomly-selected groups to develop a single design process, based on the design processes they created individually. This Design Process Negotiation #1 begins with a short discussion about how design in industry is based heavily on collaboration among many different groups and how many corporations have design processes that help everyone work towards similar goals and milestones (ID4 and ID5). Each group is provided with poster paper, markers, and sticky notes to help create and ultimately display their group design process. These design processes remain on display around the classroom for the duration of Lab #1 and are placed again on display for the duration of Lab #2. The activity lasts between 20 and 30 minutes, allowing time for a couple of the groups to share their design processes with the class.

To support student understanding of how stakeholder considerations can be integrated into the design process, the next phase of Lab #1 introduces the students to a tool they can use to isolate different stakeholder considerations which can affect their design (ID3 and ED3). The discussion begins with a reminder about the importance of stakeholders and the conversations the students had earlier in the semester during the Requirements Lab. The students are then introduced to the Stakeholder Mapping method, which is commonly used in civil and environmental engineering as part of social

sustainability efforts. The mapping method is adapted for use in aerospace vehicle design and is comprised of the following steps:

1. Categorize the stakeholders
2. Map stakeholders to design requirements
3. Consider how information about stakeholders can be collected
4. Brainstorm the different impacts these stakeholders can have on the design solution

Two examples of stakeholder mappings are also included: (1) Design of the Boeing 787 and (2) Design of the unmanned air vehicle (UAV) for the 2011-2012 AIAA Undergraduate Aircraft Design Team RFP.

Then students apply their understanding of the design process and the stakeholder mapping method to case study assessments. The purpose of these assessments is to provide students with real-world examples of the aircraft design process and the impact of stakeholders on design. Students read one case study individually, assess the design process and stakeholder analysis discussed in the case within a small group, and develop a presentation on their group's assessment of the case. Four cases were selected based on specific criteria:

1. Clear indication of a design process that can be extracted by the students,
2. Clear impact of stakeholders on the design solution and the impact of the design solution on their performance and/or satisfaction,
3. Authenticity of the case (e.g., primary sources or comprehensive descriptions of the design of the particular aircraft),
4. Diverse range of case types (e.g., military, commercial, etc.), and
5. Diversity in the quality of stakeholder consideration integration (i.e., an example where stakeholders were considered early and throughout the design and an example where lack of stakeholder consideration integration affected the design solution).

For this implementation, these cases were the B-2, Boeing 747, Gulfstream III, and F-111. The number of selected cases and types of cases can vary with the scope and size of the course. As an example, for the course examined in this study, each lab section contained enough students for eight groups. Thus, each group received one of the cases and each case was examined by two groups.

The case studies are presented to students in a packet, which includes introduction page that highlights the main information covered within the case study and provides recommendations for splitting up the reading amongst the group members. For example, the introduction page to the Gulfstream III case states,

This case study presents detailed information about different components of the Gulfstream III Executive Jet design from the perspectives of Vice-Presidents of aerospace corporations, who worked as project engineers for Gulfstream aircraft, and the engineering manager of the Gulfstream III. This packet contains the aircraft requirements, followed by three major sections:

- Early Development Information (ends on page 8)
- First Conceptual Design Definition Summaries (pages 8, 15, 29 – 32)
- Conceptual Re-Design (aka “The Next and Final Step”)

It is recommended that every student in your group reads through the Gulfstream III requirements. The remaining documents can be split up among everyone in the group to provide for more in-class time to work on the case. Supplemental pages were added to this case to help keep the story coherent, if you have questions please talk to the instructor.

Finally, the introduction page suggests areas of focus for the students as they read through the documents, specifically the various design activities discussed by the authors and the stakeholders impacted by the design solution. The introduction pages for each case study are included in Appendix E.4.

Due to the size of each case study, it is necessary to frame the activity and provide some pedagogical transparency at the start:

“For your first project this semester, you had the opportunity to think about previous aircraft designs and how they may be similar or different to other aircraft designs. Experienced design engineers work from previous designs such as these and use lessons from those previous designs and their own previous design experiences when starting a new project. As novice design engineers in aerospace, you will likely not have as many previous design experiences in your back pocket as more experienced engineers. So today, we are going to have each group engage with a case that describes the design process of a fixed wing aircraft. This activity is meant to provide you an opportunity to think about how the design process works in industry and also evaluate how stakeholders were or were not considered within each design.”

Following the introduction to the activity, time should be taken to scaffold the case study assessment process and describe how the groups could proceed, highlighting the introduction pages on each of the case studies. At this point, instructors may end class and have students complete the case study reading as homework.

During the next phase of the activity, students are provided with a five-slide template for their presentation deliverable and instructions on the format of the presentation (see Appendix E.2). Depending on the number of students in the class, the presentation portion can be implemented in a variety of ways. Ideally, each case can be presented to all of the students. For example, in this study, all four cases were presented by four of the eight groups in Lab #2. Each group should receive 7 to 10 minutes to present and 5 minutes for question-and-answer with the other groups. Since two groups examine each case, when one group presents the other group with that particular case serves as an “expert panel” for the presenting group and is responsible for asking the first round of questions. The presentations include a summary of the case study, an image of a

design process that reflects the work of the designers, a stakeholder mapping, and an evaluation of the case study. In this evaluation, student groups rate and justify the design process used in their case study (poor, acceptable, or excellent) and the designers' ability to take into account stakeholder requirements (poor, acceptable, or excellent). Even when only half of the groups present, these presentations serve as another in-class formative assessment and all of the presentations can be collected for further assessment.

Following the case study presentations in Lab #2 and a wrap-up discussion from the case studies, the students are more formally introduced to different methods for integrating stakeholders into the design process. This next phase of the lab sessions can be delivered during its own class session, if necessary. Initially, the instructor revisits the stakeholder mapping method, describing its use in social sustainability efforts with tools such as the power/interest matrix. To promote active student engagement, the groups then work directly with two of four human-centered design (HCD) methods:

- Human-Centered Design in Service Learning/Product Design
- Value Driven Design as used in Aerospace Engineering
- Context Sensitive Design in Civil and Environmental Engineering
- Participatory Design in Product Design

The information for each method is provided on a single sheet of paper containing the core concept of the method, major references, guidelines for how to approach design using this method, and an example of its implementation. These information sheets are included in Appendix E.5. Students are asked to take time to read their two information sheets and think about the merits and disadvantages to each method in the context of an aircraft design project. Then, they are asked to discuss what they learned from their reading with the rest of their group.

On the board, five columns are created, one for each of the four methods and one for stakeholder mapping. Students are given post-it notes and asked to answer the

following for each of the two methods their group examined and for the stakeholder mapping method:

- What are the merits and disadvantages to the method?
- How could this method be utilized for aircraft design?

The students write the merits (in red) and the disadvantages (in black) on the post-it notes and then put the post-it notes up on the dry erase board under the appropriate column. After approximately 15 minutes, groups are asked to briefly present the merits and disadvantages of each method. Thus, all of the student groups are presented with information about all five methods. With this information, the students are asked to vote on which method they would advise using if they were the program manager for an aircraft design project. A class-wide discussion follows with time for students to describe their reasoning. The intention of this activity is to not only introduce different methods and tools which can be used to integrate stakeholder considerations (ID3 and ED3), but also to allow students to engage with terminology that is used by designers to include stakeholder considerations (e.g., participatory design, user testing, stakeholder surveys) (ID2).

The next stage of the Stakeholders in Design labs requires students to modify their design process once again to incorporate what they have learned in these lab sessions and to indicate explicitly where they would take into account the stakeholder considerations in their design process (ID1). The purpose of this second design process negotiation is for the students to have a structure, specifically a design process, they can use as a road map for their team design projects that explicitly includes stakeholders. As such, instructors can provide students with a copy of their design process drawings for future reference.

Finally, at the end of the lab sessions, students are asked to complete a second round of reflection questions and an anonymous feedback form (see Appendix E.3). These reflection questions focus on the surprising and difficult parts of the lab sessions

themselves and on students' perceptions of whether they will consider stakeholders in their team design project. Specifically, *considering your design project for the spring semester, do you believe that you and your teammates will be able to take into consideration the effect of your design on the safety and overall satisfaction of the stakeholders? Why or why not?* Through these reflection questions, students reflect on the activities and the social constructivist learning environment of the Stakeholders in Design labs and consider what they learned from the content of the case studies, the human-centered design examples, and the design process negotiations.

4.3 Passive Intervention: Researcher as Intervention

Throughout the academic year, the researcher conducted field observations during the lectures and lab sessions. By being ever-present from the perspective of the students, the researcher served as a “passive” intervention, i.e., her presence did not require student engagement, but still may have affected students' activities. In the second term, the researcher also conducted six interviews with the course instructors at two to three week intervals throughout the semester. At the start of the sixth week of the second term, the researcher began attending attended design team meetings (i.e., weekly meetings between the student teams and the instructors) and design reviews. The purpose of observing students during design team meetings and design reviews was to further understand perceptions that students have about the importance of stakeholder considerations and how stakeholder considerations can be integrated into the design process. In addition, the observations and interviews permitted her to explore the effects of different characteristics of the learning environment on students' integration of stakeholder considerations. For the most part, the observations were made unobtrusively, without disturbing or disrupting the students and without audio or video recordings. However, the researcher's presence within the class could be considered an educational intervention (Miles & Huberman, 1994). Within case studies and other types of qualitative research,

researchers have to be mindful of “researcher” effects that might disrupt the relationships and experiences of the participants or influence participants’ actions (Miles & Huberman, 1994). Thus the subsequent chapters note the potential impact of the researcher’s passive observations.

4.4 Future Intervention: Stakeholder in Design Rubric

4.4.1 Background on Rubrics and Rubric Development

Rubrics provide a systematic methodology for judging the quality of student work. A rubric is described in the educational literature as a “simple assessment tool that describes levels of performance on a particular task and is used to assess outcomes in a variety of performance-based contexts from kindergarten through college (K-16) education” (Jonsson & Svingby, 2007, p. 131). These assessment tools are used across many disciplines to assess student reports and papers (Kellogg et al., 2001; Moskal, 2000), students’ team skills (Plumb & Sobek, 2007), oral presentations (Jones & Tadros, 2010; Moskal, 2000), and large-scale student projects (Bailey et al., 2004; Chong & Romkey, 2012; Jones & Tadros, 2010; Watson et al., 2013). In addition, many of these rubrics are specifically focused on design-related work and students’ understanding of the design process (Bailey et al., 2004; Jones & Tadros, 2010; Kline et al., 2003; Watson et al., 2013).

Beyond serving as summative assessment tools for instructors, rubrics can also provide students with a system for peer and self-assessments (Jonsson & Svingby, 2007; Kellogg et al., 2001; Kline et al., 2003; Plumb & Sobek, 2007). If distributed at the start of an assignment, students can use the rubrics to guide them as they complete the assignment or to clarify instructor expectations, as a form of pedagogical transparency (Chong & Romkey, 2012; Jonsson & Svingby, 2007; Kellogg et al., 2001; Plumb & Sobek, 2007; Watson et al., 2013). Instructors can also view rubrics as mechanisms for evaluating the effectiveness of in-class activities and assignments (Jonsson & Svingby,

2007; Kellogg et al., 2001; Watson et al., 2013). As one researcher explains, “rubrics represent not only scoring tools but also, more important, instructional illuminators” (Popham, 1997, p. 75).

4.4.2 Rubric Development

The development of the rubric followed an iterative design process that started with two prototypes that were then evaluated to inform the final design of the Stakeholders in Design rubric. Throughout, the design of the prototypes and the final rubric followed the steps for rubric development, as described in the educational literature (Jonsson & Svingby, 2007; Moskal, 2000; Plumb & Sobek, 2007; Popham, 1997; Watson et al., 2013). The process begins by defining the rubric’s purpose and objectives. Once the purpose and objectives have been defined, it is necessary to develop scoring criteria that address each objective, where the criteria should be able to be assessed by observed students or by examining student deliverables. In the case of the rubric for evaluating stakeholder integration in a team design project, the scoring criteria should also align with the existing and relevant human-centered design, human factors, and engineering design frameworks. When considering which scoring criteria are appropriate, Popham reminds rubric developers “each of these criteria [should be] eminently teachable” (1997, p. 75). With the scoring criteria defined, each criterion needs to be decomposed to clearly identify the qualities that describe the top and lowest levels of performance and an appropriate number of scoring levels. At this point, the developers should discuss the rubric length, as a balance is needed between the level of detail in the rubric and the time required for the assessment of each project. This balance is especially critical in large design courses, where project reports can range from 50 to 100 pages and the number of student teams can be substantial.

The next step is to select a scoring strategy, analytic or holistic, for the rubric. Analytic rubrics can be viewed as similar to a checklist (Moskal, 2000) or a top-down

methodology for assessment (Bailey et al., 2004). As such, each criterion is assigned a separate score by the rater, which may or may not be combined into a final score. Typically, these rubrics are used for task-specific evaluation and to help instructors and students isolate areas for improvement (Bailey et al., 2004; Jonsson & Svingby, 2007; Kline et al., 2003). Some researchers view analytic rubrics as more objective methods of assessment (Bailey et al., 2004; Jonsson & Svingby, 2007; Watson et al., 2013). Previous research has demonstrated that in open-ended cases such as the assessment of design tasks or projects, analytic rubrics can provide high levels of reliability while maintaining the validity of the rubric (Jonsson & Svingby, 2007).

Holistic rubrics, on the other hand, assess multiple criteria within a single score. Research suggests the use of holistic scoring when evaluating criteria with significant overlap (Moskal, 2000) or with scores requiring broader judgments of the quality of the work (Jonsson & Svingby, 2007; Moskal, 2000). In general, this scoring strategy restricts the ability to quickly isolate areas for feedback and improvement (Kline et al., 2003), but it can be less time consuming for instructors as compared with analytic rubrics (Kline et al., 2003). One study described holistic rubrics as “bottom-up” approaches to scoring, based on identified groupings of previous students’ responses (Bailey et al., 2004). One possible shortcoming of holistic rubrics is rater bias, in part due to the necessity to make a broad judgment about a large-scale outcome, which can negatively impact reliability (Jonsson & Svingby, 2007; Watson et al., 2013).

Once the scoring strategy is determined, the final step is to consider how the overall score will be calculated. For instance, will the scores be summed or averaged or will specific weightings be associated with the different criteria? In the case of Watson and colleagues (2013), the researchers examined potential points for each criterion (based on the criterion’s applicability to the design project) and compared those points with the evidence of student incorporation of that criterion in their project.

4.4.2.1 Objectives and Scoring Criteria

To evaluate how student teams take into account stakeholder considerations within the design process and to promote student understanding of stakeholder considerations in future design courses, the rubric must meet these objectives:

1. Evaluate how students account for stakeholder considerations during the design process as represented within their design project deliverables;
2. Compare and contrast how students integrate stakeholder considerations within design decisions at different stages of the design process as represented within their design project deliverables;
3. Articulate observable outcomes in a manner that encourages students to apply and document good design processes; and
4. Be flexible, such that it can be easily applied to the conceptual design process of a variety of design projects.

4.4.2.2 Rubric Scoring Criteria

To define the appropriate scoring criteria for these objectives, the two dimensions of the Ways Students' Experience Human-Centered Design (HCD) outcome space were examined (Zoltowski, 2010). As briefly discussed in Chapter 3, the first dimension is based on how the students experience the design process and integration, ranging from a non-existent process to an empathic process (see Figure 4) (Zoltowski, 2010). The second dimension describes how students understand the user: this could describe a lack of appreciation of the user, for example, or a desire to involve the user in the design process (Zoltowski, 2010). The outcome space illustrates the breadth of the two dimensions and the intersections students' experiences were found to inhabit (Zoltowski, 2010). Two factors were found to affect students' placement in the outcome space: previous design experience and "internally motivated or externally motivated" user understanding (Zoltowski, 2010, p. 146). These results indicate that certain threshold concepts may exist that inhibit students from fully committing to human-centered design approaches, including lack of design skills and lack of appreciation for the user (Zoltowski, 2010).

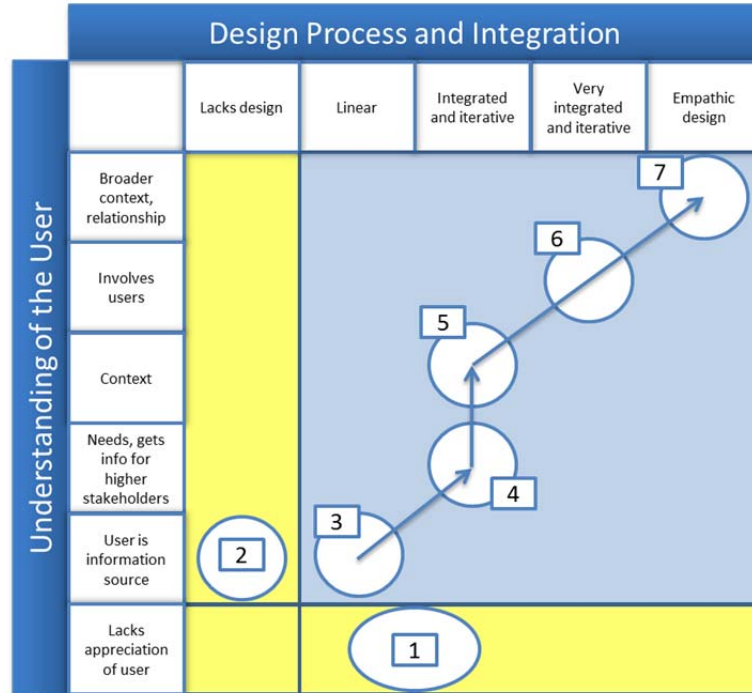


Figure 17: Students' Ways of Experiencing the Human-Centered Design Outcome Space with Seven Common Categories (Zoltowski, 2010)

Researchers have examined ways to operationalize this outcome space into a rubric or learning taxonomy (Jordan & Lande, 2012; Melton et al., 2012; Melton et al., 2010). One group of researchers utilized the outcome space to evaluate students' responses to a discipline-neutral, in-class assessment aimed at assessing students' understanding of HCD (Melton et al., 2012). The group was successfully able to categorize students' responses based on the seven categories in the outcome space labeled in Figure 4 (Melton et al., 2012). The assessments used in that study were smaller-scale, user-centered design problems, rather than the complex system design problems being examined with this work. Still, their success suggests that the two dimensions, *Understanding the User* and *Design Process and Integration*, can serve as a starting point for the Stakeholder in Design scoring criteria.

Categorizations and levels to describe students' design process knowledge and understanding are abundant in the literature. For example, there are many studies which seek to describe the differences and similarities between novices and experts (Ahmed

et al., 2003; Atman et al., 2007; Crismond & Adams, 2012). The Informed Design Teaching and Learning Matrix (Crismond & Adams, 2012) was created through a meta-literature review of the novice-expert design literature as well as related design literature from a variety of disciplines. This matrix bounds design behavior between that of a “beginning designer” and an “informed designer” (Crismond & Adams, 2012). Nine different design activities (e.g., understand the challenge, generate ideas, reflect on process) are then described for these two levels. Table 21 provides an example of the descriptions used to illustrate the behavior of a beginning designer and an informed designer.

Table 21: Example from the Informed Design Teaching and Learning Matrix (Crismond & Adams, 2012)

DESIGN STRATEGIES	BEGINNING VS. INFORMED DESIGNER PATTERNS	
	WHAT BEGINNING DESIGNERS DO	WHAT INFORMED DESIGNERS DO
Understand the Challenge	Pattern A: Problem Solving vs. Problem Framing	
	Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.	Delay making design decisions in order to explore, comprehend, and frame the problem better.

4.4.2.3 Scoring Scale and Descriptions

In considering the appropriate scoring scales and descriptions based on the criteria and the defined objectives, the literature on human-centered design, human factors, and engineering design highlighted the characteristics of approaches and designs which integrate stakeholder considerations successfully. Additionally, this literature was reviewed to explore how stakeholders can be considered at different phases of the design process.

From the human-centered design (HCD) literature, Maguire (2001) describes key principles of HCD, which include (1) the active involvement of users, (2) clear understanding and specification of the user and task requirements, and (3) iteration of design solutions. These principles are critical in completing the processes and achieving

the standards defined in ISO 13407 (a standard on HCD) (Maguire, 2001). The process for performing HCD, as defined in this ISO, includes the following steps:

- (1) **Planning** – Successful HCD brings together the stakeholders of the project to determine how HCD can contribute to the overall goals of the project and how it will be integrated into the overall design process.
- (2) **Understanding and Specifying the Context of Use** – This stage includes identifying the stakeholders and the context: What are the stakeholder-relevant objectives and tasks associated with the design? To gather sufficient data, designers may observe users in their work environment, perform task analysis, administer surveys, or run focus groups.
- (3) **Specifying Requirements** – This stage identifies what expectations or requirements the design must meet. To define the requirements, designers complete a more comprehensive and sophisticated stakeholder analysis (defining the main roles, goals, and responsibilities of the different stakeholders).
- (4) **Creating Design Solutions (and Prototypes)** – This stage includes the iterative development of low- to high-fidelity prototypes along with the final design solution.
- (5) **Evaluating the Designs** – This stage focuses on user-based testing, whether usability or ergonomic or other to ensure the design meets the needs of the user and supports user performance and safety (Maguire, 2001; Vos & Ezer, 2009).

Within the human factors literature, Chua and Feigh (2011) reviewed methods for incorporating human factors considerations into the different stages of the system design process. For the requirements and problem scoping stage of the design process, they recommended establishing agreement on top-level requirements and expectations between the customer and the design team through an analysis of the context in which the system may operate once designed (Chua & Feigh, 2011). The techniques used at this stage are similar to those used by the HCD designers in step 2, as previously mentioned, such as surveys, interviews, and focus groups (Chua & Feigh, 2011). Chua and Feigh explained that “the earlier the design team develops an appreciation for user requirements, the more effective the final design will be” (Chua & Feigh, 2011, p. 2). Their second stage is concept generation, where designers should consider what design trade-offs are necessary due to the stakeholder considerations (Chua & Feigh, 2011).

Finally, in the preliminary design stage, designers should evaluate candidate designs to verify that they meet stakeholder-related requirements (Chua & Feigh, 2011). During this evaluation, additional trade-offs may need to be examined and considerations such as training and personnel implications of the design need to be explored (Chua & Feigh, 2011).

Within the aerospace engineering design literature, previous studies have examined stakeholder integration within aerospace engineering practice and design education (Coso & Pritchett, 2013; Coso & Pritchett, 2014). From these studies and the industry case study, discussed in greater detail in Chapters 2 and 3, stakeholders are considered in some fashion within each stage of the conceptual design process. Yet, overall, stakeholder integration is dependent on the initial requirements and whether the considerations are quantifiable (Coso & Pritchett, 2013; Coso & Pritchett, 2014). In addition, beyond the stages of design described previously, some design textbooks include implicit discussions of stakeholder considerations in other sub-design stages, such as the technology integration stage.

Based on the results of examining stakeholder integration within aerospace engineering practice and design education (see Chapters 2 and 3) and reviewing relevant literature, a list of 14 questions were defined to capture different ways in which students could consider stakeholders (see Figure 18) during the design process. These questions served as the basis for the prototype and final rubrics to be discussed in the subsequent sections.

1. Do the students **identify the stakeholders** for their design problem? If so, which ones?
2. Do the students discuss how the different **stakeholders impact or are impacted by** the design?
3. Do the students consider the **regulations** related to the different stakeholders that could affect their design?
4. Do the students examine the social, political, and/or environmental **context** of their Request for Proposal?
5. Do the students consider stakeholders when **analyzing and incorporating new requirements**? If so, how?
 - RFP requirements only (e.g., 2 crew, 70 passengers)?
 - Quantitative Only?
 - Qualitative & Quantitative?
 - Context Considerations?
6. Do the students show evidence of **gathering information** about the stakeholders from publications, discussions with experts, or stakeholders themselves? If so, how do they use this information?
 - To develop requirements?
 - To identify design constraints? (e.g., heights, weight requirements in subsystem design)
 - To score/rank different concepts/ideas?
 - To evaluate the design?
7. How do the students **prioritize** the stakeholder requirements/stakeholder-related metrics?
8. Do the students consider stakeholder needs, preferences, and concerns in their definition of **Figure of Merit, Criteria, or Metrics**? If so, how?
9. Do the students include **technology options** which consider the context and stakeholder-related concerns?
10. Do the students discuss the **benefits and consequences of different technologies** as they relate to stakeholders, including the environment?
11. Do the students include the stakeholder-related concerns in their **methodology for selecting among different technologies**? If so how? (e.g., cost-related metrics)
12. Do the students consider stakeholder-related concerns in their **design of vehicle subsystems**? (e.g., fuselage, cockpit, cabin) If so, how?
13. Do the students integrate stakeholder-related parameters into **trade studies**? If so, how?
14. Do the students **revisit their design solution** to evaluate it from a stakeholder perspective and demonstrate how it meets or does not meet the design requirements?

Figure 18: Considering Stakeholders in the Different Phases of the Design Process - Results of Review of Literature and Aerospace Engineering Design Resources

4.4.2.4 Prototype #1: The Human-Centered Design Rubric

The first prototype, a Human-Centered Design Rubric addressed six phases of the design process: (1) Requirements and Problem Definition, (2) Concept Generation and Concept Selection, (3) Technology Integration, (4) Concept Development, (5) Trade Studies and Balancing Trade-Offs, and (6) Final and Overall Design. The descriptions within each phase are based on one or more of the design activities described in Figure 18 and represent the necessary component skills students must have to incorporate stakeholder requirements in that phase of the process.

The scale used to describe student performance in each phase applies from the Ways of Experiencing Human-Centered framework by Zoltowski (2010), with one exception: One category from the original framework was not considered relevant for the most common aerospace design projects. Category 2, *Service*, describes Human-Centered Design as “not design but service, helping or positively benefitting others but utilizing very limited, if any, design methods or processes to achieve that goal” (Zoltowski, 2010, p. 157). The complete rubric is included in Appendix F.1.

Each design phase in this rubric is scored out of 6, where 0 indicates that the student team lacks a basic understanding of the design project requirements and instructions and 6 indicates that the student team demonstrates a broad understanding of stakeholders and how they impact or are impacted by the design. While scoring, the rubric allows the rater to check off particular attributes, which they observed in the design reports, to help isolate the final score for a given phase of the design process. An example of the scoring for the requirements and problem definition phase is illustrated in Table 22.

Table 22: Scoring Example from the Stakeholder in Design: Human-Centered Design Rubric.

[NOTE: These scores are for the Trade Studies and Balancing Trade-Offs.]

<u>Score</u>	<u>Students...</u>	<u>Evidence</u>
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	<u>Limited or no trade studies</u> are completed. Those completed trade studies may not consider important metrics included in the project description.
1	View the focus of the design as a technical solution to the project description. Lack an understanding of the users and an appreciation of their perspective.	__ Students perform trade studies focused only on the design drivers included in the project description. __ Relationship between trades and stakeholder-considerations are not discussed.
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	__ The students perform trade studies focused on the design drivers from the project description, but also may include some parameters which impact or are impacted by the stakeholders. __ Relationship between trades and stakeholder-considerations may be discussed.
3	Attempt to keep the stakeholders' needs and how the design will be used in mind while designing. Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.	__ Trade studies include stakeholder-related design parameters and the quantification of qualitative considerations related to stakeholder requirements. __ Results demonstrate how stakeholder information can be integrated with other aspects of design.
4	Demonstrate an understanding of design as taking place within a particular context. Incorporate information not only about the stakeholders but about the context of the design.	__ Trade studies examine both stakeholder and context-related considerations. Students quantify qualitative considerations as needed. __ Students connect performance parameters with stakeholder considerations to help make various design decisions based on the trade study results.
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	__ Students clearly considered the question " What are the design tradeoffs, if any, necessitated by human factors [stakeholder/context] considerations? " __ Trade studies examine both stakeholder and context-related considerations. Students quantify qualitative considerations as needed and connect performance parameters with stakeholder considerations.
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	__ The report includes a broad understanding about how stakeholders and context concerns can be integrated into the various trade studies and design decisions.

4.4.2.5 Prototype #2: The Informed Designer Rubric

The second prototype rubric is based on the Informed Design Teaching and Learning Matrix (Crismond and Adams 2012), which described the behavior of beginning and informed designers for each of nine design activities. Two of the activities (i.e., Conduct Experiments and Troubleshoot) were removed to align with the conceptual and preliminary design work within aerospace conceptual design courses. The descriptions of beginner and informed designers and the approaches taken for accounting for stakeholder considerations in each of the design activities were derived from the case study of engineers and human factors specialists at an aerospace engineering firm presented in Chapter 2. Specifically, quotes from the interviews were mapped to the different design activities. The quotes included both idealized actions (what the design engineer should/could do), along with experiences related to this design activity as described by the participant. Following a peer review of the mappings, these quotes were condensed and summarized into descriptions of specific behaviors that students could exhibit as a beginning designer or an informed designer for that particular activity.

Each design activity of this rubric is scored out of 4, where 1 signifies that the student team completed work comparable to a beginning designer and 4 signifies that the student team completed work comparable to an informed designer. The middle scores are categorized as intermediate (score of 2) and advanced (score of 3). The decision to include two middle scores created a spectrum to allow for situations where teams exhibit both informed and beginner designer behaviors. When scoring each design activity, the raters are asked to record specific evidence for the score from the project report or design review. An example of the scoring and the scoring descriptions is illustrated in Table 23 and the complete rubric is included in Appendix F.2.

Table 23: An Example from the Stakeholders in Design: Informed Designer Rubric. [NOTE: The italic text is from the original Informed Design Teaching and Learning Matrix. The bulleted descriptions are based on the industry case study.]

	WHAT BEGINNING DESIGNERS DO	Score & Description of Evidence	WHAT INFORMED DESIGNERS DO
Understand the Challenge	Pattern A: Problem Solving v. Problem Framing		
	<p><i>Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.</i></p> <p>Do not include requirements beyond the technical aspects of what the project description includes.</p>	<p>1 = Beginner 2 = Intermediate 3 = Advanced 4 = Informed</p>	<p><i>Delay making design decisions in order to explore, comprehend and frame the problem better.</i></p> <ul style="list-style-type: none"> • Include a description of the problem they are trying to solve. • Define requirements beyond those included in the project description.

4.4.3 Stakeholder in Design Rubric

Each of these two prototype rubrics was applied by subject-matter experts to evaluate their validity, reliability, and usability. The results of this evaluation are included in Appendix F.3. While both rubrics can fulfill the initial rubric objectives, there was noticeable confounding of the design understanding and stakeholder integration dimensions. As a result, the final Stakeholder in Design rubric was developed to incorporate the strengths of both prototypes.

The rubric is broken down into three parts. The objectives of the Stakeholder in Design rubric are explicitly focused on the integration of stakeholder considerations, as opposed to how students involved users or got information from users. Thus, the first scoring criterion is called *Stakeholder Integration* and its scale and descriptors are adapted from the *Understanding the User* scale, which was used in Prototype #1. Based on the finding that design skills may be a threshold concept for students, the second scoring criterion focuses on students' *Design Understanding* and is adapted from the *Design Process and Integration Scale*, also used in Prototype #1, as well as other frameworks for design understanding.

Building on lessons learned from Prototype #1, the *Stakeholder Integration* scale (see Table 24) was adapted from the Ways of Experiencing Human-Centered framework described earlier (Zoltowski, 2010). Not all of the categories within the original framework were included, reflecting the attributes of complex system design in the projects of interest here. For instance, the high levels of performance on the Stakeholders in Design rubric adapt some of the constructs of the higher levels on the *Understanding the User* scale to encourage students to understand and leverage stakeholder considerations without necessarily requiring that they have interactions with stakeholders. In addition, the level related to *Context* was removed to avoid confounding student understanding of stakeholder considerations with student understanding of other contextual considerations. Overall, the scoring scale was created to meet the first and fourth objectives of the rubric, i.e., allowing for the evaluation of how students consider stakeholders and incorporating flexibility. The scale is neither discipline-specific nor project-specific.

Table 24: Stakeholder Integration Scale

Score	Stakeholder Integration Scale	Description
0	<i>Lacks appreciation for stakeholders</i>	Lacks integration of contextual and stakeholder considerations.
1	<i>Considers stakeholders implicitly</i>	Includes stakeholder-related considerations, but does not explicitly discuss the human aspect of the consideration. (e.g., noise and people living near the airport, cost, and the customer, etc.)
2	<i>Incorporates stakeholder considerations at isolated points</i>	Identifies stakeholder considerations at isolated points in the design process, but overall these considerations are not the basis for design decisions and are not addressed consistently through design
3	<i>Integrates stakeholder considerations consistently throughout the design process</i>	Exhibits a commitment to incorporating stakeholder considerations throughout the design process. Design decisions clearly account for their potential impact on stakeholders and related research or communication with experts/stakeholders.
4	<i>Leverages the multiple perspectives of stakeholders to pursue a more innovative, competitive design</i>	Demonstrates how multiple perspectives (and at times, competing requirements) were integrated to develop their final solution. Overall solution can be marketed as a design driven by stakeholder, context, and performance requirements.

To develop a scale for design understanding, the *Design Process and Integration* scale (Zoltowski, 2010) was adapted using terminology from Bloom’s Taxonomy (Forehand, 2012) and constructs from the Informed Design Teaching and Learning Matrix (Crismond & Adams, 2012) (see Table 25). More specifically, the Application scores (1 and 2) capture when students apply the design process as presented within their design curriculum. The higher Abstraction scores (3 and 4) are synonymous with the “Creating” construct in Bloom’s taxonomy (Forehand, 2012). These scores describe when students abstract the elements of the design process to develop a more innovative solution. This abstraction allows students to form a new design process from the elements of the design process presented in their course to match the particular context of the problem. To differentiate among the levels, the beginning designer and informed designer descriptions from the Informed Design Teaching and Learning Matrix were utilized. For example, the Abstraction II level captures the *Managed and Iterative Designing* behavior used by the informed designers (Crismond & Adams, 2012). As with the *Stakeholder*

Integration scale, the *Design Understanding* scale is flexible, such that it can be used for a variety of projects.

Table 25: Design Understanding Scale

Score	Design Understanding Scale	Description
0	<i>Design Process Knowledge is Absent</i>	Lacks a basic understanding of the design process, as exhibited by missed steps or an incorrect application of design process knowledge to the problem
1	<i>Application I: Design Process is Linear</i>	Reproduces the design process as presented within the course, but does not recognize when findings later in the design process warrant revision of earlier steps
2	<i>Application II: Design Process is Integrated and Iterative</i>	Applies the design process as presented within the course and demonstrates how the final design concept improved iteratively via feedback and additional analysis
3	<i>Abstraction I: Very Integrated and Iterative</i>	Exhibits deep understanding of the design process. Abstracts and augments the principles of the design process to reach an innovative solution to the problem through an iterative process (e.g., may develop a new tool for modeling or analysis).
4	<i>Abstraction II: Reflective Designer</i>	Exhibits a deep understanding of design. Design process is very iterative and reflective. Frequently re-evaluates ideas relative to new knowledge. Notes any limitations in the design process or modeling tools and the impact of those limitations on the final design concept.

To meet the second and third objective and to provide more information about how students considered stakeholders, the rubric includes a third section which addresses stakeholder integration within each design stage (see the questions for this section in Table 26 and the complete rubric in Appendix F.5). This section of the rubric acknowledges that students may consider stakeholders differently during the different stages of the design process. As such, the rubric divides the design process into three stages (i.e., Requirements/Problem Definition, Concept Generation/Development, and Technology Integration), which can be modified depending upon the design project, and a fourth category for the overall design.

Table 26: Stakeholder in Design Rubric [NOTE: Descriptions of the *Stakeholder Integration* and *Design Understanding* scales are on the second page of the complete rubric – see Appendix F.5]

Instructions: As you read through the project, please score each project by considering how stakeholders are integrated into each phase of the design process. Provide any specific evidence which served as the basis for your score.

	Stakeholder Integration by Design Phase			
	Requirements/ Problem Definition	Concept Generation/ Development	Technology Integration	Overall Design
Did the student(s) state an intention to incorporate stakeholder concerns at this phase? [Yes – 1pt, No – 0pts]				
Did the student(s) apply a design process at this stage that could include stakeholder concerns? [Yes – 1pt, No – 0pts]				
Was the student(s) successful in integrating stakeholder concerns? [Yes, in an integral manner – 2pts, Yes, but in a superficial manner – 1pt, No, the student(s) was not successful – 0pts.]				

Considering the students' work as a whole, use (1) the design understanding scale to rate how the team applied or abstracted the engineering design process and (2) the stakeholder integration scale to score how the team perceived and integrated stakeholders in the design of this complex system. The scales are defined and examples are provided on page two. Also please provide comments or evidence from the project to support the reasoning behind your score.

Design Understanding Score (0 to 4pts)	Stakeholder Integration Score (0 to 4pts)
Comments:	Comments:

Each design stage is examined more closely using questions about the incorporation of stakeholder considerations:

1. Did the student(s) state an intention to incorporate stakeholder concerns at this phase?
2. Did the student(s) apply a design process at this stage that could include stakeholder concerns?
3. Was the student(s) successful in integrating stakeholder concerns?

These questions examine the intent of students to incorporate stakeholder considerations relative to whether the students applied design methods that could support their intentions. The connection between statements of intent and subsequent behavior has been examined within the literature and provided a foundation for examining the possible connection between students' stated intentions and their success in integrating stakeholder concerns (Ajzen, 1991). In addition, these questions support the examination of the design project report or presentation holistically by allowing the instructor or student to look at each stage of design first and then at the whole design solution.

Thus, as seen in Table 7, scores are given for all three parts. As a result, this final rubric is holistic with some analytic components. The scores for the *Stakeholder Integration* (see Table 24) and *Design Understanding* (see Table 25) scales require the instructors or students to make broad, holistic judgments about the student teams' overall performance on the project. As with the Ways of Experiencing Human-Centered design framework, the *Stakeholder Integration* and *Design Understanding* scores should be viewed in pairs, reflecting the two dimensions of the framework. This reflection can help identify whether students' ultimate integration of stakeholders may have been more driven by their intention to integrate stakeholders or by their design understanding. The design phase questions serve as the analytic component of the rubric (see Table 26), permitting an evaluation of specific design stages and allowing for the determination of possible areas of improvement. Further, each space for scoring on the rubric itself allows

the instructor or student to provide any specific evidence that served as the basis for a given score.

The decision to pursue a more holistic scoring strategy was due in part to the necessity to balance rubric length with the time required for the assessment of a single project. As previously stated, project reports for this context range from 50 to 100 pages and instructors may have several to assess each semester. In addition, this rubric can be used alongside the project specifications (i.e., RFP) in the assessment of student reports and presentations. Thus, the rubric was restricted to one-page in length.

4.5 Summary

This chapter introduced two active interventions, a passive intervention, and a future intervention that were incorporated into a year-long senior aircraft design capstone course. The purpose of these interventions is to support students' abilities to integrate stakeholder considerations in the design of an aerospace vehicle. These interventions also provide mechanisms for examining how the characteristics of interventions and the learning environment ultimately affect students' understanding about design and the role of stakeholders in the design process. The subsequent chapters evaluate the impact of the active interventions by examining students' experiences, their integration of (or lack of integration of) stakeholder considerations throughout the academic year, and the effects of the learning environment. Additionally, within the summative assessment phase of the evaluation (Chapter 6), the rubric is applied to the team design projects and its validity, reliability, and usability are examined. Finally, the role of the passive intervention is explored within Chapter 7. The overall results of these evaluations provide insights that can lead to improvements in the design of the active and future interventions, as discussed, along with relevant future work, in Chapter 8.

CHAPTER 5– Evaluation of Students’ Experiences with the Active Interventions

Chapters 5-7 examine the implementation of the two active interventions introduced in the previous chapter within the context of a senior aircraft design capstone course. Within this chapter, the Requirements Lab and the Stakeholders in Design labs are evaluated based on how they were experienced by students and their immediate impact on students’ understanding of the integration of stakeholder considerations into aerospace vehicle design. Thus, the results of this chapter begin to explore the following research questions:

- RQ#4.1 - What characteristics of the educational interventions support students’ abilities to integrate stakeholder considerations into the design of an aerospace vehicle?
- RQ#4.2 - To what extent can the interventions help students integrate stakeholder considerations into the design of an aerospace vehicle?

These questions are addressed further in Chapter 6 and the influence of the learning environment on the effectiveness of the active interventions is investigated in Chapter 7.

The chapter opens with a description of the evaluation framework that was used to explore the overall effectiveness of the two active interventions. Both qualitative and quantitative data are used to characterize students’ experiences during the interventions and the immediate impact of the interventions. Finally, at the end of this chapter, the discussion section synthesizes the evaluation results, providing preliminary responses to the research questions.

5.1 Evaluation Framework

To determine the overall effectiveness of the active interventions and their various components, it is necessary to define an evaluation framework to guide the analysis within this chapter and Chapters 6 and 7. Evaluation in this dissertation is used for two

reasons: (1) to compare the results of the interventions (i.e., students' experiences and performance in regards to the integration of stakeholder considerations) with the intentions of the interventions (e.g., educational intervention specifications, intervention learning objectives) (Kaufman et al., 1995) and (2) to isolate other factors which may have affected the results. One of the most commonly used approaches to training evaluation is a four-level framework (Kaufman et al., 1995). The framework used for this evaluation was adapted from Kaufman's Five Levels of Evaluation, which is an expanded version of the original four-level framework for evaluating training instructional design that incorporates a fifth level addressing societal impacts of the training design (Kaufman et al., 1995). Kaufman's training evaluation framework is comprised of five levels: (1) Resources and Processes, (2) Acquisition, (3) Application, (4) Organizational and Course level, and (5) Societal level (Kaufman et al., 1995; Rees, 2012) (see Table 27).

Table 27: Kaufman's Five Level Training Evaluation Framework (Kaufman et al., 1995; Rees, 2012)

Levels	Description
Resources and Processes	Participants' perceptions of the intervention content and quality of delivery; efficient use of the resources available
Acquisition	Achievement of intervention learning objectives or desired outcomes
Application	Individual and small group application of intervention content "on the job" and after the intervention
Organizational	Organizational results in terms of benefits, performance improvements, cost benefit/costs consequences, etc.
Societal contributions	Intervention's contribution to society

Likewise, the resulting evaluation framework, displayed in Table 28, has five levels. Level 1 (Resources and Processes) examines the resources required for the implementation of the intervention and the quality of the activities within the intervention based on student satisfaction and feedback. The second level (Acquisition) determines whether the objectives or desired outcomes of the intervention were achieved. The Application level (Level 3) examines the adoption of knowledge, skills, and tools from the intervention in students' work and overall performance within the course. Level 4

(Organizational and Course) captures the interactions among the learning environment and the intervention and assesses the impact of those interactions on students' work and overall performance. Finally, the Societal level (Level 5) requires a consideration of the broader impact of the interventions outside and after the course. Overall, this framework provides a holistic picture of the effectiveness of these interventions and recommendations for further improving students' integration of stakeholder considerations.

Table 28: Evaluation Framework for Active Interventions [NOTE: Questions adapted from programmatic evaluation of STEM education initiative developed by Moon and colleagues (2011)]

#	Level	Description	Research Tool(s)	Relevant Chapters
1	Resources and Processes	What are the inputs to the lab sessions (e.g., resources, materials required, etc.) What is the quality of the intervention activities? What feedback did the participants provide about the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
2	Acquisition	Are the objectives or desired outcomes of the learning intervention met? What did the participants learn as a result of participation in the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
3	Application	Are newly acquired knowledge and skills being applied within the class? What actions are the various stakeholders taking toward improving the integration of stakeholder considerations? Who adopts what aspects of the instruction (students, student teams or instructors)? What changes are visible in the performance indicators (e.g., design project)?	Quantitative analysis of intervention artifacts; in-class evaluation; stakeholders in design rubric	Chapter 5 and Chapter 6
4	Organization and Course	What organization/learning environment barriers prevent or support adoptions? What aspects of the learning environment and intervention prove most successful for program stakeholders?	Observations of design team meetings; student focus groups; instructor interviews; stakeholders-in-design rubric	Chapter 7
5	Societal	What impacts exist outside and after the course?	Instructor interviews	Chapter 7

5.1.1 Relatedness and Perspective

Additional indicators are also needed to describe students' perceptions of and ability to integrate stakeholder considerations. From a study of students' experiences in

an interdisciplinary design course, two barriers are shown to impact students' abilities to cross disciplinary boundaries: (1) "the (in)ability to relate to interdisciplinary subject matter to one's discipline," and (2) "the (in)ability to identify and value the contributions from multiple disciplines to the interdisciplinary subject" (Richter & Paretto, 2009; Richter et al., 2009b, pg. W1E-1). These barriers are termed *relatedness* and *perspective* respectively and have been adapted to reflect the scope of this work (see Table 29).

Table 29: Relatedness and Perspective Classifications (Adapted from Richter and Paretto, 2009)

Relatedness/ Perspective	Positive/ Negative	Description
Relatedness	Positive	Students' ability to identify connections between stakeholder considerations and their work thus far in aircraft design.
	Negative	Students' inability to see connections between stakeholder considerations and their work thus far in aircraft design (e.g., it does not involve human factors)
Perspective	Positive	Students' ability to see an aircraft from various stakeholder perspectives and identify ways in which the stakeholder considerations enrich the overall design
	Negative	Students' inability to see an aircraft from more than a standard performance perspective and/or value the contributions of stakeholder perspectives to the overall design

5.1.2 Cognitive Load

Finally, research indicates that, for novices, the acquisition of complex cognitive skills such as design thinking or how to approach ill-defined problems can require significant cognitive processing (Chandler & Sweller, 1991; Kirschner, 2002; Sweller, 1988). *Cognitive load* describes the cognitive resource demands required to learn particular concepts or to solve particular problems (Chandler & Sweller, 1991; Sweller, 1988). Incorporating stakeholder considerations into a technology-centered design course requires students to have a broad perspective of design and to make connections between the design process presented within the course and the design decisions that could impact or be impacted by stakeholders. For some students, however, the current course implementation may require significant cognitive processing. This high cognitive load may be due, in some cases, to difficulty in understanding and applying key concepts within the design process and due perhaps, in other cases, to difficulty applying relevant

skills such as problem-solving or teamwork. The resulting cognitive load may prevent these students from completing the additional activities required to integrate stakeholder considerations into their designs. As such, instances suggesting that students were experiencing a high amount of cognitive load are noted for later analysis.

5.2 Methods and Limitations

5.2.1 Site and Sample

The active interventions were conducted during the first semester of a two semester aircraft design sequence. During this first semester, students attended lectures and completed individual design projects, in preparation for the team design project in the second semester (see Figure 19). The Requirements Lab was held during the first two hours of the students' three-hour lab time in the second week of the course. Seventy-eight students participated, 74 of which agreed to be study participants. The first section (i.e., Section I) included 39 study participants and the second lab section (i.e., Section II) included 35 study participants. The two Stakeholders in Design Labs were held during the first two weeks of November, after the students engaged with the aircraft design process for 11 weeks of lecture-based instruction and had completed three individual design projects. These labs were held for six hours over a two-week time period and served as a summative experience for the students to revisit the design process and begin to consider how to integrate stakeholder considerations throughout the design process. The course instructors required that the students attend the Stakeholders in Design Lab. Overall, seventy-six students participated in both lab sessions, with two additional students who were absent for the second lab session. Seventy-four of those students agreed to be study participants, with thirty-seven in each of the two lab sections.

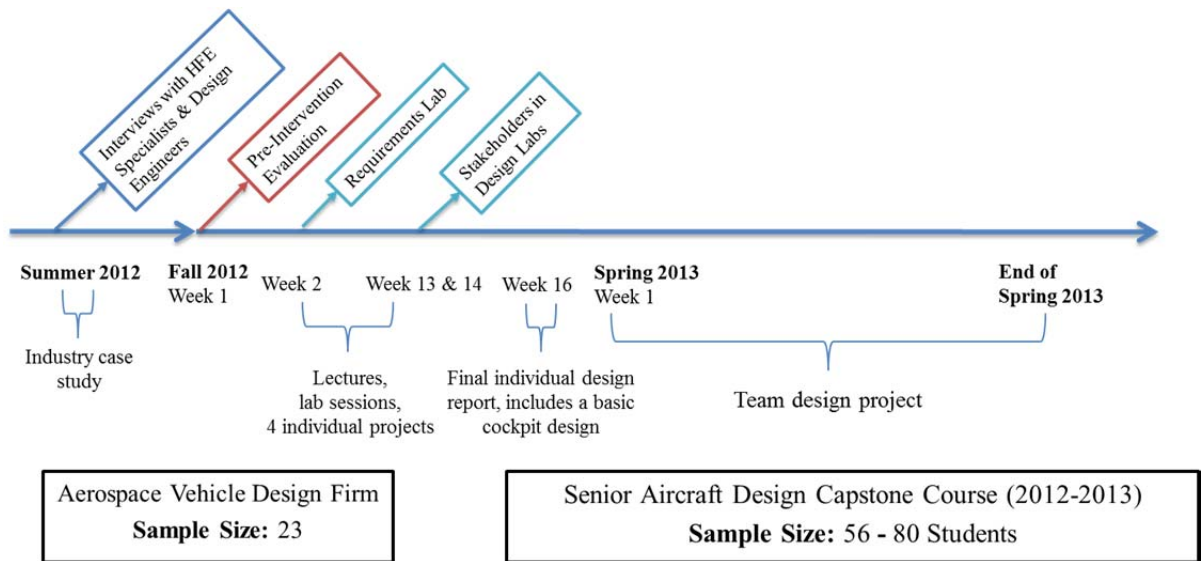


Figure 19: Data Collection and Intervention Roadmap

5.2.2 Data Collection and Analysis

Data were collected throughout both active interventions and were based on the artifacts created by the students (e.g., design processes) and formative assessment tools (e.g., student feedback forms). For the Requirements Lab, these data sources included the business jet case study responses and anonymous student feedback. In addition, general observations were made during the lab session and all notes from the dry erase board were captured for further analysis. In the Stakeholders in Design Labs, the artifacts consisted of (1) the pre- and post-lab reflections, (2) the individual and group design processes, (3) the case study presentations, and (4) the anonymous student feedback. Observations and notes from the dry erase board were again captured for further analysis. The use of multiple data sources for this evaluation permitted comparisons among the data and triangulation among the findings (Miles & Huberman, 1994).

The data were analyzed according to the particular evaluation question. For example, the Resources and Processes level asks, “how was the quality of the lab session based on learner satisfaction and feedback?” To respond to this question, student feedback was categorized into positive and negative responses. Following this initial

categorization, students' responses were reread and assigned to codes to further categorize potential trends within the data. Codes are units of classification that assign meaning to segments of the data (Miles & Huberman, 1994). Unlike the coding schemes used in Chapter 3, the data within the evaluation was most often coded using an inductive approach: Codes were developed for segments of data and revised by combining codes with similar meanings, adding new codes that capture the data included with two or more codes, or removing rarely used and unrelated codes (Miles & Huberman, 1994; Strauss & Corbin, 1990). Peer debriefing was again used to reduce researcher bias. Once the coding was complete, descriptive statistics were often used to illustrate trends within the data and compare the results within each evaluation question. Specific analysis techniques for each research question are explained more thoroughly within the appropriate results subsection.

The scope of the data analysis for this chapter is limited to the first three levels of the evaluation framework: (1) Resources and Processes, (2) Acquisition, and (3) those aspects of the Application level that were apparent during the labs themselves. The Application level, in terms of the subsequent impact on students' design perspectives and design projects, the Organizational and Course level and the Societal level are examined in detail in Chapters 6 and 7.

5.2.3 Limitations

In the results subsections that follow, it is important to keep in mind the limitations of the research design. The sample of students is from a single course in a single department at a single university, which has its own distinct curricula. To mitigate this potential limitation, comparisons were made in Chapter 3 between two student populations to demonstrate similarities in design understanding between aerospace engineering seniors at different institutions. As the two interventions were only implemented within this one population, the execution of each intervention twice allowed

for comparison among the sections. Differences among sections were examined and the few differences are noted. Due to the qualitative nature of the data collection and the analysis, researcher bias must also be taken into account. Triangulation across multiple data sources and peer debriefing were two techniques used to mitigate the impact of these biases on the results. Finally, other factors (e.g., previous experiences in design, timing of intervention as it relates to personal issues and social calendars, etc.) may have affected students' perceptions of the interventions and the effect of the interventions on the student population. As such, rival explanations were also considered throughout the analysis process, specifically within the higher levels of the evaluation framework, as presented in Chapters 6 and 7.

5.3 Results

The results subsections detail the results by intervention and by level within the evaluation approach. Table 30 captures a summary of the results by intervention and by level.

Table 30: Resource and Process, Acquisition, and Preliminary Application Evaluation Results

Overview

Level	Requirements Lab	Stakeholders in Design Lab
Resources and Processes	<i>What is the quality of the intervention activities based on students' feedback and satisfaction?</i>	
	<p>Positives: Students were generally satisfied with format and pedagogical techniques used in the lab session, specifically the social constructivist aspects of the lab and the experimentation portion.</p> <p>Negatives: Either the length of the lab was too long or the activities were too rushed.</p> <p>Improvements: Changes could be made to improve the quality of the activities and clarity of content within the lab session.</p>	<p>Positives: Many students appeared to appreciate the lab sessions and the pedagogical techniques used.</p> <p>Negatives: A number of students commented again on the length of the lab and some of the activities. Students also perceived the design process development and negotiations as the most difficult part of the labs.</p> <p>Improvements: Future iterations could include additional scaffolding with the design process negotiations and the HCD methods activity.</p>
Acquisition	<i>Are the objectives or desired outcomes of the learning intervention met? What did the participants learn as a result of participation in the intervention?</i>	
	<p>Positives: Students formulated well-constructed high-level requirements and many students were able to identify a diverse group of stakeholders. Students considered both performance and stakeholder considerations and most groups included at least three different verification and validation procedures.</p> <p>Negatives: However, stakeholder-centric focus of the lab was not clear to students.</p> <p>Improvements: Future iterations should modify learning objectives or intervention design to more explicitly emphasize role of stakeholders in requirements definition phase.</p>	<p>Positives: The results demonstrated not only how the learning objectives were met for most students, but also how the stakeholder-centric focus supported students' integration of stakeholder considerations in a variety of different ways in their final design processes.</p> <p>Negatives: Even in a stakeholder-centric learning environment, there are other constraints which may impact students' decision to incorporate stakeholders. Misconceptions about HCD methods may have also developed over the course of these lab sessions.</p> <p>Improvements: Future iterations should improve the alignment of learning objectives and intervention activities. Also, more easily-adaptable tools and HCD-related methods should be shared with students in the labs.</p>
Application	<i>Are newly acquired knowledge and skills being applied within the class?</i>	
	<p>Positives: Many students demonstrated an understanding of how the design could impact the pilot, either at this phase or in future phases. Students perceived the requirements lab content as fairly important to their team design project.</p> <p>Negatives: Many students didn't understand how or choose to identify their stakeholders upfront. The balance of performance and stakeholders considerations as seen in the lab session was also not apparent in the students' individual projects.</p> <p>Improvements: Future iterations should incorporate a focus on how to evaluate requirements as given and how to incorporate stakeholder considerations from that point in the design process.</p>	<p>Positives: Students, in general, rated the importance of the Stakeholders in Design lab content as fairly important to their team design project.</p> <p>Negatives: Some students viewed the importance of considering stakeholders as dependent on the project requirements or the instructor's strategy for evaluating students.</p> <p>Improvements: These depend on the analysis within Chapter 5.</p>

5.3.1 Active Intervention – Requirements Lab

5.3.1.1 Resources and Processes

To examine the Requirements Lab at the resources and processes level of the evaluation framework, this analysis examines students' perceptions of the lab session. In the anonymous feedback forms from the Requirements Lab, students were asked five reflection questions related to the quality of the lab (see Appendix D.1):

- (1) In your opinion, what was the purpose of this lab session?*
- (2) What did you like about the lab session?*
- (3) What did you not like about the lab session?*
- (4) What is the most important feedback you want the instructor to hear about today's lab?*
- (5) On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from this lab session are to your senior design project for this upcoming spring semester?*

Using questions two, three, and four, students' responses were first categorized as positive or negative and, as described previously, an inductive coding approach was used to uncover emerging themes within the data.

The results demonstrated that all of the students were satisfied with at least one thing about the lab session. As illustrated in Table 31, 40% of students (n = 29) enjoyed the group work and class discussions, while 26% (n = 19) liked the general design of the lab session (e.g., interactive, trial-and-error learning, thinking globally, allowing for creativity, hands-on learning). One student described how they enjoyed, “working with other students in the lab section and dealing with instructors as customers.” Another student explained how they liked “the process of response and feedback on our input - giving us thoughts and questions to further discussion. I liked being able to ask any open question.” Students also spoke highly of the design case in the experimentation portion of the lab (n = 26, 36%). Of those, 14 students (19%), with 12 from Section I, noted enjoying the opportunity to interact with stakeholders and/or instructors. Some students

also commented on the usefulness of the lab session and their interest in the requirements-focused content. One student described how the lab was “informative and useful in both my last semesters at [the university] and in the field.”

Table 31: Students' Positive Perceptions of the Requirements Lab Activities and Design [NOTE: Two students did not complete the anonymous feedback forms]

Code	Example	# of Instances	% of Sample (N = 72)
Content – Discussion of Requirements	<i>“We covered a lot of interested stuff that we haven't really encountered.”</i>	5	6.9%
Experience Portion	<i>“The bicycle example allowed us to work specifics before generalities”</i>	4	5.6%
Reflection Portion	<i>“Class discussion about what is a good requirement”</i>	4	5.6%
Experimentation Portion	<i>“We got to brainstorm every aspect of flying a business jet and get creative with it”</i>	13	18.1%
Interactions with Stakeholders	<i>“I liked interviewing experts on small business jets”</i>	14	19.4%
Usefulness	<i>“The relation to aircraft design and how to begin design”</i>	7	9.7%
Pedagogical Techniques/ Intervention Design	<i>“Liked the hands-on sessions and the active thought processes”</i>	19	26.4%
Social Constructivism (i.e., group work and discussions)	<i>“Working with teams to develop and think critically about requirements and design.”</i>	29	40.3%

Eleven students (15%) did not note any dislikes about the lab (see Table 32). However, 23 of the students (32%) disliked the duration of the lab. In their opinion, the lab was either too long or there was not enough time for the activities. The distribution of dissatisfaction over lab length was different by section. Of those students who attended Section I, nine noted that the lab was too long, three that it was too short, and one of the responses was too general to categorize. Of those who attended Section II, seven explained that the lab was too short for the designed activities and only three mentioned that the lab was “really long...” This discrepancy could be attributed to the slight increase in time spent on the experience portion (i.e., the mode of transportation activity) in Section II. Six of the seven negative comments about the experience portion came from students in Section II. A few students (n = 6, 8%) responded negatively toward the group work, while others did not like specific parts of the lab session. Of those who did not like

the design case, there were comments regarding the need to be more specific with the assignment instructions in the future (n = 8, 11%). Finally, a few students were still confused after the session about how specific (or general) requirements need to be at different stages of the process. One student described how they disliked “not feeling like there were really organized definitions - (e.g., verification, too specific vs not specific enough).”

Table 32: Students' Negative Perceptions of the Requirements Lab Activities and Design [NOTE: Two students did not complete the anonymous feedback forms]

Code	Example	# of Instances	% of Sample (n = 72)
None	<i>“Nothing. It was interesting and informative”</i>	11	15.3%
Content	<i>“Elaborate more on FAA & ICAO regulation requirements in real-world exposure.”</i>	9	12.5%
Experience Portion	<i>“The bicycle example needs work.”</i>	7	9.7%
Reflection Portion	<i>“Could have been more elaborate and more discussion”</i>	1	1.4%
Experimentation Portion (i.e., Design Case)	<i>“Exercise is realistically impossible without actual market results/customers”</i>	5	6.9%
Experimentation Portion-Assignment Requirements	<i>“An incredibly broad subject and the assignment was vague. There was an incredible number of requirements that could have been written with no clear way to filter which were best.”</i>	8	11.1%
Usefulness	<i>“I would have liked more applicable material to the lecture”</i>	1	1.4%
Pedagogical Techniques/ Intervention Design	<i>“Redundancy of bike example and plane example”</i>	3	4.2%
Social Constructivism	<i>“I do not like working in groups.”</i>	6	8.3%
Environmental Factors – Lab and Activity Duration	<i>“Too long for group work” and “Interactive portions need to be longer”</i>	23	31.9%

In reflection question four, which asked students to provide the most important feedback for the instructor, 43 students (60%) mentioned positive statements about the lab session (e.g., “it was a very engaging lab session”), while 12 students (16.7%) emphasized negative aspects of the lab session (e.g., “more time used in lecturing and less individual work”). Overall, the responses aligned with the responses to questions two and three. For instance, the positive comments focused mostly on the design of the intervention and the group components, while the negative comments were related to the

duration of the lab, the bike example, and the requirements for the experimentation problem. Twenty-five students (35%) noted possible improvements for future iterations of the intervention. Among those comments, some students discussed removing or modifying some of the activities (for example, adding presentations for the business jet problem or removing the bike problem all together). Other students reiterated the need to explicitly explain the issue of requirements and the degree of specificity needed at different stages. One student explained how “there was some confusion associated with the degree of specificity for requirements.”

Overall, this analysis indicated that students were generally satisfied with the format and pedagogical techniques used in the lab session. The students noted enjoying the social constructivist aspects of the lab (group work and discussion) and the experimentation portion. Still, the duration of the lab session, which for some was too short and others too long, was the aspect students disliked the most, and changes could be made to improve the quality of the activities and clarity of content within the lab session.

5.3.1.2 Acquisition

This analysis at the Acquisition level examined if the learning objectives were met and what the students learned by the end of the lab. Within the anonymous feedback form, question one asked students to reflect upon the purpose of the lab session. These responses were coded relative to the six learning objectives defined within the intervention designed (see Table 33). The majority of students (n = 38, 53%) viewed the purpose of the lab as introducing them to the characteristics of well-written requirements and the purpose of generating requirements. Overall, the students acknowledged the learning objectives about requirements specifically, but only a few students noted the role of stakeholders (n = 7, 10%) and verification and validation (n = 3, 4%). In addition, sixteen of the students (22%) explained that the purpose of the lab was to teach them how to write requirements or the requirements writing process. For example, one student

explained the purpose of the lab was “to introduce us to the beginning stages of design, introduction to the process behind developing requirements.” While the requirements writing process was a critical component of learning objective #5, it was not its sole focus. However, this lab was the first time in this course that students received instruction on writing requirements and, related to the questions raised earlier on cognitive load, learning this underlying topic may have occupied much of their effort. Finally, twelve of the students (17%) talked about something unrelated to the six learning objectives. One student, for instance, discussed that the purpose of the lab was to learn about “how to work in groups on projects.”

Table 33: Students' Perceptions of the Purpose of the Requirements Lab

Learning Objectives	# of Students	% of Sample (N = 72)
1. Describe the purpose of writing requirements and recognize characteristics of well-written requirements . (<i>Comprehension</i>)	38	53%
2. Explain why validation and verification are critical in the requirements definition process and give examples of different validation and verification techniques. (<i>Comprehension</i>)	3	4%
3. Identify different stakeholders affected by a design problem. (<i>Comprehension</i>)	7	10%
4. Discuss how requirements affect design and the design process. (<i>Comprehension</i>)	21	29%
5. Formulate well-constructed high-level requirements and 2 nd level requirements. (<i>Application</i>)	16	22%
6. Breakdown a problem and write requirements for performance and stakeholder considerations . (<i>Application & Analysis</i>)	13	18%

Students' responses to all five reflection questions were examined for discussions of the specific learning outcomes. In question four, the most important feedback question, for example, students mentioned how “the message got across to how in depth the requirements can be,” and “cost drives everything.” Another student noted how “this lab was very helpful in helping us begin to understand the thought processes involved in design.” When talking about the usefulness of the lab session, one student mentioned how the lab session was a “good module for working on open-ended problems commonly found in the real world.” Overall, students noted learning about design, realistic open-

ended problems, and the depth necessary when developing requirements. Yet, students appeared to have the most trouble with how general or specific the requirements should be at a given stage. For example, one student noted how “there is confusion on how specific requirements should be and when they should be specific.”

The final analysis captured whether the students achieved the learning objectives within the lab session based on the observations and checks for understanding. For the first learning objective, the observations and dry erase board notes were examined to capture the class discussion about characteristics of well-written requirements. Overall, it was clear that students were able to discuss attributes of requirements that would indicate that the requirements are well-written (see Table 34). It is important to note that there was no specific assessment for learning objective #4.

Table 34: Achievement of Requirements Lab Learning Objectives Based on Observations and Assessments

Learning Objective	Verification of Learning Objective Achievement
1. Describe the purpose of writing requirements and recognize characteristics of well-written requirements. (<i>Comprehension</i>)	In the observations, students determined that requirements should include “shall,” be specific (but not too specific or too general), have a hierarchy, not be redundant or conflicting, be based on customer wants, and be measurable.
2. Explain why validation and verification are critical in the requirements definition process and give examples of different validation and verification techniques. (<i>Comprehension</i>)	The students, in general, provided a variety of verification and validation procedure examples within the design case, and most groups included at least three different procedures (at least one of each and then an additional verification or validation procedure).
3. Identify different stakeholders affected by a design problem. (<i>Comprehension</i>)	Students were able to identify several stakeholders beyond the customer. However, the overall diversity of stakeholders was limited within many of the groups, especially in Section I.
4. Discuss how requirements affect design and the design process. (<i>Comprehension</i>)	-
5. Formulate well-constructed high level requirements and 2 nd level requirements. (<i>Application</i>)	Students demonstrated an understanding of how to write well-written requirements. Overall, students used the correct format when writing their requirements and only eight groups needed to modify their requirements based on their lack of measurability or specificity.
6. Breakdown a problem and write requirements for performance and stakeholder considerations. (<i>Application & Analysis</i>)	Students demonstrated an ability to balance performance requirements with stakeholder requirements. Of the 20 groups, only one group lost points for not including sufficient performance requirements.

The design case was used to verify the achievement of learning objectives #2, #3, #5, and #6. Each of the student groups in both sections (20 in total) submitted a single solution to the design case. Each solution included a list of stakeholders, a list of design requirements, and a list of verification and validation procedures. To assess the achievement of the third learning objective (*identification of different stakeholders*), the number of stakeholders on each list was recorded along with notes about the diversity of the stakeholders within each list. Across both sections, the average number of stakeholders identified was 6.5. However, an examination of each section separately illustrated that Section II had a higher average number of identified stakeholders (Mean = 7.1) when compared with Section I (Mean = 5.9). This difference is consistent with the number of stakeholder identified during the class discussion in the Reflection portion of

the lab session. When discussing the stakeholders for a commercial aircraft design, the students in Section II developed a longer list of stakeholders than their peers in Section I. An examination of the diversity of the stakeholder lists found that only half of the groups included maintainers (3 of the 10 groups from Section I; 7 of 10 groups from Section II). In addition, only 7 of 20 groups (1 of the 10 groups from Section I; 6 of the 10 groups from Section II) included government agencies (e.g., FAA). This difference is again consistent with the stakeholders the students mentioned during the discussion portion of the lab. Examples of stakeholder lists are included in Table 35.

Table 35: Examples of the Strongest and Weakest Design Case Stakeholder Lists from Each Section

Section I		Section II	
Weakest	Strongest	Strongest	Weakest
Oil companies	Int'l business travelers	Elite Flight Company	Customers
Government	Pilots	Customers (Business Companies)	Passengers
Not NBA players	Manufacturers	Users (Pilots, Flight Attend., Businessmen, Maint. Crew)	Flight Crew/Attendants
	Ground personnel	Suppliers	Manufacturers
	Airport	Airports (Crew, ATC)	Mechanics Repairing the Aircraft
	Mechanics	Environment (Animals, Nature)	
	Communication company (to hold business calls/use wifi)	Local Airport Residence	
	Flight crew	FAA	

For the second learning objective (*verification and validation procedures*), a scoring scheme quantitatively assessed the student groups' proposed verification and validation procedures for their design requirements. Verification procedures should serve to demonstrate that the requirements have been met. Validation procedures determine if the requirements defined are indeed the right requirements, i.e., if they meet the needs of the mission and customer. Groups' responses were awarded a maximum of 4 points based on the following scheme:

- 0 points if no validation or verification procedures were listed,

- 1 point (max 2 points) per a validation or a verification procedure, and
- 1 point (max 2 points) for listing more than one procedure for each of validation or verification.

Groups' scores ranged from 0 to 4, with an average of 2.8 across all of the groups. In general, the students provided a variety of verification and validation procedure examples within the business jet example (examples included in Table 36), and most groups included at least three different procedures spanning both verification and validation. Overall, there were no noticeable differences between sections; however, as observed from Table 36, there were differences in how teams within both sections elaborated on the particular procedures.

Table 36: Examples of Some of the Strongest and Weakest Verification and Validation Procedures in Students' Design Case Solutions from Each Section

Section I		Section II	
Strongest	Weakest	Strongest	Weakest
Customer research to see if desires are met. Comparison to already operating vehicles. Simulation to confirm flight capabilities Research on all designation regulations Comparison studies on cost vs. capabilities Comparison study on fuselage size vs. flight capabilities Comparison study on noise level requirements vs cost Customer research to see if desires are met	Flight Testing User Feedback	There shall be flight test programs to validate conformity w/ all standard and applicable FAA regulations along w/compliance of target market needs. There shall be structural (loading and fatigue testing) There shall be CFD and flight simulations to ensure appropriate aerodynamic/performance specifications are met before production	Flight Test Market Survey

Finally, student groups' business jet requirements lists were evaluated to explore the extent to which students could construct well-written requirements (LO #5) and whether they included both performance and stakeholder considerations (LO #6). As with the verification and validation procedures, a scoring scheme was used to evaluate the

requirements lists created by the students. Groups could receive a maximum of five points, based on the following scoring rules:

- Were the requirements well-constructed? (with a maximum possible score of 3 points)
 - 1pt – All requirements are correctly formatted
 - 1pt – All requirements are measurable (at lower level) or 0.5pts – Most requirements are measurable
 - 1pt – All requirements are specific
 - -1pt – Several requirements are redundant or conflicting
- Do the requirements include both performance and stakeholder considerations? (with a maximum possible score of 2 points)
 - 2pts – Requirements include both stakeholder and performance considerations.
 - 1pt – Requirements include a majority of either stakeholder-specific or performance-specific considerations.
 - 0pts – No requirements included

The scores ranged from 3 points to 5 points and the average score across all of the groups was 4.66. Overall, the students used the correct format when writing their requirements and only 8 of the 20 groups needed to modify their requirements based on their lack of measurability or specificity. Of the 20 groups, only one group lost points for not including many performance requirements: This group had mostly stakeholder-related considerations (specifically passenger-focused), but did not include considerations such as cruise altitude, speed, or takeoff/landing distances.

Based on the formative assessments from the active intervention and the in-class observations, students formulated well-constructed high-level requirements and many students were able to identify a diverse group of stakeholders. Students considered both performance and stakeholder considerations, and most groups included at least three different verification and validation procedures. From students' perspectives, the lab introduced them to requirements and the process for generating well-written requirements. Future iterations of this active intervention should consider modifications to the intervention design to better align with the learning objectives. In addition, to avoid

confusion among students, the intervention should incorporate further clarification on the level of specificity necessary for design requirements. Finally, students' perceptions of the lab session demonstrated that the focus on stakeholders was perhaps not explicit, or at least not realized by the students. Even though the activities included interactions with stakeholders and the design case required students to identify stakeholders, it may be necessary to modify the learning objectives or parts of the intervention design to more explicitly emphasize the role of stakeholders within the requirements definition phase of the design process.

5.3.1.3 Application

The Application level of the evaluation questions focuses on the extent to which the newly acquired knowledge and skills are being applied “on the job,” or in this case, in the course. Chapter 6 includes discussions of the connections between both active interventions, visible changes in performance indicators (e.g., an end of term in-class evaluation), and students' application of these principles in the team design project. This subsection focuses on the more immediate markers of learning within the Requirements Lab through anonymous feedback questions and the reflection questions from the Stakeholders in Design Labs (see Appendix E.3) two months after implementation.

The first analysis examined students' perceptions of the importance of the Requirements Lab content for their team design project. In the anonymous feedback forms administered after each of the active interventions, students were asked to rate, on a scale from 1 to 10, the importance of the lab content for their upcoming team design project. Students' responses immediately after the lab session demonstrated a general perception that the lab's content was important (Median = 9.0). One student, for example, shared their view of the content of this lab as “a vital set of skills that was never taught in another class at [the university]” (score: 10). Still, the range of the importance scores was large, from 3 to 10. Other students, for instance, noted how “I did not learn anything in

the lab design related” (score: 3) and “writing good requirements is important but it is a skill learned through experience in industry and in life” (score: 5).

After the Stakeholders in Design Labs, the median relative importance decreased to 8.0 out of 10. On the anonymous feedback forms, students were asked to include the last four digits of their student identification number, which maintained the anonymity of the students but permitted the pairing of students’ responses across the interventions. Using this paired sample of students ($n = 63$), a Wilcoxon Signed Ranks Test demonstrated that students’ perception of the relative importance of the Requirements Lab content decreased significantly between August and November, $Z = -3.809$, $p < .001$, $r = -0.339$. The r value in this case represents the effect size, which is a statistical parameter quantifying the size of the difference between the two sets of data. In this case, the effect size is 0.339, which is considered a medium effect. Thirty-three of the students’ importance scores decreased between Week 2 and Week 14, while 10 of the students’ scores increased and 20 were ties. In students’ comments, a few discussed how the importance of the lab is dependent on the requirements within the senior design project. One student explained how the Requirements Lab content is “relevant but many [requirements] will probably be supplied” (score: 6), while another student discussed how they were “not sure how much design flexibility students are given” (score: 7). Students also discussed the importance of the Requirements Lab in terms of their final grade in the course, the design process and the final solution. One student related the Requirements Lab to one of the Stakeholders in Design Lab activities as they discussed how “[requirements help] to guide the beginning design process as can be seen in the design processes developed by most groups” (score: 8). Other students mentioned how “requirements must be met to pass the course,” (score: 9) and “I think one of the key metrics we will be graded on is how effectively we defined, considered, and met the requirements,” (score: 9).

The second analysis examined the actions taken by students between the Requirements Lab and the Stakeholders in Design Labs. Within the Stakeholder in Design pre-lab reflections (see Appendix E.3), students were asked to describe the extent to which they considered the safety and satisfaction of the pilot in their most recent individual design projects, which combined constraint analysis and the sizing of the fuselage and cockpit. Thus, it was possible to analyze whether students identified the pilots as stakeholders or if there were any pilot-related requirements that affected their design in the first few projects. Students' responses were coded based on whether or not the student considered the pilot in their most recent project. Following this initial analysis, an inductive approach was used to classify (1) the ways in which students considered the pilot where they reported doing so and (2) the reasons students did not consider the pilot.

Overall, 24 of the 74 students who responded (32%) to the question reported not considering the pilot in their previous projects, while only 11 (15%) reported taking into account pilot considerations. Over half of the students described somewhat considering pilot safety and/or satisfaction. Of those students who incorporated pilot considerations, almost 30% (n = 22) discussed the requirements for the fourth individual design project for the term which included the design of the cockpit and fuselage space (see Table 37). Nineteen students (26%) specifically included the pilot in regards to safety considerations. Ricky explained that

“The safety was somewhat considered. I intentionally did not design my aircraft to be produced out of carbon, but to leave aluminum as a primary structure and skin material. This was done in order to avoid excessive structural failures of the vehicle if it gets under enemy's attack.”

Two students specifically discussed how pilot safety and satisfaction are keys to mission success, while Hunter and another student expressed personal connection to the pilots that drove their considerations. Hunter described how,

“I designed my cockpit for the pilots to have the maximum visibility possible and to be very safe. After researching the A-10 & learning about all the safety features it has, I chose to include most of the same features in my aircraft. Growing up I wanted to be a fighter pilot but grew too tall, so I wanted to design my aircraft to where I would feel safe and very satisfied while piloting it.”

Others mentioned examining previous aircraft and regulations to determine how and what to design as it related to the pilot.

Table 37: Most Common Ways Students Incorporated Pilot Considerations in the Initial Individual Design Projects

How students considered the pilot	n	N = 74
Design of the cockpit and fuselage space (includes weight and visibility considerations)	22	29.7%
Safety considerations (includes safety features, aircraft stability, etc.)	19	25.7%
Indirect considerations	6	8.1%

For those that did not include pilot considerations in their projects, 43% of the students cited the project requirements as the reason for not incorporating pilot considerations. Lee explained how,

“In the most recent design the pilot's safety and satisfaction was not considered. This is because the requirements that were being met did not include the effect on pilots.”

Twenty students (27%) emphasized that the safety and satisfaction of the pilots are considered later in the design process. A few other students (n = 6, 8%), like Noah, noted “the only thing related to the pilots satisfaction that I considered was that they had enough room to sit rather comfortably. Other than that, I didn't really think about it.” Two students mentioned being unaware of the needs and wants of pilots, while a few students mentioned not having enough time to incorporate these details or were not sure how to incorporate pilot considerations.

Table 38: Most Common Reasons Students Cited for Not Incorporating Pilot Considerations in the Initial Individual Design Projects

Why students didn't consider the pilot	n	N = 74
It's not in the [performance or project] requirements (nor is it required for mission success)	32	43.2%
Safety and satisfaction are considered later in the design process	20	27.0%
The student just didn't think about it	6	8.1%

A few students clearly identified pilots as stakeholders earlier in the design process and perceived their considerations as part of the requirements. Dylan even explained how survivability is pilot-related performance requirement for this project, “because our aircraft specifically had a requirement for survivability, the pilot safety was directly considered as part of this metric.” Overall, however, it appeared that students disagreed as to whether pilot considerations were inherent in the requirements document. In the case of Blake and Mitchell, Blake discussed how,

“The design project involved designing a close-air support vehicle. As such, I had to consider [*sic*] visibility angles for the pilots and have also had to keep in mind that the cockpit will need to be overdesigned since it will be shot at during the mission. Both of these relate to mission success, which is why I kept them in mind but had this not been a fighter aircraft I can understand how it would be easy to overlook pilot safety during the initial design.”

Mitchell viewed the project requirements from a different perspective:

“I put little thought into the overall satisfaction of pilot. The mission of this aircraft is to be able to provide close air support. This means to cut down on weight anywhere possible so more payload can be stored. If the means [*sic*] to cut pilots comfortability while in the cockpit then it must done. Most pilots who fly fighter jets aren't expected to be provided w/comfort but w/the tools to fly the

aircraft safe and soundly. I put more emphasis into the visibility angle which directly results to the safety of the pilot.”

The different perspectives of the role of stakeholders in the individual projects suggest that many students may have been unaware of how to evaluate already written requirements to identify and incorporate the considerations of the design’s stakeholders.

Students’ reflections about pilot considerations and their individual projects illustrate differences in students’ abilities to make connections between stakeholder considerations and aircraft design and students’ values as they relates to incorporating stakeholder considerations into an aircraft design. To capture these differences, the relatedness and perspectives categories described in Section 5.1.1 were used to code students’ responses. The results illustrated how 22 students (30%) demonstrated an inability to make connections between their work and, in this case, pilot considerations. Adam explained, for example, that he did not consider pilot safety or satisfaction, since “the project requirements do not require you to consider the safety of the pilots.” Sixteen students’ responses (22%), however, were classified as relatedness-positive. Adrian’s response, for instance demonstrated an understanding of the connections between the implicit survivability requirement, pilot safety, and a particular design decision:

“I considered safety heavily in this design as survivability is a primary consideration for an aircraft of this role. I included redundancy of control surfaces and Hot/Hi loading scenarios for example. At least in my mind safety is closely related to satisfaction, especially in a combat aircraft.”

The perspective category, on the other hand, captured students’ (in)abilities to see an aircraft from more than a standard performance perspective or to value the contributions of stakeholder perspectives. Of the 20 responses classified under the perspective category, 12 were coded as perspective-negative. Connor, for instance, described how he “did not consider safety/overall satisfaction of the pilots in the design because at that point, [he] was concerned with aircraft performance.” Jackson was one of

the eight students to discuss the inclusion of pilot considerations from a perspective-positive view. He explained how,

“Currently, the pilot's safety is one of my top three priorities influencing the design. I actually redesigned the entire fuselage because I thought the pilot was too exposed. A piloted aircraft, especially a military aircraft, rely on highly trained, calm pilots to accomplish its mission. The pilot must be confident that the aircraft will respond to him and will be safe.”

Overall, the students demonstrated an understanding about how the design could impact the pilot, either at this phase or in future phases, but many of them didn't identify the pilot as a stakeholder upfront (LO #3). In addition, for many of the students, the incorporation of both performance and stakeholder requirements, as discussed in LO #6, was not a priority at this point in the design process. The focus was on performance requirements.

Finally, it is important to mention that it was clear that some students were unable to consider the pilot in their first few design projects. For seven students, the high cognitive load caused by the baseline project requirements may have prevented them from incorporating the pilot considerations. Taylor, as an example, “did not elaborate much on that specifically, since it was not based on the requirements, so [he] tried to do as much work on what was asked for which made [him] forget about other important parameters.” Bryson, similarly, explained how “I did not consider the safety and satisfaction of the pilot at this point. I am just trying to get the aircraft to work first. Then I will consider the pilot.” Cognitive load is revisited throughout this study to understand if a relationship exists between high cognitive load in a design course and students' abilities to incorporate stakeholder considerations.

5.3.2 Active Intervention – Stakeholders in Design Labs

5.3.2.1 Resources and Processes

To examine the Stakeholders in Design Labs at the Resources and Processes level of the evaluation framework, students were asked to complete anonymous feedback forms at the end of the Stakeholders in Design Labs (see Appendix E.3). These reflection questions were similar to those used before and included a reflection question about the Requirements Lab:

- (1) In your opinion, what was the purpose of this lab session?*
- (2) What is the most important feedback you want the instructor to hear about today's lab?*
- (3) On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from the requirements lab session (presented in August) are to your senior design project for this upcoming spring semester?*
- (4) On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from the lab sessions from these last two weeks are to your senior design project for this upcoming spring semester?*

The responses were analyzed using the same inductive coding approach as with the Requirements Lab reflection questions. Of the 73 students that participated in the labs, 67% of the students (n = 49) provided positive feedback about the sessions. Sixteen students (22%) spoke positively about the interactive, hands-on, social constructivist techniques used (see Table 39). Students also enjoyed the case studies and presentation as well as the overall content of the lab. Four students (5.5%) mentioned the usefulness of the lab sessions. A couple of students suggested incorporating this information in AE lectures or prior to senior year. One student specifically mentioned that

“I think we should have learned about this way before senior year. We design things in previous classes which obviously aren't as good as they can be without fully considering stakeholders or design process properly.”

Table 39: Students' Positive Perceptions of the Stakeholders in Design Lab Activities and Design

Code	Example	# of Instances	% of Sample (N = 73)
General Positive Feedback about Lab Sessions Overall	<i>The lab is effective. It opened our eyes in understanding the thorough process of design</i>	15	20.6%
Content	<i>I think it is important in the senior design class to consider how the stakeholders of a typical design process will be affected.</i>	6	8.2%
Case Study & Case Study Presentations	<i>Presentations were cool, and having different projects between class groups made it interesting to listen to the different points of each program's design.</i>	9	12.3%
Usefulness	<i>I feel these are important concepts to learn and how they apply to real world cases. I feel this should be a permanent addition to senior design.</i>	4	5.5%
Pedagogical Techniques/ Social Constructivism	<i>Did a wonderful job interacting with the students. Instead of just lecturing or letting us work on one thing for 3 hours, it was interesting and interactive.</i>	16	21.9%

Students provided negative feedback about the duration of the two lab sessions once again (see Table 40). The sample of the student population who noted that the lab sessions were either too long or too rushed (n = 18, 24.7%) slightly decreased when compared with the results from the Requirements Lab (n = 23, 31.9%). Other students disliked the amount of readings within the case studies, while some students were confused by the readings and new terminology within the Human-Centered Design (HCD) methods activity.

Table 40: Students' Negative Perceptions of the Stakeholders in Design Lab Activities and Design

Code	Example	# of Instances	% of Sample (N = 73)
Content	<i>While stakeholder mapping is extremely important, it would have been nice to better synthesize other ideas into the design process.</i>	7	9.6%
Lab Session Activities	<i>Good lab, case studies were interesting; but lab was a little long and also activities could've been a little more interesting</i>	5	6.8%
Usefulness	<i>Tailor the lab to just consider the prelim design, so it is more relatable to our projects</i>	2	2.7%
Pedagogical Techniques/ Social Constructivism	<i>I think this was well done though perhaps a little bit more formality in the expectations and requirements may have made people take it a little more seriously and put more effort in.</i>	3	4.1%
Environmental Factors - Time	<i>SOOO LONG!!! Too much time spent doing group activities - sometimes that is good but with this content it just lengthened the lab</i>	18	24.7%

In the post-lab session reflection questions, students were asked to describe what parts of the labs they found most difficult (see Appendix E.3). Their responses were again evaluated using an inductive coding approach. The results aligned partially with the negative perceptions from the anonymous feedback forms. Ten students commented on the length of the lab sessions (Table 41). Five students reported difficulty with parts of the HCD methods activity and eight students mentioned challenges with the social constructivism components of the lab sessions. However, the component of the lab sessions that the most students cited as causing them difficulty was the design process development (n = 25, 34%). Jordan, for example, explained that in his opinion, it was difficult

“coming up with a neat, non-nebulous, complete design process that was flexible for different vehicles or requirements. (We are only students, and coming up with a process we expect to be handed down to us when we enter the job market is very, very daunting.)”

Eleven students noted difficulty with stakeholder integration, which included stakeholder mapping, the identification of stakeholders, and understanding stakeholders in general. Nine students discussed challenges with aspects design thinking. These challenges

captured students' lack of comfort with ill-structured, ill-defined, and open-ended problems and the need to broaden their perspective of design to incorporate the concepts from the lab sessions. Overall, the students highlighted areas for improvement within the lab sessions, which are addressed again later in this chapter and within Chapter 8. Still, many students appeared to appreciate the lab sessions and the pedagogical techniques used.

Table 41: Students' Perceptions of Difficult Concepts within the Stakeholders in Design Labs

Code	Example	# of Instances	% of Sample (N = 73)
Design Process Development	<i>The most difficult part was tracing through my thought process and creating a standard design process.</i>	25	34.3%
Environmental Factors – Lab and Activity Duration	<i>They are mind-numbingly long. But I suppose that's the time we are given</i>	10	13.7%
Pedagogical Techniques/ Social Constructivism	<i>Working with new random groups (not chosen by us)</i>	8	10.96%
Lab Activities (e.g., Case Studies and HCD examples)	<i>The most difficult part was understanding the human-centered design methods because it's different than we're used to</i>	10	13.7%
Stakeholder Integration	<i>Picking our specific ways the stakeholder affected the design - some are easy (epa \$, etc.) some such as the pilot/crew interactions become a little more complicated.</i>	11	15.1%
Design Thinking and Broadening Design Perspectives	<i>Weighing ambiguous topics and goals. The fact that there is not a right answer and that sometimes even an answer is not consistently agreed upon within a group. It is challenging to zero in on one solution when [an abundance] of possibilities exist.</i>	9	12.3%

5.3.2.2 Acquisition

The Acquisition level of the evaluation framework examines whether the learning objectives defined by the intervention were met and what the students learned as a result of participation in the lab. The analysis started by determining which learning objectives students discussed when describing the “purpose of the lab session.” Within the anonymous feedback form, students were asked to reflect upon the purpose of the lab session. These responses were coded based upon the two learning objectives defined within the intervention (see Table 42). Over 50% of the students (n = 41) noted that one

of the aims of the lab was to help them understand how stakeholder affect (or are affected by) the design process and a particular design solution (LO #1b). Over 30% (n = 26) discussed learning about the importance of stakeholders and being able to identify the different stakeholders for a given design (LO #1a). Many students (n = 9, 12%) perceived additional components to learning objective #2 (see italicized text in Table 42). Rather than only focusing simply on the assessment of different HCD-related methods, the students viewed this objective as also incorporating the ability to discuss different methods for incorporating stakeholder considerations into a design. For instance, one student described the purpose of the lab as “to get us to understand the importance of stakeholders in design process and the final product; see the various approaches used to satisfy stakeholders; incorporate the stakeholder-driven approaches into our own designs.” About 50% of students (n = 37) noted that one of the aims of the lab was to better understand the design processes, different approaches to design, and the various elements within the design process. As an example, one student explained,

“The purpose of this lab session was to give engineers information about things to consider when designing things, specifically aircraft. Most importantly the value of each step in the design process was considered along with the introduction of stakeholders and their importance.”

Finally, over 15% of the students (n = 13) mentioned that the purpose of the lab session was to have them develop their own design process to use on the team design project. Overall, this analysis indicated that students recognized the first learning objective as one of the aims of the lab session, while the activities and discussions within the lab prompted the students to realize additional learning objectives.

Table 42: Students' Perceptions of the Purpose of the Stakeholders in Design Labs

Learning Objectives	# of Students	% of Sample (n = 73)
(1a) Students will be able to identify different stakeholders of a fixed wing design (<i>Comprehension</i>)	26	35.6%
(1b) Explain how their concerns affect (or are affected by) the design solution (<i>Application</i>)	41	56.2%
(2) Students will be able to assess methods for integrating stakeholder considerations into the design process (<i>Analysis</i>) and describe different methods for ways to include the stakeholder in a design process	9	12.3%
(OTHER) Students will be able to discuss the design process, along with different approaches to design and the various elements within these processes.	37	50.7%
(OTHER) Students will be able to develop their own design process to use with their team design project which incorporates the lessons learned in these labs (e.g., how to incorporate stakeholder considerations).	13	17.8%
Other (e.g., <i>real world design, what design means to us, communication, "how to think", etc.</i>)	13	17.8%

The next analysis focused on students' perceptions of what they learned as a result of participation in the labs. Student responses to two of the reflection questions were coded inductively to understand the knowledge and skills students' perceived learning over the course of the two labs. On the anonymous feedback forms, students reflected on the most important feedback they would like to give the instructor. Within those responses, five students noted (1) developing a new understanding and perspective of the design process and/or (2) realizing the importance of considering stakeholders and the need to examine parameters related to stakeholders and the environment within the design process. One student, when describing their experience explained, "the lab gave me different perspective into design process and I am able to look into different parameters such as stakeholders & environment into account [*sic*]."

In the post-lab reflections, students discussed which part of the lab they found most surprising. Many students focused on design and the design process. Twenty-five students (34%) noted how much they had learned about the different approaches to the design process over the course of the two labs (see Table 43). For example, Gavin described "how intensely iterative and in depth the design process can be," and Zachary

explained how “it was surprising how many approaches to design process exist.” From the perspectives of the students, the case studies demonstrated how an aircraft design firm might design an aircraft and the successes and challenges design engineers face throughout the design process. Hunter specifically noted “the amount of time it takes to design & develop an aircraft & the number of people involved in the process.” These reflections emphasize how students viewed discussions about design processes and approaches to design as critical components of these lab sessions.

When discussing the role of stakeholders within the design process, 12% of the students (n = 9) noted their surprise in learning how performance parameters drive design within aerospace and how that influences the integration of stakeholder considerations into a design solution. Students also mentioned both learning objectives as concepts which surprised them during the lab session. For example, seventeen students (23%) were surprised how stakeholders impact (and are impacted by) design decisions and the overall design process, which was part of learning objective #1. Learning objective #2 was captured through six students’ responses (8%) about the different approaches for integrating stakeholder considerations. In Jackson’s response, for instance, he described, “understanding, all of a sudden, how biased aircraft design is to value centric methods, and that sometimes that isn't necessarily a good thing.” Finally, seven students (9.6%) mentioned that the labs helped them recognize how they previously had not considered all of these stakeholders when thinking about their designs. Blake noted his surprise in “how little I as a designer think about the effects of my design on the user.” These discussions suggest that this active intervention supported student learning about the design process, different approaches to design, and the role of stakeholders within the design process.

Table 43: The "Surprising" Parts of Students' Experiences in the Stakeholders in Design Lab

Code	Example	# of Instances	% of Sample (N = 73)
Approaches to the Design Process	<i>That there are so many different design processes; I always just assumed you just built whatever was required.</i>	25	34.25%
Design in Industry	<i>How design processes from established companies, such as Gulfstream, made such large errors during their design processes</i>	13	17.8%
Aerospace Engineering and the Integration of Stakeholder Considerations	<i>The fact that human centered design is often neglected in aerospace industry, even though it is mainly built for humans for better life quality</i>	9	12.3%
Importance of Stakeholder Considerations (LO #1a)	<i>The sheer variety and complexity of stakeholders, and how/why they are significant to design.</i>	12	16.4%
Design Decisions and Stakeholder Considerations (LO #1b)	<i>The extent to which stakeholder considerations can make or break a design process</i>	17	23.3%
Approaches for Integrating Stakeholder Considerations (LO #2)	<i>How involved stakeholders can be in the design process. They are the driving factor in most processes and can make or break a design.</i>	6	8.2%
Stakeholders Not Considered Previously	<i>The detail of the stakeholders. Would never have thought to include all of the important stakeholders like maintenance, passengers, manufacturers, would have just designed something and expected it to be built and implemented.</i>	7	9.6%

The next analysis examined whether the learning objectives were achieved based on the observations and formative assessments (see Table 44). The first learning objective focused on students' ability to identify the different stakeholders and describe how their concerns affect (or are affected by) a design solution. In the case study assignment, students were split up into 16 groups, and each group was required to create a stakeholder mapping for their particular case. This stakeholder mapping needed to include all of the different relevant stakeholders for this design and connections between those stakeholders, the design requirements, and the specific impacts of those stakeholders on the final design solution. The following three-point rating scale was used to evaluate each group's stakeholder mapping:

- *Needs Improvement* – Only identified stakeholders and did not consider connections to design solution OR did not identify most of the stakeholders within the case,
- *Acceptable* – Identified most or all of the stakeholders and included some of the connections to the design requirements and impacts, and
- *Exhaustive* – Included an exhaustive discussion of the design’s stakeholders, associated design requirements, and the impact of stakeholders on the design solution.

Table 44: Data Analysis Methods and Results Summary for Evaluation of Stakeholder in Design Labs Learning Objective Achievement

Learning Objective	Data Analysis Method	Overarching Result
(1) Students will be able to identify different stakeholders of a fixed wing design and explain how their concerns affect (or are affected by) the design solution (<i>Comprehension & Application</i>)	Examination of stakeholder mappings within the case study presentations using rating scale	Most groups (10 of 16) successfully identified the stakeholders and connected their considerations to requirements and design impacts.
(2) Students will be able to assess methods for integrating stakeholder considerations into the design process (<i>Analysis</i>) and describe different methods for ways to include the stakeholder in a design process	Qualitative evaluation of the observations and notes from the board during the HCD methods activity	Students were able to discuss and assess the different HCD methods presented. However, misconceptions about some of the methods may have developed over the course of this activity.
(OTHER) Students will be able to discuss the design processes, along with different approaches to design and the various elements within these processes.	Examination of design processes within the case study presentations using rating scale	Most groups (13 of 16) were able to successfully understand and discuss different approaches to design. The groups who needed improvement on their processes did not create process models, but, instead, included a list of actions.
(OTHER) Students will be able to develop their own design process to use with their team design project which incorporates the lessons learned in these labs (e.g., how to incorporate stakeholder considerations).	Examination of students’ design processes. Metrics included: shapes of design process flow, number of iteration points, integration of stakeholders.	Most groups found ways to incorporate stakeholders into their design process. 10 of 16 considered stakeholders at more than one point in the design process. The number of iteration points within their design process increased over the course of the labs (ED5).

In the case study activity, most groups (10 out of 16) developed acceptable or exhaustive stakeholder mappings which considered many stakeholders (see Table 45). These considerations motivated much of the discussion during the presentations. The groups who needed to improve their mappings either did not clearly include all the stakeholders discussed in the cases and/or did not map the stakeholders to the design

requirements discussed in the cases. Three examples are included in Figure 20-7. The first example is a group who developed an exhaustive mapping and in the development of this mapping realized that the B-2 design team did not consider the U.S. taxpayer as a stakeholder. In the second example, the group captured a diverse group of stakeholders affected during the design of B-2, but could have examined other stakeholders and included more specific information about the design requirements related to those stakeholders. Finally, in Figure 22, the group included most of the stakeholders, but didn't discuss their impact on the design solution or design requirements.

Table 45: Case Study Assessment Scores [NOTE: Section I groups are denoted by “a” following their group number, while Section II groups are denoted by a “b” following their group number]

Group	Case	Design Process Understanding Score	Stakeholder Integration Score
3a	Boeing 747	Needs Improvement	Needs Improvement
8a	Boeing 747	Acceptable	Acceptable
2b	Boeing 747	Acceptable	Exhaustive
4b	Boeing 747	Acceptable	Acceptable
6a	B-2	Acceptable	Acceptable
7a	B-2	Exhaustive	Exhaustive
1b	B-2	Exhaustive	Acceptable
5b	B-2	Exhaustive	Needs Improvement
2a	F-111	Acceptable	Needs Improvement
5a	F-111	Needs Improvement	Needs Improvement
6b	F-111	Acceptable	Acceptable
7b	F-111	Exhaustive	Acceptable
1a	Gulfstream 3	Needs Improvement	Needs Improvement
4a	Gulfstream 3	Acceptable	Needs Improvement
3b	Gulfstream 3	Acceptable	Acceptable
8b	Gulfstream 3	Acceptable	Acceptable

B-2 Stakeholder Mapping

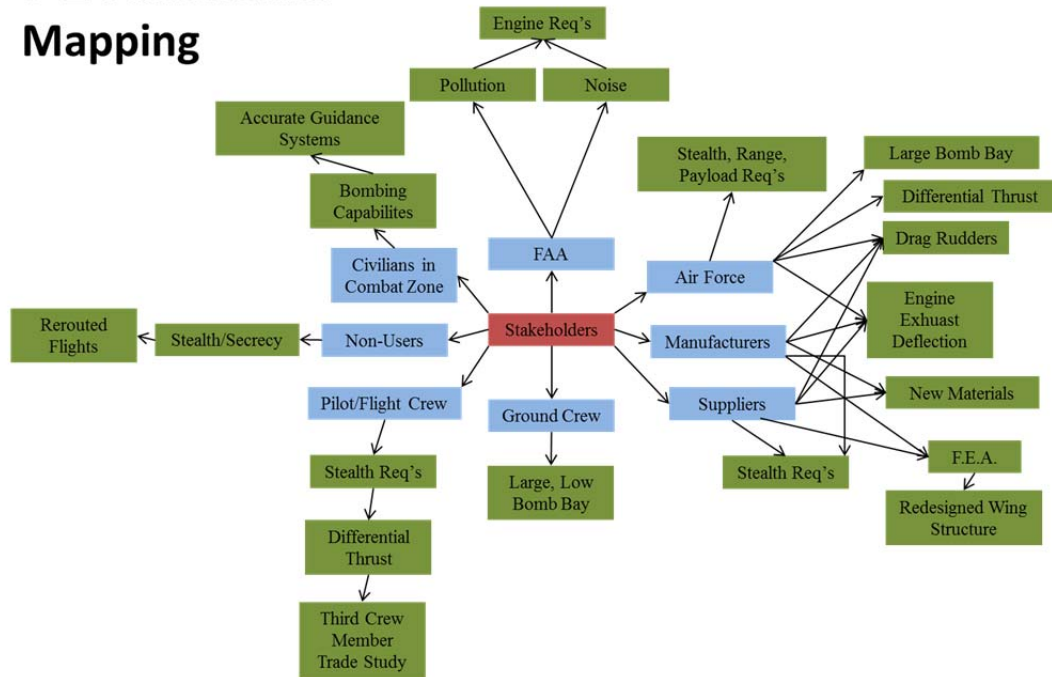


Figure 20: Group 7a Exhaustive Stakeholder Mapping of the B-2 Case Study

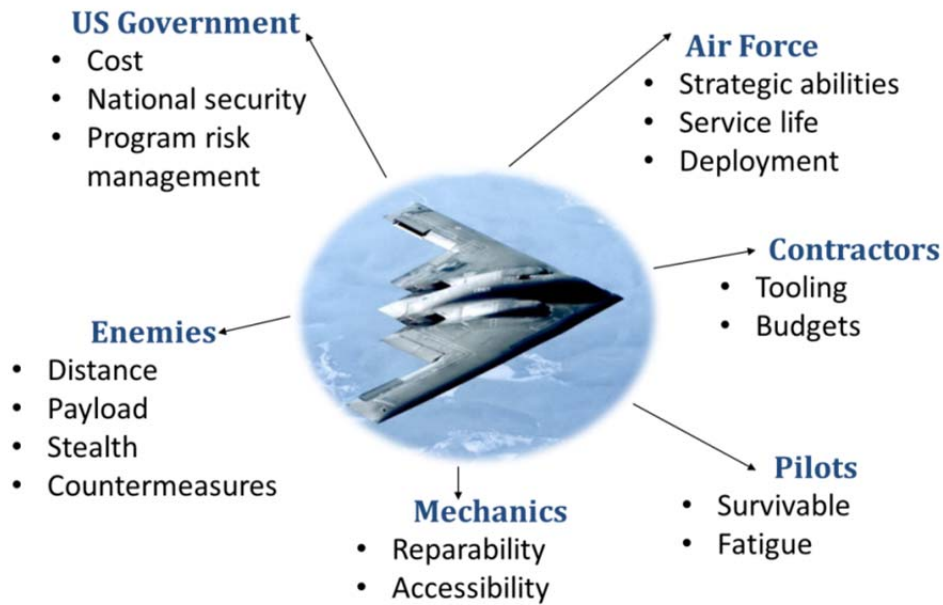


Figure 21: Group 1b Acceptable Stakeholder Mapping of the B-2 Case Study



Figure 22: Group 5b Needs Improvement Stakeholder Mapping of the B-2 Case Study

Another requirement of the case study deliverable was a model of the design processes used by the aircraft design teams. From the feedback forms, students noted an objective of the lab was to help them understand and discuss different approaches to design and the various elements within these processes. This case study deliverable can thus be used as a formative assessment of this additional learning objective. The following three-point rating scale was developed to evaluate the design processes within the deliverable:

- *Needs Improvement* – Demonstrated some understanding of the elements of the design process, but either needed to elaborate on the various elements or transform the elements into an actual process,
- *Acceptable* – Demonstrated clear understanding of the design process used in their case study & portrayed it clearly to audience, or
- *Exhaustive* – Went above and beyond in their portrayal of the design process used within the case study.

Most groups (13 of 16) created acceptable or exhaustive models of the design processes examined (see Figure 23 and Table 45). The groups who needed improvement on their processes did not create process models but, instead, included a list of actions

(see Figure 24). A couple of the groups created elaborate models of the design processes (see Figure 25). In addition, one of the groups thought holistically about the processes and noted a difference between the design process they use in the aircraft design capstone course, which they called focus-based, and the industry design process, which was described as filter-based.

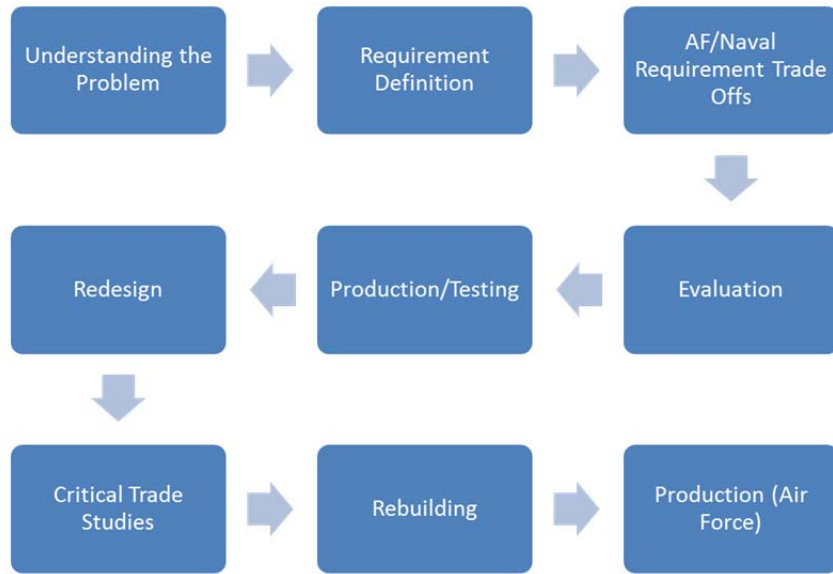


Figure 23: Example of an Acceptable Design Process for the F-111 Case Study

Design Process

- They did not understand the problem.
- We iterated and compared while they lacked the trade-off studies.

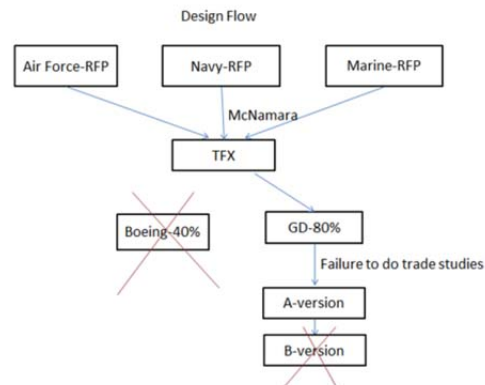


Figure 24: Example of a Needs Improvement Design Process for the F-111 Case Study

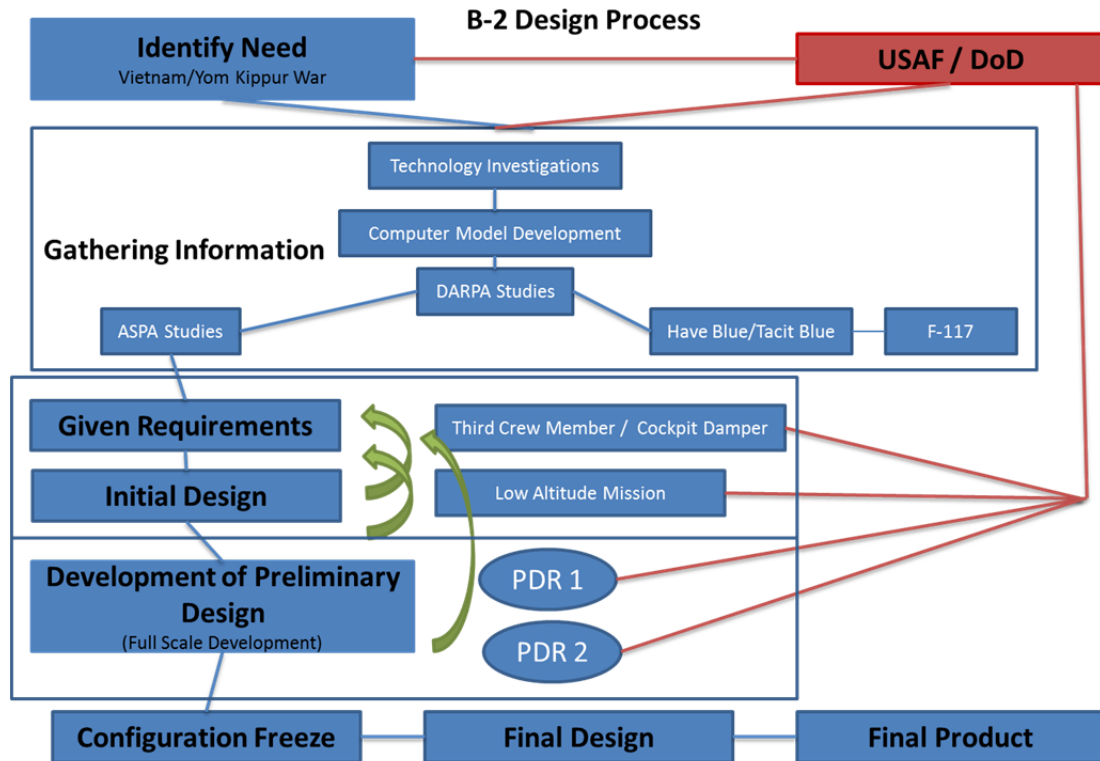


Figure 25: Example of an Exhaustive Design Process for the B-2 Case Study

Learning objective #2 focused on students' understanding and assessment of different methods for incorporating stakeholder considerations into a design. In the second session of the Stakeholders in Design labs, students learned about different approaches, such as Value-Driven Design and Participatory Design, for integrating stakeholder considerations within a design process. Through observations of students' small-group discussions and a class-wide discussion, it appeared that students were able to describe the approaches and discuss their advantages and disadvantages (see Figure 26).

Human-Centered Design (1 vote)

- Good communication/satisfied stks
- Good for redesign of components that effect fewer stakeholders
- Could help to cut down number of iterations in conceptual design process
- End-user focused design
- Performance profitability
- Limited in scope
- Requires prototyping
- Limits number of users
- Rapid prototyping
- Modify design
- Can have too many hands in DP

Participatory Design (16 votes)

- Simple (no additional design step)
- Effective
- Allows end user to evaluate a product before mass production
- More voices/input
- More decisions based on trade-offs
- Requires a prototype
- Assumes user knows what's best for themselves

Figure 26: Section I's Advantage (Green Text) and Disadvantage (Black Text) list for Human-Centered Design and Participatory Design Methods [NOTE: The votes are the number of students who voted to use principles of that method in their team design project.]

Still, the HCD methods activity may have created some confusion among the students. In the feedback questions discussed earlier, students discussed their confusion about the terminology used within some of the methods and some advantages and disadvantages recorded by students did not correctly map to the method. For example, students noted one of the disadvantages to the Human-Centered Design and Participatory Design methods was the requirement of prototypes. However, while prototypes are commonly used in these methods, they are not required. This confusion may have affected students' understanding of which methods were appropriate for use in their team design project.

Based on the in-class votes, the majority of students from both sections preferred the idea of using Value-Driven Design or Participatory Design to the other options. In Section I, the votes were split 18 for Value-Driven Design and 16 for Participatory Design. In Section II, Value-Driven Design received 27 votes and Participatory Design received 10 votes. The discussions of the advantages and disadvantages of each method suggest that those who voted for Value-Driven Design wanted a method which was “the

most effective” and “could consider both qualitative and quantitative aspects.” Both sections also described this method as the method that “pleases the important stakeholders.” The Participatory Design votes, on the other hand, aligned with the students’ modifications to their initial design process. The student-generated design processes (described in greater detail in the subsequent sections) illustrated students’ belief that access to stakeholders was the one of the main methods for integrating stakeholder considerations. Twelve of the 16 groups discussed “interactions with stakeholders” as one way they would incorporate stakeholder considerations into their team design project.

One of the tangible takeaways from the Stakeholders in Design Labs was the student-created design processes, intended to be used as guide at the start of their team design project at the start of the second semester. The student groups created an initial design process at the start of the first session and revised their design process at the end of the second session. Each design process was created on poster paper with markers and sticky notes. Following the lab sessions, the design processes were photographed and recreated electronically. Effort was made to accurately represent the students’ design processes electronically. To determine whether students achieved the final emerging learning objective, each design process was evaluated using the following metrics:

- *Classification of the Process* (i.e., was it a list, a circular process, a vertical flow, etc.) (Mosborg et al., 2005)
- *Stakeholder Integration Score* –
 - 0pts – No mention of stakeholders
 - 1pt - Stakeholders integrated in the last half of the design process ONLY
 - 2pts - Stakeholders integrated in the first half of the design process ONLY
 - 3pts - Stakeholders integrated in two places within the design process
 - 4pts - Stakeholders integrated in three or more places within the design process

- *Iteration Points* – Score captures students’ understanding of iteration within a design process by counting the number of iteration points within the process drawings.
- *Stakeholder Integration Activities* – Classification of the activities where students integrated stakeholder considerations explicitly

When examining the design processes developed by these student groups at the start of the lab sessions, six of the 16 groups created list design processes, 4 groups developed horizontal flows and 6 vertical flows. In other words, the processes were mostly linear. While iterations were included in most of the design processes (an average of 2 iteration points across the 16 groups), the majority of the groups (n = 12) included iteration only as a step or sub-step within their design process, as compared to indicating that iteration may need to cycle back to earlier stages of design or repeat more than once. Additionally, one group did not include any form of iteration. The highest number of iterations points was Group 3 in Section I with 3 iteration steps and 3 iteration arrows (see Figure 27). For comparison, at the start of the active intervention, only one group (see Figure 27) had included stakeholders within their design process by noting a need to identify the stakeholders early in the design process and to present the design to stakeholders to get feedback once the configuration had been frozen. The classification for each group’s design process is included in Table 46.

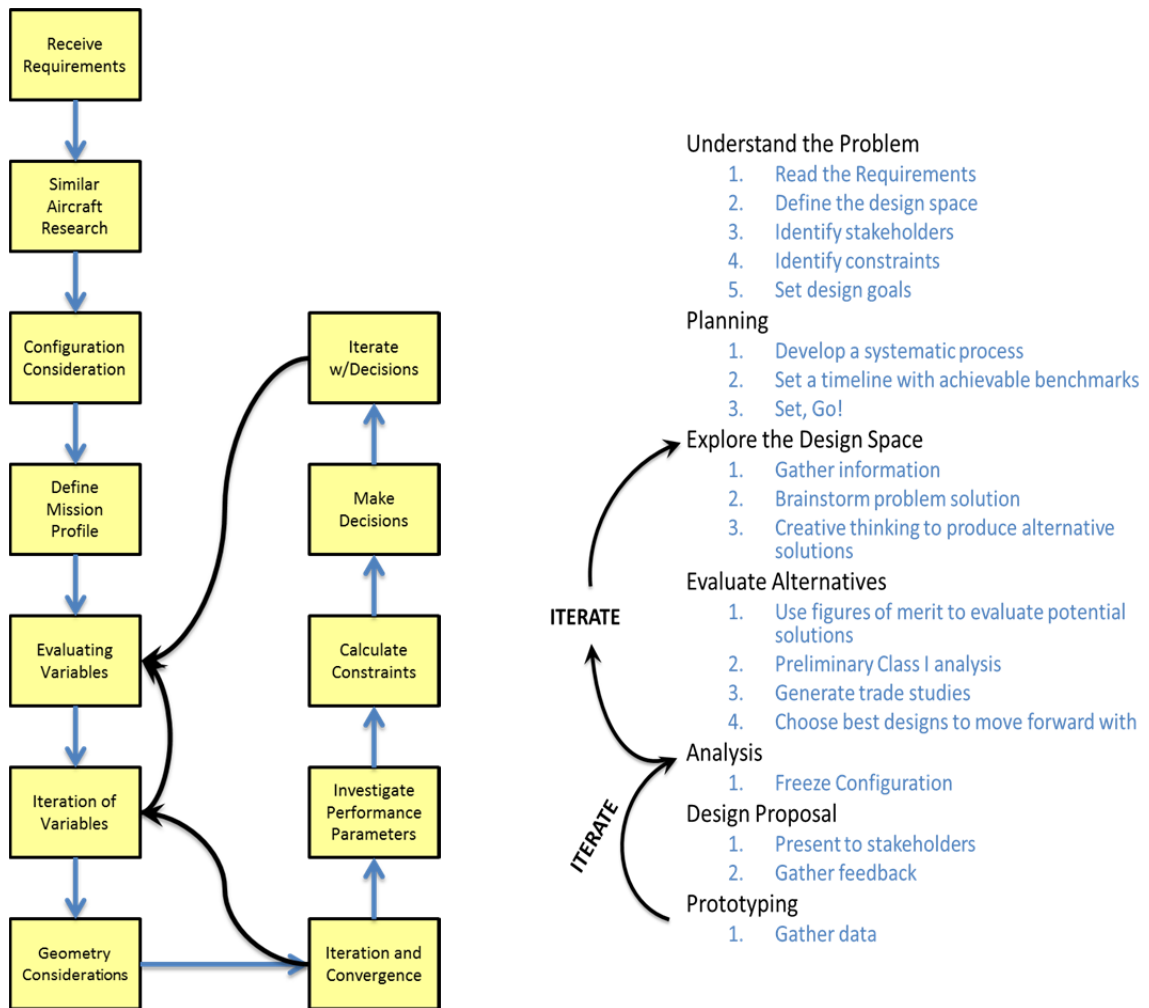


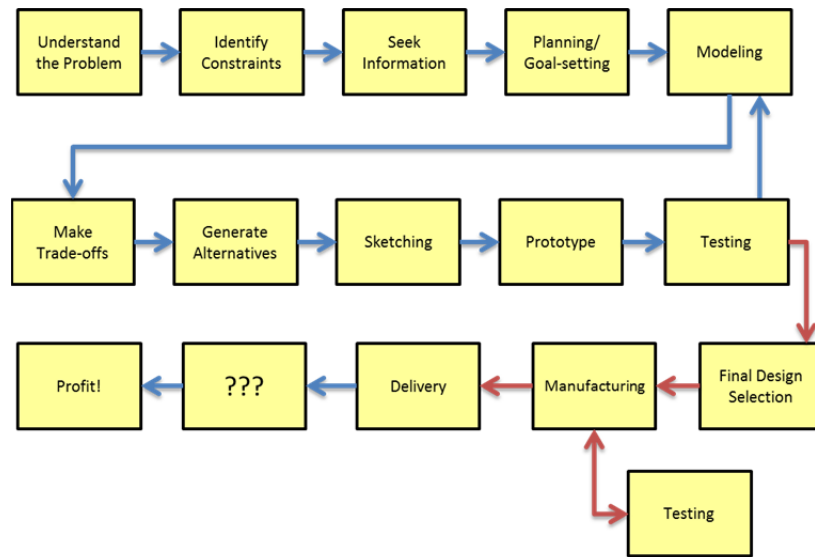
Figure 27: Initial Group Design Processes [Left: Group 3 – Section I, Example of Highest Number of Iteration Points; Right: Group 1 – Section II, Example of Only Design Process to include Stakeholders]

The final design processes included 6 lists, 7 vertical flows, and 3 horizontal flows. While there was no decrease in the number of lists, three of the final design processes included circular components, which suggests a small deviation from linear design processes. In terms of iteration points, using a Wilcoxon Signed Ranks Test, the number of iteration points was found to have increased significantly over the course of the lab sessions, $Z = -2.008$, $p < .05$, $r = -0.35$. Every group included iteration either as a step or among steps with 10 groups including steps and 11 groups including iterations among steps. Group 5 from Section II did not have any iteration points in the initial

process; however, iteration was one of their constant processes in their final design process (see Figure 28). Overall, the results, as illustrated in Table 46 suggest an increase in students' understanding of iteration as a critical component within the design of complex systems.

Table 46: Examination of Student-Generated Design Processes

	Group #	Classification of Sketch	Stakeholder Integration	Iteration Points	Classification of Sketch	Stakeholder Integration	Iteration Points
	Initial Design Process				Final Design Process		
Section I	1a	Vertical flow	0	1	Vertical & circular	2	3
	2a	Horizontal flow	0	4	Horizontal & circular	4	6
	3a	Vertical flow	0	6	Vertical with iterations	4	6
	4a	List	0	2	List with iterations	4	4
	5a	List	0	2	List - <i>communication</i> down the side	4	1
	6a	List	0	2	Vertical flow	3	2
	7a	Vertical flow	0	1	Vertical flow	4	1
	8a	Vertical flow	0	1	Vertical with iterations	3	3
Section II	1b	Vertical flow	3	2	List with iterations	4	3
	2b	List	0	1	List	4	1
	3b	List	0	1	Vertical flow	0	1
	4b	Horizontal flow	0	1	List and circular	0	1
	5b	Horizontal with constant process	0	0	Horizontal flow with constant process	4	1
	6b	Horizontal with vertical substeps	0	2	Horizontal with vertical substeps	1	3
	7b	Vertical flow	0	3	Vertical flow	2	2
	8b	List w/notes	0	3	List with more notes	2	3



CONSTANT PROCESSES

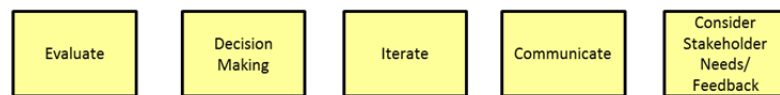


Figure 28: Group 5 – Section II Final Design Process [NOTE: The group included iteration as a constant process, after having not included any iteration points in the initial design process.]

Finally, 14 of the 16 groups incorporated stakeholders into their final design process. Ten of those groups considered stakeholders at more than one point in the design process with nine groups including stakeholders in three or more places within the process (see Figure 29 for an example). Using a Wilcoxon Signed Ranks Test, the increase in stakeholder considerations was found to be significant with a large effect size, $Z = -3.347$, $p = 0.001$, $r = -0.598$. The most common way students integrated stakeholders into their design process was through interactions with stakeholders. Twelve groups discussed different iterations with stakeholders as part of their processes, from testing to presenting to seeking information from stakeholders. Other groups mentioned identifying stakeholders as part of their design processes (5 groups), researching stakeholder needs (3 groups), prioritizing or determining value of value of stakeholders (3 groups), and evaluating the design with stakeholders in mind (5 groups). Still, two groups did not include stakeholders in their final design process (see Figure 30). Overall, however, these

different analyses demonstrate not only how the learning objectives were met by most of the students, but also how the stakeholder-centric focus supported students' integration of stakeholder considerations in a variety of different ways in their final design processes.

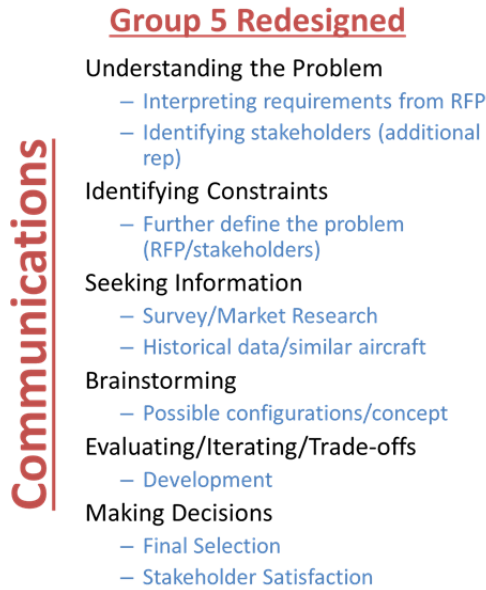


Figure 29: Example of Stakeholder Integration in the Final Design Process within Three or More Places

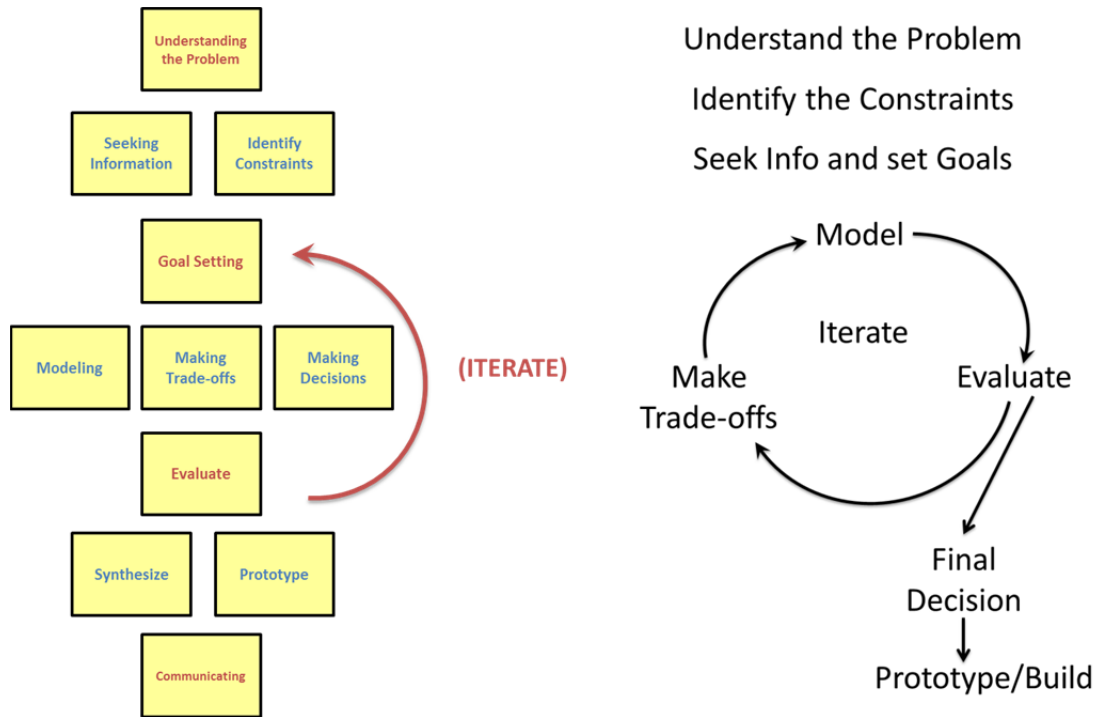


Figure 30: Final Design Processes with No Integration of Stakeholder Considerations

The final analysis of students' acquisition of knowledge and skills from the Stakeholders in Design Labs evaluated students' post-lab reflections to see if students perceive that they will integrate stakeholder considerations into the team design project. Specifically, students were asked whether they believed that their team would take into consideration stakeholder satisfaction and safety in their design project. Students' responses were separated into affirmative and negative classifications, and then an inductive coding approach was used to categorize the reasons why students responded in a certain manner. Overall, 46 of the 73 students who responded (63%) said that they believed that they would consider stakeholders within their team design project. Only five (6.8%) said they would not incorporate stakeholder considerations, while 22 students (30%) mentioned that they may consider the safety and satisfaction of the different stakeholders.

Access to tools and greater awareness of stakeholder considerations were some of the main reasons why students believed they would consider stakeholders within their team design project (see Table 47). Owen, for example, explained that, "the project is a mystery and not all elements may apply but this [experience] has certainly given me the tools to take a new perspective in terms of understanding stakeholder concerns as they relate to the real-world industry." Beyond the most common reasons, students also believed they would consider stakeholders because it would help them achieve a better design or because they have a greater understanding of stakeholders. Additional reasons included access to stakeholders and the fact that stakeholder considerations are important in the real world.

Table 47: Most Common Reasons Students Present for Incorporating Stakeholder Considerations into Team Design Project

Reasons	Example	# of Instances	% of Sample (N = 73)
They have the tools to do so (e.g., design process, information, etc.)	<i>Yes because in our design process we include a lot of time in the research section which will include discovering safety aspects and researching who all of the stakeholders are that are involved with the project.</i>	13	17.8%
They have a greater awareness of stakeholders (and their importance)	<i>Yes. This lab adds perspective that our designs are not solely about performance, and other stakeholders need to be accounted for.</i>	15	20.5%
They have the skills and knowledge to consider stakeholders	<i>We are very limited in the amount of feedback which we can get from our stakeholders so it will be difficult to fully meet their satisfaction and safety requirements, however based on the skills we've learned and the fact we will specifically consider each stakeholder, it is likely we will produce a design that meets a majority of their needs.</i>	7	9.6%

The main reasons for not including stakeholders were based on concerns about lack of access to stakeholders and the type/focus of the team design project requirements (see Table 50). For those students who believed they would not consider stakeholders in their projects, additional reasons included a lack of information and skills. Students also mentioned how considering stakeholders is not something they would normally do; therefore, they would need to be more conscientious about it during the design process. Furthermore, Mason noted how much time it would take to “just meet the set project requirements,” which reflects apprehension that cognitive load could prevent him, or others, from integrating stakeholder considerations into the team design project.

Table 48: Most Common Reasons Students Present for not Incorporating Stakeholder Considerations into Team Design Project

Reasons	Example	# of Instances	% of Sample (N = 73)
They don't have access to stakeholders (to ask questions to or get feedback from)	<i>No, I do not believe we will have an accurate idea of stakeholder satisfaction. The RFP will define requirements but communication with stakeholders can't happen.</i>	11	15%
The project will not (may not) have a focus on stakeholders (or include stakeholder-related requirements)	<i>Unsure. It depends on how stakeholder sensitive the project will be, how well-defined/constrained the requirements are, and what kind of teammates I'm paired up with.</i>	8	11%
The students won't have time or the resources	<i>No, within the given time, it is hard to accommodate every single stakeholder into account; thus, I will need to rank who or which one is the most important one among the lists.</i>	5	6.8%

Twenty-seven of the responses discussed how stakeholder considerations do or do not fit within the aircraft design learning environment. Ten of these responses discussed tools or characteristics of the environment which permitted stakeholder considerations to be integrated into the team design project, while 17 focused on how the integration of stakeholder considerations was not possible in this learning environment (see Table 49). As James explains, “we will be able to consider safety, but not to a high extent due to resource constraints as well as dealing just with a theoretical project.”

When examining students' responses for relatedness or perspective discussions, seven responses described an (in)ability to make connections between aircraft design and stakeholder considerations (see Table 49). Six of these responses were positive, showcasing students' abilities, and one was negative. The perspective category was used to classify 10 of the responses (see Table 49). Only one of the responses was considered to illustrate a negative perspective about integrating stakeholder considerations, while 9 had a positive classification. When looking back at their previous projects in the pre-lab reflections, students attempted to make connections between their work and stakeholder considerations or shared some of their values in their responses. From the analysis of the post-lab reflections, the data suggest that students view the tools, the project

requirements, and the environment as impacting their integration of stakeholder considerations, rather than their individual abilities or values.

Table 49: Students' Reflections about their Team Design Project - Relatedness, Perspective, and Fit

Relatedness/ Perspective	Positive/ Negative	Response
Relatedness	Positive	<i>I believe yes, I will be paying greater attention to the design decision I make and evaluating possible results and their effects on each party involved.</i>
		<i>I believe most of the safety and satisfaction of stakeholders will not be considered. For instance, the project this semester would require a lot more protection around the pilot from ground fire. However, most people aren't going to add that extra weight. Since we unfortunately don't get to create anything real, these aspects will be overlooked.</i>
	Negative	<i>No, I do not believe we will have an accurate idea of stakeholder satisfaction. The RFP will define requirements but communication with stakeholders can't happen.</i>
Perspective	Positive	<i>Absolutely. In order to be successful, and to have a winning design this must be done.</i>
	Negative	<i>Yes we will likely consider the users as it leads to a better aircraft design, or at least more realistic airplane design.</i>
Fit	Positive	<i>To some extent I will most likely be more aware of considering users from things other than a performance standpoint, though I still think my main concern will be performance. This is because the aircraft industry today seems to be focused on meeting regulations & requirements as efficiently as possible, not things like comfort & non-user satisfaction.</i>
		<i>I think we will but I think it will require consciously taking a minute to step back and analyze. It isn't the most natural thought as a designer and until it becomes natural we will need to be sure to consider it throughout the design process.</i>
	Negative	<i>Yes because in our design process we include a lot of time in the research section which will include discovering safety aspects and researching who all of the stakeholders are that are involved with the project.</i>
		<i>Yes, we are more than capable; however [the university] puts the probability of us instituting this knowledge in our design very low. Should we have a senior design like Cincinnati, there would be actual stakeholders and we would ensure human factor compliance.</i>
		<i>Yes. We will know what to look for beyond the RFP. It will be more limited since we do not have access to focus groups, but we can keep stakeholders in mind.</i>

5.3.2.3 Application

As previously discussed, the evaluation of whether students applied knowledge and skills from the Stakeholders in Design Labs “on the job” is described in detail within Chapter 6. However, as with the Requirements Lab, students were asked on the anonymous feedback form about their perceptions of the importance of these labs to their

team design project. Based on students' responses immediately after the lab sessions, students' perceptions of the relative importance (Median: 8.0) aligned with students' perceptions of the Requirements Lab (Median: 8.0) with a range of scores from 1 to 10. Students provided positive and negative feedback about the labs when rationalizing their scores. When these responses were coded using the relatedness and perspective categories, the results indicated four relatedness-positive comments, 2 relatedness-negative comments, 5 perspective-positive comments and 5 perspective-negative comments (see Table 50). In addition, seven students explicitly noted that they did not believe the content of the lab fit within the aircraft design learning environment. One student provided the following reasoning for their score: "In terms of the grade: 5, In terms of learning to be a good engineer: 10." The diversity of viewpoints did not permit the use of this analysis to predict students' future performance, but the analysis in Chapter 6 provides more information about the effect of these perceptions on students' integration of stakeholder considerations.

Table 50: Relatedness and Perspective-related Comments within Discussion of Stakeholders in Design Lab Importance Relative to Team Design Project

Relatedness/ Perspective	Positive/ Negative	Lab Importance Score	Response
Relatedness	Positive	10	<i>Stakeholders have a large influence in determining requirements</i>
		7	<i>It will help us make sure all stakeholders are considered in design, but still a small part of the overall project.</i>
	Negative	5	<i>But it really depends on whether it is another military aircraft that has a lot of set requirements that need to be met before other stakeholders are involved.</i>
		3	<i>3 - I plan to mainly focus on performance and a modified Roskam method next semester, not "the design process" & stakeholders, though it is nice to know that they should be considered.</i>
Perspective	Positive	10	<i>10 - we design for the stakeholders considering them is very important.</i>
		8	<i>Being able to incorporate stakeholders more effectively in the design process should yield more promising results.</i>
	Negative	6	<i>6, though important, this won't affect my grade as much as requirements.</i>
		7	<i>I think it is relevant and important to consider stakeholders but is not everything.</i>

5.4 Discussion and Summary

Overall, the evaluations of the active interventions, as presented in this chapter, focus on understanding students' experiences in the lab sessions. As such, the findings begin to answer Research Questions 4.1 and 4.2:

- RQ#4.1 - What characteristics of the educational interventions support students' abilities to integrate stakeholder considerations into the design of an aerospace vehicle?
- RQ#4.2 - To what extent can the interventions help students integrate stakeholder considerations into the design of an aerospace vehicle?

In addition, the results provide evidence of the educational intervention specifications within students' experiences during the active interventions (see Table 51).

The Requirements Lab received generally positive feedback from the students and students appeared to capture the main concepts and skills from the lab. However, the

stakeholder-centric focus of the lab may have been obscured for some students completely, or only partially, within the requirements content. Still, the first active intervention introduced students to the concept of stakeholders which provided the students with some foundation prior to the start of the second active intervention. In addition, the most common method of incorporating stakeholder considerations that students included within their final design process was “interacting with stakeholders.” This result suggests that students saw value from their interactions with stakeholders in the Requirements Lab and see value in the perspectives of stakeholders, who may or may not be aerospace engineers (ID5 and ED4). Chapter 6 revisits students’ adoption of lab concepts and skills, as evidenced by an in-class evaluation and the team design projects, to further evaluate the effectiveness of the Requirements Lab.

As is discussed more thoroughly in Chapter 8, future iterations of the Requirements Lab should be more stakeholder-centric and include a focus on how to evaluate given requirements, especially within courses focused on conceptual aerospace vehicle design. Within this lab, students should view stakeholder identification as part of this process and the lab should provide students with an opportunity to practice how to incorporate stakeholder considerations based on a given set of requirements. With these improvements, this lab can help students integrate knowledge about stakeholder considerations at the start of the design process.

The stakeholder-centric learning environment (ID1) created within the Stakeholders in Design Labs supported students’ understanding of aircraft design stakeholders and why their considerations are important to designers. The use of real-world case studies not only demonstrated the impacts of integrating (or not integrating) stakeholder considerations, but also helped students recognize different approaches to design and the importance of iteration within the design process (ED5). Additionally, in the reflections, students discussed how the case studies illustrated some of the challenges of cross-disciplinary design (ID4 and ID5). While by the end of both active interventions

students appeared to grasp the concept of stakeholders and a stakeholder mapping, the language and terminology of HCD methods (ID2) caused confusion for some students who were unfamiliar with concepts related to HCD. Finally, aspects of the labs influenced how students view their ability to incorporate stakeholder considerations into their team design project. The data suggest that students view the tools, the project requirements, and the environment as affecting their integration of stakeholder considerations, rather than their individual abilities or values.

This chapter serves to introduce the short-term impacts of the Stakeholders in Design Labs by examining students' experiences during the labs. Chapter 6 and 7 further explore the effect of the Stakeholder in Design Labs, and the other interventions, on students' integration of stakeholders within the class and the team design project. Then, Chapter 8 revisits both interventions to provide recommendations for additional improvements to the instructional activities and overall design.

Table 51: Examination of the Interventions based on the Education Intervention Specifications

#	Educational Intervention Specifications	Used in the Design of:	Based on Implementation
ID1	Shall create a stakeholder-centric learning environment with activities structured to encourage students to appropriately value stakeholder considerations in their design activities.	Framing of Both Interventions	The stakeholder-centric learning environment was developed most successfully in the Stakeholders in Design Lab
ID2	Shall introduce a language and vocabulary for discussing stakeholder considerations and the role of stakeholders in design.	<i>Requirements Lab:</i> Intro. to "Stakeholders" <i>Stakeholders in Design Labs:</i> HCD Methods	Students became familiar with "stakeholders" and "stakeholder mapping," but the HCD methods introduced may have caused some confusion.
ID3	Shall provide students with tools and resources that can bridge their current approach to aircraft design with an approach that incorporates stakeholder considerations explicitly.	<i>Requirements Lab:</i> Identify Stakeholders <i>Stakeholders in Design Labs:</i> Stakeholder Mapping & HCD Methods	Stakeholder Mapping, along with other approaches shared in the final design processes, could be used by students in their team design projects.
ID4	Shall provide students with experiences and training in cross-disciplinary problem-solving	<i>Stakeholder in Design Labs:</i> Case Studies	Students were introduced to some of the challenges of cross-disciplinary design.
ID5	Shall demonstrate to students the value of cross-disciplinary work and examinations of designs from multiple perspectives .	<i>Stakeholder in Design Labs</i>	The final design processes illustrated students' perceptions of the value of interacting with stakeholders.
ED1	Shall increase students' awareness of contextual and stakeholder-related considerations.	<i>Requirements Lab & Stakeholders in Design Labs</i>	Students have developed a greater awareness of stakeholder considerations.
ED2	Shall highlight the importance of considering context and a variety of stakeholders , beyond simply the economic context and the customer.	<i>Stakeholders in Design Labs:</i> Learning Objectives & Case Studies	Whether they integrate these stakeholders into their projects, the students are aware of the diverse group of stakeholders impacted by an aircraft design.
ED3	Shall introduce students to methods for explicitly incorporating stakeholder considerations which are novel or qualitative in nature and may be difficult to quantify.	<i>Requirements Lab:</i> Design Case <i>Stakeholders in Design Labs:</i> Stakeholder Mapping & HCD Methods	Stakeholder Mapping, along with other approaches shared in the final design processes could be used by students in their team design projects. Yet, these may not be sufficient for considerations which are qualitative in nature.
ED4	Shall provide students with opportunities to learn from interactions with clients or other stakeholders during the design process.	<i>Requirements Lab:</i> Interactions with Stakeholders	Students enjoyed interacting with stakeholders in the Requirements Lab and incorporated this approach into their final design process.
ED5	Shall promote the importance of iteration and trade-offs within the design process.	<i>Stakeholders in Design Labs:</i> Design Process Negotiation & Case Studies	Students' understanding of the importance of iteration in the design process changed over the course of the labs. The impact of the labs on students' understanding of trade-offs has yet to be analyzed or observed.

CHAPTER 6 - Summative Evaluation: Students' Application of Intervention Content and Tools

The previous chapters described the design of two active interventions implemented at different stages of a year-long senior aircraft design capstone course and examined students' experiences within, and their responses to, the interventions. This chapter presents a summative assessment that explores students' subsequent integration of stakeholder considerations into their understanding of design and their team design project.

The chapter begins with a re-introduction to the evaluation framework, noting the *Application* level that guided this summative assessment process. Then, the assessment instruments (i.e., an in-class evaluation and the Stakeholders in Design Rubric, as introduced in Chapter 3), data collection and data analysis methods are discussed, followed by the findings. The subsequent sections connect these findings with the characteristics of the active interventions, their specifications, and the previous analysis of students' experiences during the interventions. Finally, the results of this chapter into are related to these research questions:

- RQ#4.1 - What characteristics of the educational interventions support students' abilities to integrate stakeholder considerations into the design of an aerospace vehicle?
- RQ#4.2 - To what extent can the interventions help students integrate stakeholder considerations into the design of an aerospace vehicle?

6.1 Evaluation Framework: Application

Following the evaluation framework defined in the previous chapter (see Table 52), this chapter focuses on the Application level (Level 3) to examine the adoption of knowledge, skills, and tools from the active interventions in students' understanding of design and their team design project. Specifically, the methods in this chapter are used to respond to the following questions:

- (1) *Are newly acquired knowledge and skills being applied within the class?*
- (2) *What actions are the students taking toward improving the integration of stakeholder considerations?*
- (3) *What changes are visible in the performance indicators (e.g., design project)?*

Table 52: Evaluation Framework for Active Interventions

#	Levels	Description	Research Tool(s)	Relevant Chapters
1	Resources and Processes	What are the inputs to the lab sessions? (e.g., resources, materials required, etc.) What is the quality of the intervention activities? What feedback did the participants provide about the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
2	Acquisition	Are the objectives or desired outcomes of the learning intervention met? What did the participants learn as a result of participation in the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
3	Application	Are newly acquired knowledge and skills being applied within the class? What actions are the various stakeholders taking toward improving the integration of stakeholder considerations? Who adopts what aspects of the instruction (students, student teams, or instructors)? What changes are visible in the performance indicators (e.g., design project)?	Quantitative analysis of intervention artifacts; in-class evaluation; stakeholders in design rubric	Chapter 5 and Chapter 6
4	Organization and Course	What organization/learning environment barriers prevent or support adoptions? What aspects of the learning environment and intervention prove most successful for program stakeholders?	Observations of design team meetings; student focus groups; instructor interviews; stakeholders-in-design rubric	Chapter 7
5	Societal	What impacts exist outside and after the course?	Instructor interviews	Chapter 7

6.2 Summative Assessment Methods

This summative assessment of the interventions is comprised of two analyses as presented in the timeline in Figure 31. The first is a comparison of the in-class evaluations administered at the beginning and the end of the first semester of the course, and the second is a qualitative and quantitative analysis of the students' team design projects using the Stakeholders in Design rubric introduced in Chapter 4. These two methods are detailed in this section.

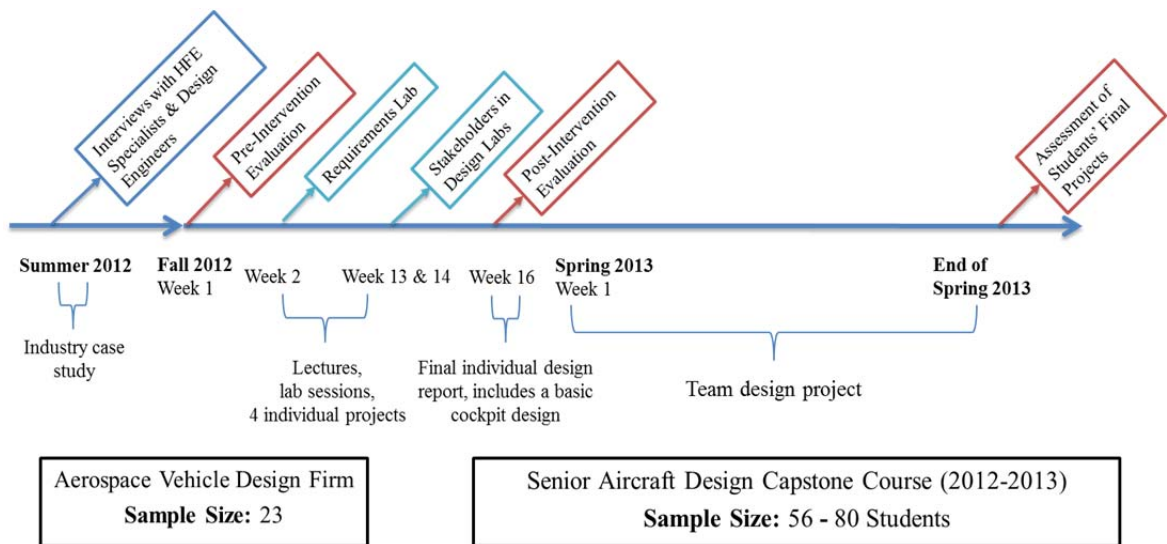


Figure 31: Data Collection and Intervention Roadmap

6.2.1 In-Class Evaluation

During the final week of the first semester of the capstone course, an end-of-term (i.e., post) evaluation was administered to the students using the same format as the in-class evaluation discussed in Chapter 3. Thus, this evaluation was taken after the two active interventions (i.e., the Requirements Lab and the Stakeholders in Design Labs), but before the students started on their final design project spanning a second semester. The evaluation was approved by Georgia Tech's IRB prior to distribution. As with the in-class evaluation from the start of the term, the evaluation consisted of four parts: (1)

design self-efficacy, (2) design ranking test, (3) contextual competence scale and follow-up question, and (4) submarine design scenario (see Table 5).

Table 53: Review of In-Class Evaluation Components

Section of Evaluation	Purpose	Associated Reference	# of Questions	Format of Responses
Design Self-Efficacy Scale	Assess students' confidence in their design skills	(Carberry et al., 2010)	9	Quantitative Ratings
Design Ranking Test	Explore students' perceptions about the design process (Responses can be compared with similar studies.)	(Adams & Fralick, 2010)	3	Ranked List of Items, Open-Ended Response
Contextual Competence Scale	Assess students' belief in their ability to integrate contextual considerations into a design solution	(Ro et al., 2012)	4	Quantitative Ratings
Context in Design Question	Explore students' perspective of how context can affect fixed wing design		1	Open-Ended Response
Submarine Design Scenario	Capture students' connections between design requirements and the stakeholders who can be affected by the design		2	Open-Ended Responses

The evaluation was administered via pencil and paper during one of the final lectures of the semester. Eighty students completed the start-of-term (i.e., pre) evaluation, but only 56 students completed this post-evaluation. Comparing the distribution of the demographics between the two samples, chi-square tests indicated there are no significant differences in distributions between the pre- and post-sample with regards to gender, citizenship, previous design coursework, participation in a problem-based learning course, or industry experience (see Table 54). Thus, while the post-evaluation sample is smaller than that of the pre-evaluation, statistically the 56 students represent a random selection of the larger, pre-evaluation sample.

Table 54: Results of Chi-Square Tests to Determine Randomness of Sample [NOTE: If p-value is less than .05, significant differences exist between the distributions of the demographics within the two samples.]

	Distribution - Pre	Distribution - Post	p-Value
Gender	90% Male, 10% Female	91.1% Male, 8.9% Female	1.00 (Fisher's Exact Test)
Citizenship	88.8% US Citizens, 6.2% International, 5.0% Permanent Residents	89.3% US Citizens, 7.1% International, 3.6% Permanent Residents	.908 (Pearson's)
Previous Design Coursework	37.5% Yes, 62.5% No	33.9% Yes, 66.1% No	.719 (Fisher's Exact Test)
Problem-Based Learning Experience	62.5% Yes, 37.5% No	64.3% Yes, 35.7% No	.858 (Fisher's Exact Test)
Industry Experience	65% Yes, 35% No	66.1% Yes, 33.9% No	1.00 (Fisher's Exact Test)

6.2.2 Evaluation of Student Design Projects

In the second semester of the course, students separated into ten teams, ranging in size from six to nine students, to develop a conceptual design in response to a Request-for-Proposals (RFP). The course instructors selected the RFP developed by the American Institute of Aeronautics and Astronautics (AIAA) as the specification for the final projects and as an assessment tool (AIAA, 2012a). In general, the RFP implicitly incorporated stakeholders through noise and emissions requirements and explicitly incorporated stakeholders through an optional passenger time trade study (see Appendix G for the complete RFP). Throughout the term, each team was required to attend weekly design team meetings with the instructors. The students were also responsible for presenting their conceptual design at a midterm and final design review. Finally, each team submitted a report at the end of the semester, documenting their design solution and their approach for developing that solution.

6.2.2.1 Application of Stakeholder in Design Rubric to Evaluate Student Design Projects

6.2.2.1.1 *Evaluation by Subject-Matter Experts*

To evaluate the integration of stakeholder considerations and the impact of the intervention within the students' final design reports, a group of seven subject-matter experts (SMEs) were recruited to assess student performance on their team design reports using the rubric and to evaluate the rubric from an instructor perspective. The group represents researchers and engineering educators in varying sub-disciplines of aerospace engineering, including conceptual aircraft design and cognitive engineering.

Each of the SMEs was provided a rubric packet with an explanation of the rubric objectives, the scales, and the scoring method. In addition, the packet included a rubric design questionnaire (adapted from the work of Moskal and Leyden, 2000, and Stevens and Levi, 2005). The questionnaire examined the clarity of the scoring criteria, the descriptions, the scale, and the overall rubric, along with content validity, construct validity, and criterion validity (Moskal & Leydens, 2000; Stevens & Levi, 2005) (see the complete questionnaire and complete examination of validity, reliability, and usability of the rubric in Appendices F.4 and F.6).

Prior to applying the rubric, each SME was required to receive one-on-one training. This training was provided to support consistency and overall understanding of the rubric among the SMEs (Plumb & Sobek, 2008; Watson et al., 2013). The SMEs were introduced to the rubric and the individual scales and were encouraged to not consider the rating process as a "grading" process: a well-done design project does not necessarily mean the team must receive a "4" on the *Stakeholder Integration* scale or the *Design Understanding* scale. The converse was true for a poor design project. Additionally, a team that performs poorly in one scale may perform well in another.

Following training, the SMEs were asked to read and assess the reports from the team design projects created by the students in the second semester of the capstone course. All reports were used with approval by Georgia Tech’s IRB (see Appendix A.4) and, as such, were de-identified to preserve the confidentiality of the students. Due to the size of each design project (approximately 90 to 100 pages), six of the seven SMEs were assigned four of the ten reports, while the seventh SME read all ten reports. This assignment allowed for all of the reports to be rated by at least three SMEs. To examine the variability among the raters, all of the SMEs read and rated one of the reports. Finally, each report assignment was organized such that the SMEs did not read the same projects in the same order. The distribution of reports is illustrated in Table 55.

Table 55: Assignment of Reports to SMEs [NOTE: All identifying information was removed from each report prior its distribution]

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7
A	1	1			1		
B	1		1			1	
C	1			1			1
D	1	1			1		
E	1		1				1
F	1			1		1	
G	1	1	1	1	1	1	1
H	1	1					1
I	1		1		1		
J	1			1		1	

6.2.2.1.2 Evaluation of Midterm and Final Design Reviews

To examine how students’ integration of stakeholder considerations may have changed over the course of the semester and further isolate factors affecting this integration, the rubric was used to evaluate each team’s progress at the two design reviews. Specifically, each team’s *Stakeholder Integration* and *Design Understanding* were scored based on their presentation at the Midterm and Final Design Reviews. Additional qualitative analysis, based on the observations of design team meetings

(detailed in Chapter 7), was used to provide a rich description of the teams' integration of stakeholder considerations throughout the design project.

6.2.2.2 Limitations

The initial evaluation of the Stakeholder in Design Rubric (see Appendix F.6) highlighted the overall validity of the rubric, but also possible limitations. Specifically, the overall inter-rater reliability of the scale was low, as SME's scores varied little for some teams and significantly across the scores given other teams. One possible reason behind these results could be that scores provided only a few rating options. Thus, small differences in the SMEs' scoring strategy could result in, for example, a '0' by one rater and a '1' by another. As a result, the qualitative discussions by the SMEs in regards to each team's performance were also analyzed to better understand the SMEs' ratings. In addition, the holistic nature of the *Stakeholder Integration* and *Design Understanding* scales increase the possibility for rater bias to negatively affect inter-rater reliability. To mitigate the impact of this potential bias, the midterm and final design review scores, along with an understanding of each team's progress over the course of the semester, were used to capture a richer story of each team's final design solution and better evaluate the SMEs' design report scores. Finally, it is important to note that the students were not provided with this rubric while completing their projects, nor was it part of the instructors' assessment tools. Thus, teams may have viewed the integration of stakeholder considerations as outside of the scope of the design project. This possible limitation is discussed in greater detail in Chapter 7.

6.3 Results and Discussion

The results are presented beginning with the in-class evaluations and moving on to the quantitative and qualitative analysis of the team design projects.

6.3.1 End of Term In-Class Evaluation

6.3.1.1 Students' Design Understanding and Self-Efficacy

The first scale assessed students' design self-efficacy (Carberry et al., 2010). The same validation and reliability procedures were conducted as with the start of term in-class evaluation. The results of these validation procedures are included within Appendix C.4. Factor scores were also calculated using the same methods as those from the pre-evaluation, and the regressed scores were converted back to a continuous 1 to 100 point scale.

Overall, the students reported an increase in design self-efficacy between the pre- and post- evaluations (See Figure 32). Using only the data from the 56 students who completed both evaluations, a paired samples t-test revealed that the students reported on average significantly greater design self-efficacy at the end of the semester (Mean: 78.42, SE: 1.44) than at the beginning of the semester (Mean: 67.76, SE: 1.74), $t(55) = 6.727$, $p < .001$, $r = .67$. The overall effect size (r) reflects a very large difference between the scores from the start of the semester to the end of the semester. In terms of the individual design self-efficacy scores, 49 of the students reported greater self-efficacy, while only seven reported a decrease in self-efficacy.

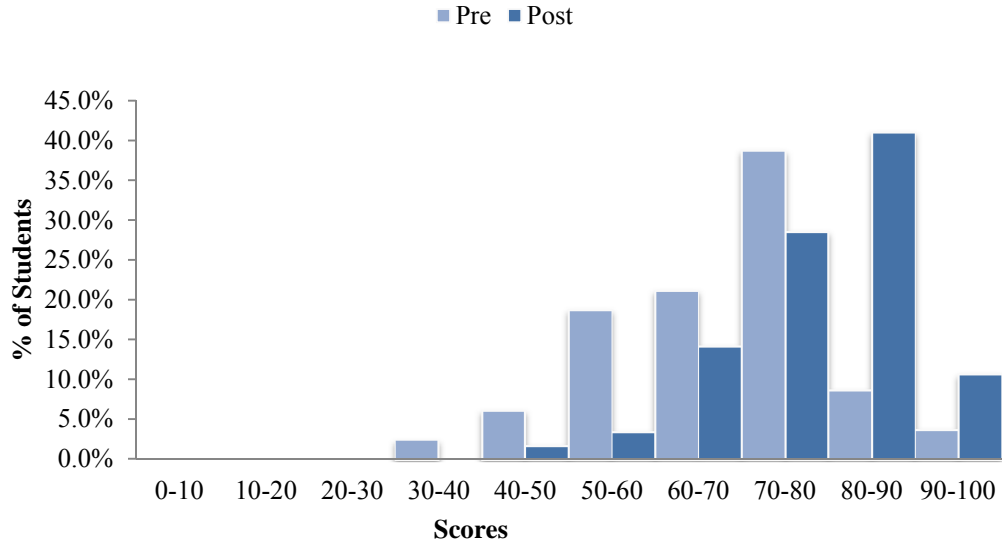


Figure 32: Histogram Comparing Design Self-Efficacy Factor Scores from the Pre- and Post-Evaluations

Considering the raw scores of the individual items, students reported the highest self-efficacy for problem-scoping and communication activities: *researching a design need*, *identifying a design need*, and *communicating a design* (see Table 56). Students also reported the lowest level of self-efficacy for *constructing a prototype*. These results overall are consistent with students’ perceptions of their abilities at the start of the semester. When examining the order of the activities (from highest self-efficacy to lowest), as the above results suggest, students’ self-efficacy among the different design activities did not significantly change over the course of the semester, $\chi^2(8) = 15.33, p > .053$.

Table 56: Descriptive Statistics for Design Self-Efficacy Items [NOTE: Confidence levels were rated from 0 - "Cannot do at all" to 50 - "Moderately" to 100 - "Highly certain can do"]

#	Item	Pre-Evaluation			Post-Evaluation		
		Min	Max	Median	Min	Max	Median
2	Identify a design need	30	100	80	60	100	80
3	Research a design need	20	100	70	50	100	90
4	Develop design solutions	30	100	70	50	100	80
5	Select the best possible design	30	100	70	40	100	80
6	Construct a prototype	10	100	70	0	100	70
7	Evaluate and test a design	10	100	70	20	100	80
8	Communicate a design	10	100	70	40	100	80
9	Redesign	0	100	60	40	100	80

The Design Ranking Test was again applied to examine students' design understanding and overall perceptions of different design activities. During the post-evaluation, the most important design activities were related to problem-scoping (i.e., *understanding the problem, identifying constraints*), *communicating* and *iterating*; the least important design activities included *imagining, abstracting, and sketching*. In comparing the evaluation results, the problem-scoping activities and *communicating* are relatively as important in the post-evaluation as they were in the pre-evaluation, with a small decrease in *understand the problem* (see Figure 33). One of the most substantial changes occurred with *iterating*, where 23.8% of the students in the pre-evaluation selected it as one of the most important design activities, as compared with 69.6% of students in the post-evaluation (see Table 57). These findings align with previous research discussed within Chapter 3 (Adams & Fralick, 2010; Hohner et al., 2012). Overall, the same design activities were selected as least important, although the percentage of students selecting each varied. For example, the largest change occurred with *imagining*, where 53.8% of the students viewed it as one of the least important activities in the pre-evaluation to 73.2% of students in the post-evaluation.

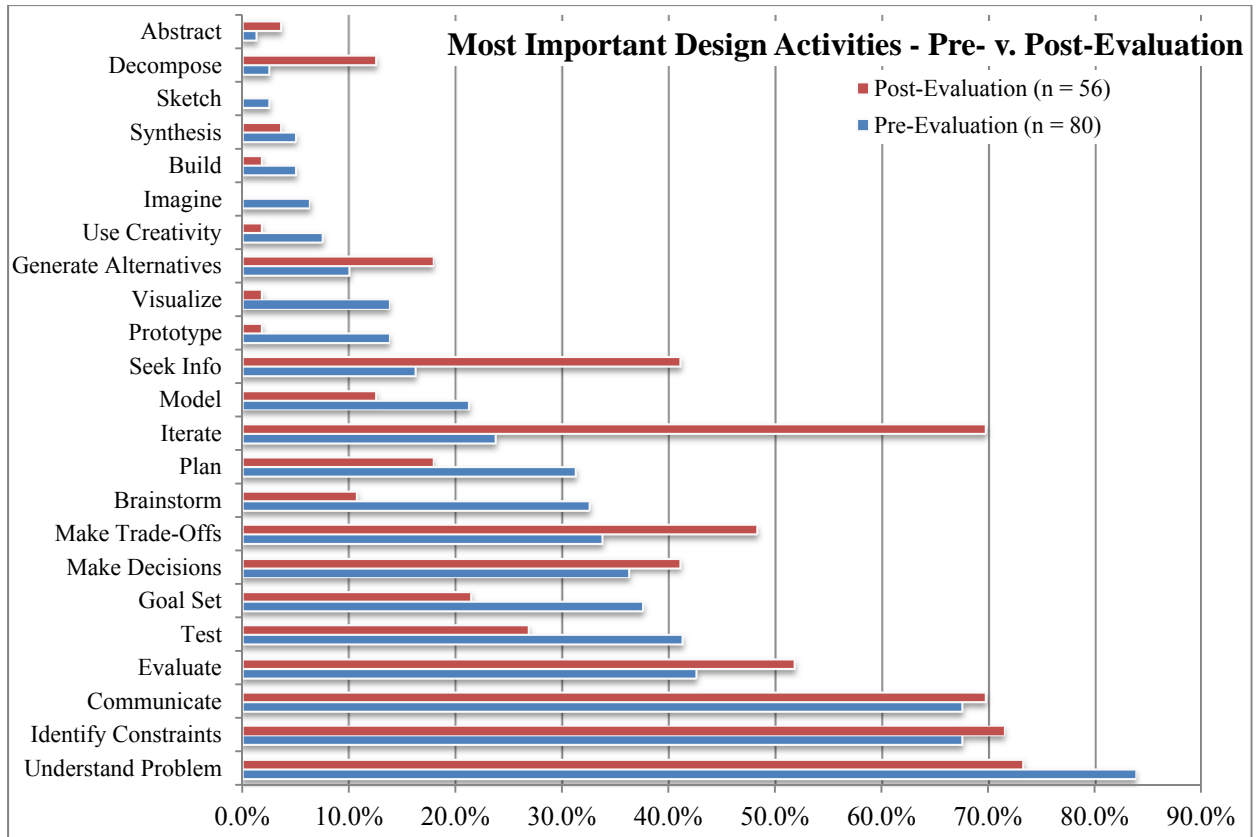


Figure 33: Comparison of Most Important Design Activities – Pre- v. Post- Evaluation

Table 57: Comparison of Most and Least Important Design Activities from Pre- to Post-Evaluation

	Most Important Activities			Least Important Activities		
	% Pre	% Post	% Change	% Pre	% Post	% Change
Understand the Problem	83.8	73.2	-10.6	0.0	0.0	0.0
Identify Constraints	67.5	71.4	3.9	2.5	1.8	-0.7
Communicating	67.5	69.6	2.1	1.3	1.8	0.5
Evaluating	42.5	51.8	9.3	5.0	0.0	-5.0
Making Trade-offs	33.8	48.2	14.4	11.3	1.8	-9.5
Iterating	23.8	69.6	45.8	33.8	1.8	-32.0
Seeking Info	16.3	41.1	24.8	7.5	3.6	-3.9
Sketching	2.5	0.0	-2.5	70.0	58.9	-11.1
Imagining	6.3	0.0	-6.3	53.8	73.2	19.4
Abstracting	1.3	3.6	2.3	60.0	66.1	6.1
Building	5.0	1.8	-3.2	57.5	53.6	-3.9
Decomposing	2.5	12.5	10.0	51.3	46.4	-4.9
Synthesizing	5.0	3.6	-1.4	46.3	50.0	3.7
Visualizing	13.8	1.8	-12.0	30.0	48.2	18.2

In Chapter 3, the similarities among aerospace engineering populations were examined, comparing the students in this study with senior aircraft design students from

Virginia Tech and aerospace engineering professionals. The VT student population, which did not receive any specific design or stakeholder-related intervention, also completed the Design Ranking Test at the beginning and end of their first semester in the aircraft design capstone course (Butler, 2012). Comparing their ratings with those collected here in the post-evaluation and with those of AE professionals, Kendall's Tau rank statistic determined that the correlations among the populations were statistically significant (see Table 58). For the most important design activities, the ranks of this study's population were moderately correlated with the rankings provided by the AE professionals, $\tau = .475$, $p < .01$. However, a stronger correlation was found between the participants in this study and the VT students, $\tau = .690$, $p < .001$. It is important to note that the correlations between the participants in this study and the AE professionals did not increase from the pre-evaluation to the post-evaluation as much as the correlations between the VT students and the AE professionals. In addition, the correlation among the senior aircraft design students at both institutions decreased between the two evaluations. As a result, these populations were less similar at the end of the first semester of the design sequence than at the beginning, which could be a result of the stakeholder-related interventions or other differences in the aircraft design curricula for these populations. The same pattern can be noted among the least important design activities.

When comparing the individual choices of each population, a higher percentage of the participants in this study selected *iterating* as one of the most important activities, as compared with VT students and the AE professionals (see Figure 34). A similar trend appears with *making trade-offs*. *Using creativity* and *generating alternatives* were still selected by a higher percentage of the AE professionals than either student population.

Table 58: Kendall's Tau Rank Comparison Values among Populations (p-values are included in parenthesis) [NOTE: Results for AE Professionals and VT students from Butler (2012)]

	Survey Sampling	Professional/ Study students	Professional/ VT students	Study students/ VT students
Most Important Activities	Pre-Test	.467 (.003)	.433 (.005)	.781 (.000)
	Post-Test	.475 (.003)	.590 (.000)	.690 (.000)
Least Important Activities	Pre-Test	.603 (.000)	.560 (.000)	.788 (.000)
	Post-Test	.655 (.000)	.726 (.000)	.686 (.000)

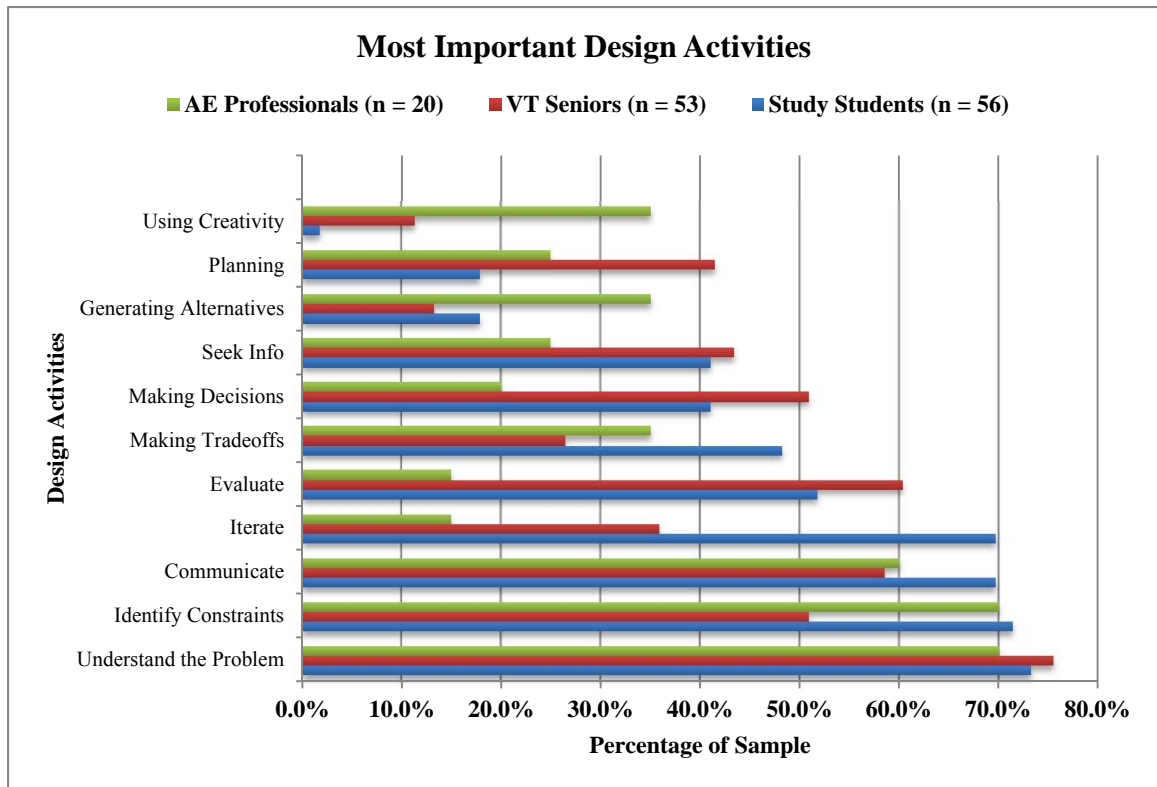


Figure 34: Most Important Design Activities for Aerospace Engineering Students and Professionals in the Post-Evaluation

Based on these results, the design understanding of the participants in this study appears to have shifted away from the VT aircraft design students. *Making trade-offs* and *iterating* became more important design activities for this study's student population. In addition, problem-scoping activities and communicating remained the most important activities for these students and the activities with which they reported the highest level of self-efficacy.

6.3.1.2 Students' Competence and Perceptions About Context

To examine students' understanding of the effects of different contexts (e.g., social, environmental, etc.) on engineering solutions, a four-item contextual competence scale was used (Ro et al., 2012). The rating scale for these items went from 1 (little or no knowledge/ability) to 5 (very high knowledge/ability) with a 3 representing "adequate" knowledge or ability. The same validation and reliability procedures were conducted with this scale as with the pre-evaluation. The results of these validation procedures are included within Appendix C.4. Factor scores were also calculated in the same manner as those for the pre-evaluation, and the regressed scores were converted back to a continuous 1 to 5 point scale.

Overall, the aircraft design students reported an increase in contextual competence between the two evaluations (See Figure 35). Using only the 56 students who completed both evaluations, a paired samples t-test revealed that, on average, the students reported significantly greater contextual competence at the end of the semester (Mean: 3.70, SE: 0.065) than at the beginning of the semester (Mean: 3.20, SE: 0.077), $t(55) = 6.179$, $p < .001$, $r = .64$. As with the design self-efficacy results, the effect size represents a large difference between the scores at the start and at the end of the semester. Examination of the individual contextual competence scores demonstrated that 46 of the students reported greater competence, while only 10 reported a decrease in contextual competence.

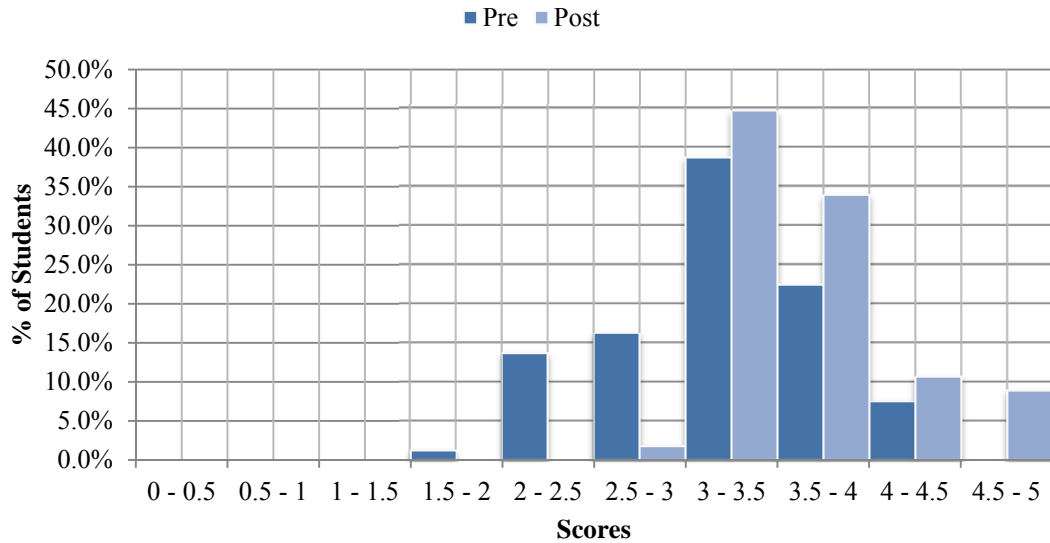


Figure 35: Histogram Comparing Contextual Competency Factor Scores from the Pre- and Post-Evaluations

Considering the raw scores of the individual items (see Table 59), the distribution of ratings for each of the items increased shifted towards higher scores between the two evaluations. In the post-evaluation, the students rated their competency in “knowledge of connections between technological solutions and their implications for the society or groups they are intended to benefit” as the lowest in the final evaluation (Median: 3, Min: 2, Max: 5).

Table 59: Distribution of Contextual Competence Items [NOTE: Rating Scale: 1 (little or no knowledge/ability) to 5 (very high knowledge/ability) with 3 representing "adequate" knowledge or ability]

	Item	1	2	3	4	5
1	Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem.	<i>Pre: 5%</i> <i>Post: 0%</i>	<i>Pre: 33.9%</i> <i>Post: 1.8%</i>	<i>Pre: 53.6%</i> <i>Post: 37.5%</i>	<i>Pre: 41.1%</i> <i>Post: 55.4%</i>	<i>Pre: 7.1%</i> <i>Post: 3.6%</i>
2	Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	<i>Pre: 0%</i> <i>Post: 0%</i>	<i>Pre: 32.1%</i> <i>Post: 1.8%</i>	<i>Pre: 64.3%</i> <i>Post: 51.8%</i>	<i>Pre: 44.6%</i> <i>Post: 37.5%</i>	<i>Pre: 1.8%</i> <i>Post: 8.9%</i>
3	Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	<i>Pre: 3.8%</i> <i>Post: 0%</i>	<i>Pre: 23.2%</i> <i>Post: 0%</i>	<i>Pre: 57.1%</i> <i>Post: 35.7%</i>	<i>Pre: 42.9%</i> <i>Post: 46.4%</i>	<i>Pre: 14.3%</i> <i>Post: 17.9%</i>
4	Ability to recognize how different contexts can change a solution	<i>Pre: 2.5%</i> <i>Post: 0%</i>	<i>Pre: 19.6%</i> <i>Post: 3.6%</i>	<i>Pre: 55.4%</i> <i>Post: 21.4%</i>	<i>Pre: 53.6%</i> <i>Post: 58.9%</i>	<i>Pre: 10.7%</i> <i>Post: 16.1%</i>

A qualitative follow-up question, after the contextual competence scale, asked students to consider how context affects fixed wing aircraft design. Specifically, students were asked to describe how “the ability to recognize how difference contexts could change a solution” might relate to fixed wing aircraft design. Qualitative analysis of the 53 responses, following the methods described in Chapter 3, isolated emerging themes within the data. In addition, the analysis captured differences between students’ breath of understanding about stakeholders and contextual considerations at the start of the first semester of the design sequence and at the end of that semester.

During the post-evaluation, a higher percentage of students discussed a macroscopic, or global, perspective about the design and the impact of context (from 36% in the pre-evaluation to 54% in the post-evaluation) (See Table 60). Comparing the 44 students who completed this question in both evaluations with a Wilcoxon signed ranks tests, the scope of influence discussed in their solutions was significantly broader in the post-evaluation, $Z = -2.236$, $p < .05$. $r = -.24$. While the effect size reflects only a small difference between the evaluation results, an examination of individual changes

revealed 5 students switched from a global perspective to a local perspective, 15 switched from local to global, and 24 retained their initial perspective (either global or local).

Table 60: Frequency of Different Scopes of Influence within Students' Open-Ended Responses: Pre- v. Post-Evaluation

Design Scope of Influence				
	Pre	% of Sample	Post	% of Sample
Local	42	60.0	23	43.4
Global	25	35.7	29	54.7
Neither	3	4.3	1	1.9
Total Sample	70	100	53	100

The majority of students (48% in the pre-evaluation and 53% in the post-evaluation) discussed various types of contextual considerations, including cultural, political, and social considerations. The most common types discussed in the post-evaluation, economic and environmental considerations were consistent with the most common types defined in the pre-evaluation (see Table 61).

Table 61: Frequency of Different Types of Contextual Considerations in Students' Open-Ended Responses: Pre- v. Post-Evaluation

Types of Contextual Considerations				
	Pre	%	Post	%
Cultural	3	4.3	3	5.7
Economic	15	21.4	10	18.9
Ethical	2	2.9	0	0.0
Environmental	14	20.0	16	30.2
Historical	1	1.4	1	1.9
Political	11	15.7	6	11.3
Social	3	4.3	6	11.3
Total Sample	70		53	

The percentage of the sample who discussed stakeholder-related considerations rose from 30.4% to 55% between the two evaluations. Using McNemar's Test with paired samples (n=44), students' incorporation of stakeholders in their discussion about how context relates to aircraft design changed significantly between the two evaluations ($p < .05$, $\phi = 0.4$). For McNemar's Test, the effect size is calculated using ϕ , a measure of effect size also used with chi-square tests. The result indicates a medium difference between the incorporation of stakeholders in the two evaluations. The most common

stakeholders discussed in the pre-evaluation were customers (81%), while a diverse set of stakeholders were discussed in the post-evaluation, including customers (31%), passengers (24%), stakeholders in a broad sense (24%), and countries/societies (10.3%) (See Table 62). For instance, Chase explained,

“From the point of view of an engineer who doesn’t live by an airport, performance at the cost of noise is acceptable. From the context of someone living by an airport, noise is not acceptable. The propulsion solution could change to meet both contexts.”

Ricky, on the other hand, considered the perspectives of different countries and markets for aircraft sales: “Different countries have different environmental requirements when it comes to authorizing a certain type of aircraft to cross its air space. Knowing different sets of legal requirements will eventually affect the decision process when designing an aircraft for a specific market.” Additionally, close examination of individual responses revealed evidence of student development between the evaluations. In the pre-evaluation, for example, Ethan wrote “the ability does not relate much to fixed wing aircraft design.” However, in the post-evaluation, Ethan included the following response: “All fixed wing aircrafts need to be designed according to its context. For example, what do the customers need the most? What type of aircraft needs to be designed?” For Jayden, who wrote “no idea what that means” in the pre-evaluation, he appeared to develop an understanding of “context” over the course of the semester. In the post-evaluation, he explained how “the requirements & mission profile greatly affect the decisions made in design.”

Table 62: Frequency of Different Stakeholder-Related Discussions within Students' Open-Ended Responses: Pre- v. Post-Evaluation

Stakeholder-Related Considerations				
	Pre	%	Post	%
Stakeholders	22	31.4	29	54.7
Sample	70		53	
By Stakeholder Type				
	Pre	%	Post	%
Customer	18	81.8	9	31.0
Countries/Societies	2	9.1	3	10.3
User	2	9.1	3	10.3
Manufacturers/Corporations	1	4.5	1	3.4
Pilot	1	4.5	1	3.4
Airports	0	0.0	2	6.9
Nonuser	0	0.0	2	6.9
Passengers	0	0.0	7	24.1
Stakeholders (general)	0	0.0	7	24.1
Sample	22		29	

6.3.1.3 Stakeholders in Design

In the last section of the post-evaluation, students responded to the same scenario-based design task from the pre-evaluation (i.e., the design of a personal submarine - see Chapter 3). As before, the students were tasked with selecting team members from a list of disciplines and creating an initial list of requirements for the submarine. The data were analyzed qualitatively using the coding scheme based on the categories described in Table 7 and Table 8 and defined in detail in Appendix C.2.

Table 63: Frame of Reference Categories

Frame of Reference	Description
Technical	Technical or engineering vocabulary, design issues, decisions about having the submarine
Logistical	Cost, funding, construction process, maintainability issues, resources needed
Natural	Water, topography, animals, plants, weather, weather predications, damage caused by sub on environment
Social	People, safety, concerning people, towns, living areas, fields of engineering and education

Table 64: Design Consideration Categories

Design Considerations	Description
Submarine	The submarine itself, but specifically the non-user focused systems, the technology which could be used, and the locations where the submarine might operate
Surroundings	The environment surrounding the submarine, which includes aquatic life, the ocean ecosystem, etc.
Stakeholders	These focus on the various stakeholders, ranging from the design of the submarine controls (operator) to market research (potential customer) to considerations affecting maintainers and competitors.

For their teams, students once again selected the following disciplines most often: aerospace engineers (73.2%), mechanical engineers (67.9%), and electrical engineers (69.6%) (see Table 65). Comparing the responses of the 56 students who completed both the pre- and post-evaluations, McNemar’s Test revealed a significant increase in the inclusion of a user or customer on the students’ submarine design teams, $p < .01$, $\phi = 0.334$.

Table 65: Most Commonly Selected Disciplines for the Submarine Design Team: Pre- vs. Post-Evaluation

	Pre	%	Post	%	% Change
Aerospace Engineer	61	76.3	41	73.2	-3.0
Mechanical Engineer	55	68.8	38	67.9	-0.9
Electrical Engineer	53	66.3	39	69.6	3.4
Materials Science Engineer	48	60.0	23	41.1	-18.9
Systems Engineer	47	58.8	25	44.6	-14.1
Project Manager	35	43.8	32	57.1	13.4
User	29	36.3	24	42.9	6.6
Financial Analyst	24	30.0	18	32.1	2.1
Customer	10	12.5	17	30.3	17.8
SAMPLE	80		56		

To analyze the diversity of each team the students selected, team members were classified: (1) *submarine and technical*, (2) *submarine and logistical*, (3) *surroundings and logistical*, and (4) *stakeholder and logistical* (as described in detail in Chapter 3). If students included team members from all four categories, they received a score of a four. A score of a three represented selecting members from three of the four categories and the scores continued in that fashion. Overall, the team compositions were relatively

similar between the evaluations (see Table 66). Students selected team members with expertise related mostly to the technical submarine considerations, while team members with an expertise in marine environments were selected the least often. The diversity of the teams was examined by exploring how many different categories each student's team included (see Table 67). There were no significant differences in team diversity scores between the evaluations ($p = .285$). Overall, students generally included team members from three categories in both the pre- and post-evaluations.

Table 66: Composition of Student Selected Teams: Pre- vs. Post-Evaluation

Category	Pre	%	Post	%
Submarine, Technical	223	47	154	46
Submarine, Logistical	97	20	72	21
Surroundings, Logistical	63	13	35	10
Stakeholder, Logistical	96	20	74	22
Total	479	100	335	100

Table 67: Diversity of Disciplines within the Submarine Design Teams: Pre- vs. Post-Evaluation

Score Frequency	Pre	%	Post	%
1	1	1	0	0
2	17	21	8	14
3	44	55	37	66
4	18	23	11	20
Total Sample	80	100	56	100

When describing the design considerations for the submarine, no significant difference was found between the number of design considerations that students included in the pre- and post-evaluation ($p = .758$). The majority of considerations, according the categories defined in Chapter 3 and Table 68, were focused on the vehicle design and performance (65%), aligning with the results of the pre-evaluation. Examining the 56 students who completed both evaluations, the change in the percent of design considerations which included contextual considerations was not found to be significant. However, a paired samples t-test showed that students reported significantly more stakeholder-related considerations in the post-evaluations (Mean: 25%, SE: 1.8%) as

compared with the pre-evaluations (Mean: 19.8%, SE: 1.8%), $t(55) = 2.624$, $p < .05$, $r = .33$.

Table 68: Breadth of Design Discussion Results by Category: Pre- (n=80) vs. Post-Evaluation (n= 56)

Design Analysis	Pre	Post
Technical Details	69%	65%
Considers Context	10%	10%
Considers Stakeholders	21%	25%
Total Sample	100%	100%

6.3.1.4 Summary

These results illustrate how the senior design students within this sample developed over the course of the first semester. The students began with a moderate to high confidence level in their abilities to design and that confidence level increased over the semester. They are still most confident in their ability to complete problem-scoping activities and to communicate a design solution. Once again, these activities align with the students' beliefs as to which design activities are the most important. As compared with the beginning of the semester, the students view making trade-offs and iterating as more important design activities within the design process.

The students perceive an improvement in their ability to consider context from an adequate level to an almost high level. The student's understanding of context continues to include the economic and environmental considerations of a mission, but also considers the effects of a diverse group of stakeholders and incorporates a macroscopic, or global, perspective about aircraft design. When asked to develop a design team and requirements for a personal submarine, the students likely select a participatory design strategy by including a user or customer. The students continue to select engineers who focus on the technical and logistical considerations of the submarine. The majority of the design considerations they discuss focus on the vehicle performance and logistical aspects of the design, but also include contextual and stakeholder-related considerations of the design.

6.3.2 Analysis of Team Design Projects

6.3.2.1 Final Design Reports

Each team submitted a report that detailed their design and how they fulfilled the requirements included in the RFP. As described earlier in this chapter, each report was evaluated by at least 3 SMEs using the Stakeholders in Design rubric. The resulting scores from this evaluation for the *Stakeholder Integration* scale and the *Design Understanding* scale are included in Table 69 and Table 70. As discussed in Appendix F.6, The SME's scores varied little for some teams and significantly for other teams. With both scales, only 40% of the ratings per team were within one performance level. In the subsequent analysis, the scores have been averaged.

For the project reports, the highest scores in *Design Understanding* belonged to Teams J, A, and C, while the highest scores in *Stakeholder Integration* were from Teams C and B. The lowest scores belonged to Teams B and G in *Design Understanding* and Teams E and A in *Stakeholder Integration*. The relationship between the scales was not found to be significant ($p > .05$). For the class as a whole, the median *Design Understanding* score was 2 (9 of 34 ratings) on the design reports. However, for *Stakeholder Integration*, while 16 of 34 ratings were also a 2, only 3 ratings were a 3 or higher, signifying that teams identified explicit stakeholder considerations at a few isolated points in the design process.

Table 69: Design Understanding Scores by SME

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7	Average	Ranking
A	3	2			2			2.33	2
B	1.5		1			1		1.17	9
C	3			1			3	2.33	2
D	2.5	2			2			2.17	2
E	3		2				1	2.00	2
F	1			3		1		1.67	4
G	1.5	1	1	0	3	1	1	1.21	6
H	2	2					1	1.67	5
I	2		1		3			2.00	3
J	2.5			4		2		2.83	1

Table 70: Stakeholder Integration Scores by SME

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7	Average	Ranking
A	0	2			1			1.00	9
B	2		2			2		2.00	2
C	3			2			3	2.67	1
D	0	2			2			1.33	4
E	0		0				0	0.00	6
F	0			2		2		1.33	4
G	1	2	2	0	1	1	2	1.29	4
H	1.5	2					2	1.83	1
I	2		0		3			1.67	2
J	0.5			3		2		1.83	1

The scores within the *Stakeholder Integration by Design Stage* reflected the same variability among the SMEs' scores, as shown in Table 71. In some cases, the SMEs disagreed completely as to a team's intention to incorporate stakeholder considerations and overall success in incorporating those considerations. The scores illustrate this disagreement among the SMEs, as sometimes half of the SMEs gave a score of zero and half gave a score of one. Two clear distinctions are noticeable from these scores. The first is the *Technology Integration Intention* score (only 32% received a '1'), signifying that most of the student teams did not state an intention to incorporate stakeholder considerations at this phase of the design process. Both the *Requirements* and *Technology*

Integration Application scores (only 39% and 41% received a ‘1,’ respectively) illustrates that most of the student teams did not apply a design process that supported the integration of stakeholder considerations in those design stages. Finally, *Overall Design Success* score (68.6% received a ‘1’ or ‘2’) which suggests that the students were somewhat, superficially successful at integrating stakeholder considerations into their final design solutions and reports.

Table 71: Scores for Stakeholder Integration by Design Stage Across Teams and SMEs [NOTE: Intention and Application Scores had to be 0 or 1, while Success Scores could be 0, 1, or 2]

Scores Across Teams and SMEs			
	0	1	2
Requirements/ Problem Definition			
<i>Intention</i>	50%	50%	-
<i>Application</i>	60.6%	39.4%	-
<i>Success</i>	55.6%	36.1%	8.3%
Concept Generation/ Development			
<i>Intention</i>	48.6%	51.4%	-
<i>Application</i>	54.3%	45.7%	-
<i>Success</i>	47.2%	44.4%	8.3%
Technology Integration			
<i>Intention</i>	67.6%	32.4%	-
<i>Application</i>	58.8%	41.2%	-
<i>Success</i>	50%	47.1%	2.9%
Overall Design			
<i>Intention</i>	51.4%	48.6%	-
<i>Application</i>	54.5%	45.5%	-
<i>Success</i>	31.4%	57.1%	11.4%

6.3.2.2 Midterm and Final Design Reviews

During both design reviews, I assigned scores to each team using the *Design Understanding* and *Stakeholder Integration* scales from the Stakeholders in Design Rubric. The scores are included in Table 72. Overall, the scores between the midterm and final design reviews are fairly consistent. A Wilcoxon signed ranks test found no significant differences between the scores from the midterm design reviews and the final design reviews (i.e., *Design Understanding* scores, $p = .180$ and *Stakeholder Integration* scores, $p = 0.655$). These results suggest that, for this sample, students’ performance at

the Midterm Design Reviews predicts their performance in later design reviews. The highest scores in the final design review for *Design Understanding* were Teams C, J, F, and D, while the highest scores for *Stakeholder Integration* were Teams H, C, and J. The lowest scores belonged to Teams I, A, B, and G for Design Understanding and Teams I, A, and B for Stakeholder Integration. The scores for *Design Understanding* and *Stakeholder Integration* were also found to be positively correlated for both the midterm ($r = .718, n = 10, p < .05$) and final design reviews ($r = .882, n = 10, p < .01$).

For the class as a whole, the median *Design Understanding* score at the final design reviews was a 2, which is consistent with from the SMEs' assessment of the final design reports. This score signifies that the students applied an iterative design process. For *Stakeholder Integration*, the median score at the final design review was 2, which suggests that most teams identified stakeholder considerations only at isolated points in the design process. When compared to the scores of the final design reports, the students may have considered stakeholders only implicitly in the final reports, compared to more explicit consideration in the final design reviews. Still, these teams did not necessarily use these considerations as a basis for design decisions. Overall, these scores suggest that most students fit within categories 3 and 4 in the Ways of Experiencing Human-Centered Design outcome space. Category 3 describes how human-centered design is a linear design process, where stakeholders are incorporated to the extent "that it does not make the design too messy or difficult and the process involves little or no feedback or iteration," (Zoltowski, 2010, p. 157). Category 4 illustrates an integrated and iterative design process where teams keep stakeholder needs and the impact of the design on stakeholders in mind during the design process (Zoltowski, 2010).

Table 72: Midterm and Final Design Review Design Understanding (DU) and Stakeholder Integration (STK) Scores

Team	Midterm Design Reviews		Final Design Reviews	
	DU	STK	DU	STK
A	1.5	1.5	1.5	1.5
B	1.5	1.5	1.5	1.5
C	3	3	3	3
D	2.5	2	2.5	2
E	2	1.5	2	2
F	1.5	2	2.5	2
G	1.5	2.5	1.5	2
H	2	2	2	2.5
I	0.5	1	0.5	0.5
J	2.5	2	3	2.5

To capture how students considered (or did not consider) stakeholders during the design process, instances of stakeholder considerations were recorded using the fourteen questions listed in Table 18 from Chapter 4. It is important to note the specific RFP for this team design project focused on the design of a hybrid electric propulsion regional-sized commercial airliner (see Appendix G). The objective statement of the RFP explicitly stated, “considering hybrid electric propulsion and advanced modular batteries, design a regional-sized commercial airliner with the lowest operating cost per seat-mile for the economic mission of 400 NM.” Additionally, the RFP included implicit requirements for reductions in emissions and noise, and one *optional* explicit passenger-related requirement, “the value of passenger time can also be considered in the economic analysis.”

Half of the teams explicitly included some form of stakeholder identification within their midterm design review or final design review and discussed how the different stakeholders impacted or are impacted by the design. The manner of this discussion ranged from group to group and in some cases (e.g., Teams C and F) it appeared that these impacts may not have been the reason for particular design decisions. All but one team explicitly discussed stakeholder-related regulations which could impact

their design (e.g., ICAO noise regulations, FAA requirements for fuselage and handling qualities).

Four of the ten teams (Teams C, F, I, and J) somewhat considered the environmental context of the RFP through discussions of community noise and the NASA ERA project, for example. All of the teams briefly mention stakeholders when they presented the minimum requirements as included within the RFP (e.g., required number of passengers and crew members). Two teams briefly mentioned the FARs as part of those requirements. To gather information about stakeholder-related considerations, the student teams researched a variety of different areas. For example, some teams examined current regional aircraft to understand the typical aisle height. To inform their cost calculations, Team H found information from an airline about the percentage of time the airplane could be down for maintenance. Team C had discussions with airline mechanics to gather feedback about their design decisions and distributed a survey to possible airline passengers to help with the configuration selection process.

In terms of the Figures of Merit (FOMs), students implicitly and explicitly incorporated stakeholder considerations as they examined cost, design risk, emissions, noise, maintainability, cabin noise, passenger comfort, maneuverability, and aesthetics. Overall, the teams included more stakeholder considerations in their FOMs than strictly performance considerations (e.g., range, speed, weight). On average, teams defined over half of their FOMs (53.5%) based on stakeholder considerations, as compared with performance considerations (46.5%) (see Table 73). Still, the average weighting of the performance-related FOMs (3.55 out of 5) was higher than the weight of stakeholder-related FOMs (3.36 out of 5). Additionally, it was unclear for many of the teams how they developed their rankings for the stakeholder-related FOMs or how these FOMs affected the design decisions throughout the design process. For some teams, the FOM were indicators of valuing (or not valuing) particular stakeholders. During the midterm design reviews, for example, Team D discussed how the airlines and the passengers were

their most important stakeholders, but passenger considerations did not appear in the FOMs. When comparing these results with the rubric scores, the team with the highest average weight for stakeholder considerations, Team I, scored the lowest in terms of *Stakeholder Integration* and *Design Understanding*. The driving factor of this RFP was *operating costs*. As a result, this factor should be a high priority FOM. Yet, only Teams F, I, and J included operating costs as an explicit figure of merit. Three other teams included “cost,” while the remaining 4 teams selected “manufacturing cost,” “build cost,” “weight,” and “energy cost” as their cost-related FOM. This lack of explicit focus on *operating costs* is revisited later in this section and in Chapter 7.

Table 73: Distribution of Figures of Merit by Team

[NOTE: Weights range from 1 (least important) to 5 (most important)]

Team	# of FOMs	Perf. FOMs	%	Avg. Weight	STK FOMs	%	Avg. Weight
A	11	5	45.5%	3.20	6	54.5%	2.67
B	9	2	22.2%	4.50	7	77.8%	2.14
C	5	2	40.0%	4.50	3	60.0%	4.00
D	8	4	50.0%	3.00	4	50.0%	4.00
E	4	4	100.0%	3.75	0	0.0%	0.00
F	7	2	28.6%	3.00	5	71.4%	3.00
G	7	5	71.4%	3.80	2	28.6%	4.00
H	8	4	50.0%	3.25	4	50.0%	3.75
I	8	3	37.5%	3.00	5	62.5%	4.80
J	10	2	20.0%	4.50	8	80.0%	3.38

As part of the project, the teams were required to evaluate different technologies which, when integrated, would improve the overall design. In general, teams considered technologies for weight, fuel, and drag performance savings. Half of the teams incorporated technologies that reduced emissions, noise, and costs. To improve the passenger experience and support pilot situational awareness, Team H included technologies such as the SmartView pilot system and the Advanced Active Noise and Vibration Suppression system. When considering the consequences of technology integration, most teams did not consider the effects of new technologies on maintenance

costs and overall maintainability. By the final design review, two teams (Teams A and B) had incorporated the effects of technology integration on maintenance; Team B, for example, noted how the maintenance cost increased due to the integration of new technologies, but they also demonstrated how that the increased cost was offset by a reduction in fuel costs. Thus, other than some exceptions, the teams generally did not consider stakeholders when selecting and integrating new technologies, which is constant with the SMEs' assessment of the design reports.

In the design of the fuselage, students had to balance FAA regulations with the project requirements, the battery integration, and for some teams, stakeholder considerations. Even though the teams used their textbook as a guide to the fuselage design, the resulting designs included a diverse set of passenger and payload configurations. The aisle heights, for example, ranged from 5'8" to 6'6" feet. Four of the teams discussed the impact of the battery integration on the size of the fuselage. The result for most of these teams benefited the passenger who would experience wider aisles, wider seats, or both. Two of the teams explicitly incorporated characteristics of the Boeing 787 to improve passenger experience and/or manufacturability. Yet, there were still teams whose integration of stakeholder considerations at this stage was incomplete. Team D, for example, placed the luggage compartment at the front of the aircraft, but did not assess the impact of that placement on ground operations. This incomplete consideration of stakeholders was not standard across all the teams, as Teams C and J not only explored the impact of their fuselage design on ground operations, but also re-designed the ground operations systems to support the use of their design at airports (see Figure 36).

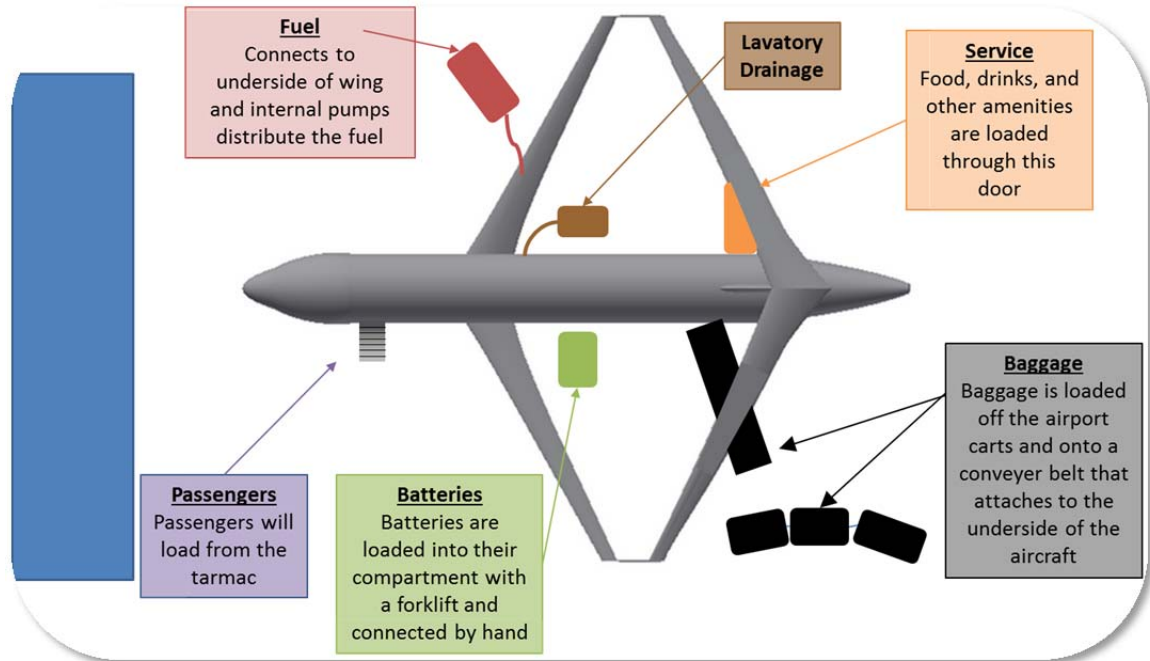


Figure 36: Team J's Re-design of Ground Operations due to Fuselage Design and Overall Aircraft Design

As previously mentioned, the RFP defines *operating cost* as the driving factor within the design, providing students with explicit information about the preferences of their customer. Along with the lack consideration of *operating costs* within the FOMs by some teams, many teams didn't consider operating costs in the first half of the semester. Despite explicit remarks by the instructors, by the time of the midterm design reviews, only 4 of the 10 teams completed trade studies using operating cost per seat-mile (Teams C, E, F, and H). For the other teams, there was general confusion about what was considered an operating cost and an assumption that development and acquisition costs were sufficient for trade studies. Team A, for example, were told explicitly by the instructors in both Week 6 and Week 7 about the need to consider certain stakeholder-related considerations (i.e., operating costs, maintenance costs, landing fees, etc.). At the midterm design reviews, however, these considerations still had not been included in their trade-studies and were only indirectly discussed as they relate to the technologies. Team J, on the other hand, stated they had considered direct operating costs in their

midterm review trade studies, but had instead considered development costs. These costs did not incorporate costs for maintenance and crew, as an example. These trade studies were also used to make critical design decisions about cruise Mach number and the number of batteries to be used for the short range, economic flight. By the time of the final design review, most teams had incorporated operating costs per seat-mile into their trade studies. However, it is unclear whether these trade studies affected their design decisions or if they were only conducted to fulfill course requirements.

At the end of their presentations, four teams revisited their design solution to verify it met the requirements and/or to evaluate it from a stakeholder perspective (Teams A, B, C, and H). These discussions included comparisons between the final design and the baseline design (Team A) and assessments of the design's effects on stakeholders (Teams C and H). When evaluating the design from a stakeholder perspective, Team C explored the perspectives of the airports, airlines, passengers and non-users. However, from this evaluation, it was clear they did not entirely consider the impact of their design on maintainers. Team H, on the other hand, included a stakeholder mapping to briefly illustrate how the aircraft design met stakeholder needs (see Figure 37). While this mapping is not an extensive formal evaluation, as compared with Team C, it provides some information about the stakeholder considerations impacted by their design.



Figure 37: Team H's Stakeholder Mapping

6.3.2.3 Summary

A summary of the results is presented in Table 74. Based on the summative assessment of the team design projects, the teams generally applied an iterative design process. However, most teams did not prioritize the main design driver for the project, *operating costs*, early on in their design process, which may have resulted in design decisions that did not consider this design driver. Stakeholder integration, on the other hand, varied between the design reviews and the design reports. During the design reviews, teams were found to consider stakeholders at isolated points within the design process, while the design reports illustrated only implicit stakeholder consideration. Overall, the quantitative distinctions among the SMEs for stakeholder integration within the Technology Integration phase aligned with the qualitative findings from the midterm and final design reviews. Teams (with the exception of Team H) integrated stakeholder considerations implicitly, if at all, within the Technology Integration phase of the design

project. However, discrepancies still exist on a team-by-team basis between the scores for *Stakeholder Integration* from the design reviews and the scores for the final design reports. For example, within the design reviews, teams demonstrated an ability to identify stakeholders and incorporate stakeholder considerations into configuration selection, which included defining FOMs. Yet, in the design reports, the SMEs did not generally view the teams as successfully incorporating stakeholder considerations within the Concept Generation phase. This phenomenon is examined further later in Chapter 7.

Table 74: Review of Summative Assessment of Team Design Projects [NOTE: MD Stands for Midterm Design. FD Stands for Final Design. All Final Design Report Scores are the Median Scores from the SMEs' Assessment.]

Team	Stakeholder Integration by Design Stage (as determined in Design Reviews)	Stakeholder Integration by Design Stage: Success Median Scores				Design Understanding			Stakeholder Integration		
		Problem Definition	Concept Generation	Technology Integration	Overall Design	MD Review	FD Review	FD Report	MD Review	FD Review	FD Report
A	Problem Definition, Concept Generation, Fuselage Design, Trade Studies	0	1	1	1	1.5	1.5	2	1.5	1.5	1
B	Concept Generation, Fuselage Design, Cost Analysis	0	1	0	0.5	1.5	1.5	1	1.5	1.5	2
C	Problem Definition with Stakeholder Analysis, Concept Generation, Fuselage Design, Operations Analysis	1	1	1	2	3	3	3	3	3	3
D	Problem Definition, Implicit Consideration in Concept Generation, Fuselage Design	1	0	1	1	2.5	2.5	2	2	2	2
E	Fuselage Design	0	0	0	0	2	2	2	1.5	2	0
F	Problem Definition, Concept Generation, Fuselage Design, Trade Studies	0	1	0	1	1.5	2.5	1	2	2	2
G	Implicit Concept Generation, Fuselage Design	0	0	0.5	0.5	1.5	1.5	1	2.5	2	1
H	Concept Generation, Technology Integration, Stakeholder Analysis of Final Design	0	1	0.5	1	2	2	2	2	2.5	2
I	Concept Generation, Fuselage Design	1	1	1	1	0.5	0.5	2	1	0.5	2
J	Concept Generation, Fuselage Design, Operations Analysis	1	1	0	1	2.5	3	2.5	2	2.5	2

6.4 Examining the Interventions

The Application level of the evaluation framework examines whether the knowledge and skills from the active interventions were applied within the post-evaluations and team design project and what changes were visible in performance indicators. The summative assessment of the in-class evaluations and the team design projects highlight students' approaches to the design process that incorporate stakeholder identification, some balance of performance and stakeholder considerations, among other results (see Table 75). This section relates the findings from these assessments to the overall design and individual components of the active interventions.

6.4.1 Requirements Lab

The overall goal of the Requirements Lab, the first active intervention, was to introduce students to requirements, their importance, and how and why stakeholder-requirements should be incorporated into the requirements definition phase of the design process. When considering how the concepts from the lab manifested within the design project, it is important to note that half of the teams explicitly included some form of stakeholder identification (e.g., stakeholder mapping) within their midterm design review, final design review, or final design project report. This result supports the educational intervention specification, ID3 (related to Requirements Lab Learning Objective #3), which states that the interventions should provide students with tools and resources to assist their explicit incorporation of stakeholder considerations.

In the final presentations, 9 out of the 10 teams considered stakeholder-related regulations. In terms of incorporating stakeholders into the design requirements, most of the teams discussed the RFP requirements. Within the design reviews, however, it was difficult to tell if teams factored stakeholders into the requirements they used to define the design. As noted within the previous chapter, students may not have understood how

to evaluate requirements as given and how to incorporate stakeholder considerations. A key example is the incorrect prioritization of operating cost per seat-mile throughout the design process. Even though most teams included cost either implicitly or explicitly within their FOMs, over half of the teams did not consider these costs in detail until after the midterm design reviews; thus, it is unlikely many of their design decisions were based on this FOM. Further, the cost measures often applied did not reflect actual operational cost drivers. If teams had a greater awareness about how to evaluate requirements from the perspective of identifying stakeholders and prioritizing their needs and wants, the teams may have considered operating costs as the highest priority design driver.

In the concept generation and configuration selection phase of the design process, students demonstrated an ability to balance performance and stakeholder considerations, which supports the valuing of stakeholder considerations as specified in ID1. This balance was not apparent in the previous semester, as evidenced by students' reflections about their individual design projects and as discussed in the previous chapter. Even though the performance considerations, in general, were prioritized higher than the stakeholder-related considerations, the teams did select more stakeholder-related FOMs than performance FOMs.

Finally, the Requirements Lab provided the students multiple opportunities to interact with stakeholders directly (ED4 - shall provide students with opportunities to learn from interactions with clients or other stakeholders during the design process). The results of the post-evaluations illustrated that students may have viewed these interactions as critical or essential to incorporating stakeholder considerations. For example, there was a significant increase in the post-evaluations in students' inclusion of a user or customer on the submarine design teams. As a result, many of the teams may have perceived that stakeholder considerations could not be adequately integrated into their designs in the second semester, since they would have no direct contact with any of the project's stakeholders. Team C, on the other hand, reached out to stakeholders twice

during the terms to understand the impact of their design on maintainers and to capture information from potential passengers.

Table 75: Overview of Summative Assessment Results

	Level	Requirements Lab	Stakeholders in Design Lab
		<p><i>Are newly acquired knowledge and skills being applied within the class?</i></p> <p><i>What actions are students taking toward improving the integration of stakeholder considerations?</i></p> <p><i>What changes are visible in the performance indicators (e.g., design project)?</i></p>	
Summative Assessment	Application	<p>Positives: Students demonstrated an awareness of a diverse set of stakeholders and the relationship between requirements and design. They identified stakeholders for their team design project in at least one of the deliverables. They also appeared to integrate stakeholder considerations where interactions with stakeholders were possible and the design scenario had an explicit stakeholder focus. They incorporated stakeholder-related regulations and balanced performance and stakeholder considerations during configuration selection.</p> <p>Negatives: Student teams made many design decisions without considering the impact on stakeholders or stakeholder-related metrics. Many teams incorrectly prioritized the requirements and the main design drivers. Interactions with stakeholder in this lab may have affected students' beliefs that they could not integrate stakeholder considerations in their project without these interactions.</p> <p>Improvements: Future iterations should incorporate a focus on how to evaluate requirements as given and how to incorporate stakeholder considerations from that point in the design process.</p>	<p>Positives: Students demonstrated an increased awareness of stakeholders and their considerations. Many teams utilized stakeholder mapping as part of their design process. They appeared to integrate stakeholder considerations in the case where interactions with stakeholders were possible and the design scenario had an explicit stakeholder focus. Students also developed a deeper understanding of the importance of iteration within design.</p> <p>Negatives: Some student teams discussed stakeholders, but only superficially; as a result the teams made design decisions without considering the effect on stakeholders. Also, many teams incorrectly prioritized the requirements and the main design drivers.</p> <p>Improvements: Future iterations should focus on how to evaluate a design problem to prioritize or determine the value of the different stakeholders. The labs should also encourage students to value design decisions that are based on stakeholder considerations.</p>

6.4.2 Stakeholders in Design Labs

In the first semester of the design course, students, in general, rated the importance of the content of the Stakeholders in Design Labs as fairly important to their team design project. The teams, in general, completed an integrated and iterative design process to develop their final design solution, which may relate to their experience developing a design process within the lab session. Half of the teams utilized the stakeholder mapping tool within their midterm design review, final design review, or final design project report, which aligns with ID3 and is consistent with the findings

discussed in the previous chapter. Within the final design processes from the Stakeholders in Design Labs, the students mentioned incorporating stakeholders in their team design project by identifying stakeholders as part of their design processes, researching stakeholder needs, prioritizing or determining value of stakeholders, and evaluating the design with stakeholders in mind. These design activities, along with the stakeholder mapping technique, were additional tools and resources for the students to use (ID3). Overall, most teams utilized one or more of these design activities over the course of their design process.

Additionally, in the comparison of the pre- and post-evaluations, a substantial change emerged within students' responses to the open-ended context question, demonstrating students' abilities to consider a variety of stakeholders (ED2). Specifically, the most common stakeholders discussed in the pre-evaluation were customers, which were mentioned by 81% of those who discussed stakeholders. Yet, in the post-evaluation, students discussed a diverse set of stakeholders, including customers (31%), passengers (24%), stakeholders in a broad sense (24%), and countries/societies (10.3%). This discussion of a diverse set of stakeholders can be related to the case study activity from the Stakeholders in Design Labs where groups considered many stakeholders, including the U.S. taxpayers and enemies. While students clearly considered stakeholders beyond the customer, the context question answers in the post-evaluation indicated that students still focused mainly on the economic and environmental contexts of a design solution.

In the submarine-design scenario, students reported significantly more stakeholder-related considerations in the post-evaluations than the pre-evaluations. These results suggest an increased awareness by students of stakeholder considerations, which aligns with Educational Intervention Specification ED1 (related to Stakeholders in Design Labs LO#1). Within the post-lab reflection questions, students discussed how they would be able to take into account stakeholder satisfaction and safety in their final project because of a greater awareness of stakeholders and their considerations. In

addition, the stakeholder mapping portion of the case study activity required the students to connect stakeholders with design requirements, promoting an understanding of the relationship between stakeholder considerations and requirements. In the team design projects, half of the teams also discussed how the different stakeholders impacted or are impacted by the design. The manner of this discussion ranged from group to group and in some cases (e.g., Teams C, D and F) it appeared that these impacts may not have been the reason for particular design decisions.

For example, one of the SMEs noted that Team D kept discussing to stakeholder considerations, but it was not clear how much these considerations affected the team's design decisions. This behavior is consistent with the behavior of Team D at the midterm design review. Team C, on the other hand, completed a stakeholder survey, solicited information from stakeholders, and attempted to leverage the idea of incorporating stakeholders to create a more innovative design. Adrian, one of Team C's members, explained in the post-lab reflections that he would consider stakeholders in the team design project, "Even if this is not something specifically mentioned in the RFP, it may be a difference maker as to the best design." Yet, as one SME noted, while the team included many stakeholder concerns, it "seemed that the results of those encounters were minimized and explained away with an 'un-changing' final design point in mind."

During the Stakeholder in Design Labs, students began to formalize factors which they perceived as supporting the integration of stakeholder considerations into the design of a complex system, specifically interactions with stakeholders and design requirements with a stakeholder focus. As mentioned in the previous section, there was a significant change from the pre-evaluations with the increased inclusion of a user or customer on the students' submarine design teams in the post-evaluations. This result suggests that the interventions may have fulfilled specification ID5 (i.e., shall demonstrate to students the value of cross-disciplinary work and examinations of designs from multiple perspectives) and demonstrates the potential impact of ED4 (i.e., shall provide students with

opportunities to learn from interactions with clients or other stakeholders during the design process).

Within the Stakeholder in Design Labs, students were introduced to different methods for incorporating stakeholders into the design process. Participatory design, one of these methods, recommends having a user or the customer on the design team itself. This method received the second highest number of votes for which method the individuals would use in a future aircraft design project. In addition, the final student-generated design processes from the Stakeholders in Design Labs illustrated students' perceptions of the value of interacting with stakeholders. As discussed in Chapter 5, the lab activities may have impacted students' understanding of the design environment necessary for incorporating stakeholder considerations, as evidenced by the post-lab reflections and the end-of-term evaluation results.

Through the post-lab reflections, students noted various challenges to integrating stakeholder considerations into their team design project, including the lack of access to stakeholders and possible lack of focus on stakeholders in the requirements for the team design project. The submarine design scenario resolved both of these challenges, as the project team selection list included stakeholders (users and customers) and the design scenario explicitly included stakeholders. Thus, the increase in stakeholder considerations and the inclusion of a user or customer on the students' design team could be attributed to students' understanding of methods for integrating stakeholder considerations following both active interventions.

For their team design projects, only Team C solicited information from stakeholders directly. In addition, while the RFP did not ask for a personal submarine, implicit and explicit stakeholder considerations were included within the RFP. Yet, students didn't focus on the *operating cost* component, which was defined as the driving factor for the design, and not one team examined the optional passenger time requirement. (This phenomenon is examined further in Chapter 7.)

Finally, examining the educational intervention specification ED5, the Stakeholders in Design Labs included implicit elements (specifically the case study and design process development) to promote the importance of iteration and trade-offs within the design process. The results discussed in the last chapter demonstrated how students' understanding of the importance of iteration in the design process evolved over the course of the labs. Specifically, the student-generated design processes revealed a statistically significant increase in the number of iteration points between the start and end of the lab sessions. The post-evaluation aligned with those results as one of the most substantial changes in students' rankings of the most important design activities occurred with *iteration*. In the case of *making trade-offs*, the activity also became a more important design activity for students over the course of the semester. However, it was not possible to determine if that increase could be attributed to the Stakeholders in Design Labs.

6.5 Discussion of Research Questions and Summary

Overall, the results of the assessments and evaluations in this and the previous chapter address the following research questions:

- RQ#4.1 - What characteristics of the educational interventions support students' abilities to integrate stakeholder considerations into the design of an aerospace vehicle?
- RQ#4.2 - To what extent can the interventions help students integrate stakeholder considerations into the design of an aerospace vehicle?

Within the Requirements Lab, the stakeholder identification exercises and the interactions with stakeholders affected not only students' actions during the team design project and post-evaluation, but also students' perceptions of a design environment which is capable of integrating stakeholder considerations. As a result, students were able to identify a diverse set of stakeholders in the post-evaluation and within their team design project. However, most teams (excluding Team C) may have perceived the team design

project as inappropriate for stakeholder integration since they were unable to interact with project stakeholders.

In the Stakeholders in Design Labs, the stakeholder identification exercises and the introduction of the stakeholder mapping tool supported students' identification of a diverse set of stakeholders and the exploration of a design's effect on stakeholders. The HCD methods activity further emphasized interactions with stakeholders and, thus, may have reinforced students' perceptions of a design environment that is appropriate for the integration of stakeholder considerations. The case study and design process development activities provided real world examples of where and how iteration and stakeholder considerations ultimately impact a final design solution. In the post-evaluation, the students included iteration more within their intended design process and ranked it higher than the comparison student population and the AE professionals. Through the design project, teams used many of the stakeholder-related design activities defined in the design process development activity at isolated points within the design process. These activities supported their integration of stakeholder considerations to some extent, but many teams still did not consider stakeholders within their design decisions. Post-lab reflections revealed a perception that the project requirements will ultimately affect the students' ability to integrate stakeholders. While the stakeholder-centric design scenario in the post-evaluation supported this perception, stakeholder integration within the team design project may have been impacted by the implicit or optional nature of the stakeholder-related requirements in the RFP.

CHAPTER 7 - Impact of the Learning Experiences and the Learning Environment

In the last two chapters, the focus was on students' experiences in the interventions and students' adoption of intervention content. This chapter further considers the characteristics of students' learning experiences and the aircraft design capstone learning environment to respond to research question #4.3:

- What characteristics of the engineering design learning experience and learning environment support or hinder students' integration of stakeholder considerations into the design of an aerospace vehicle?

The chapter begins by revisiting the evaluation framework and previously used indicators, and introducing an additional theoretical lens for exploring the aircraft design learning environment. The research design, including the data collection and analysis methods, is then presented along with a short discussion of their limitations. The subsequent discussion of the results highlights the learning environment characteristics that prevented or supported the effectiveness of the interventions. It is followed by a discussion section that examines the interventions using the complete evaluation framework and formalizes a response to Research Question 4.3. The chapter closes with a summary and foreshadows recommendations for intervention modifications that are discussed in the conclusions of the thesis.

7.1 Evaluation Framework and Relevant Theoretical Lenses

In the previous two chapters, the lower levels of an evaluation framework, adapted from Moon, et. al (2011) and Kaufman, et. al (1995), were used to examine each intervention and its impacts on students' integration of stakeholder considerations within the senior aircraft design capstone course. In this chapter, the focus is to isolate the characteristics of the learning experiences and environment supporting or hindering the effectiveness of the interventions. These characteristics relate to the two highest levels of the framework, Level 4 (Organizational and Course) and Level 5 (Societal) (see Table

76). The Organizational and Course level explore (1) the learning environment barriers that prevent or support students' integration of stakeholder considerations and (2) the aspects of the learning environment and intervention that prove most successful for program stakeholders (i.e., instructors and students). The Societal level examines the broader impact of the interventions outside and after the course.

Table 76: Organization and Societal Levels of the Evaluation Framework

#	Level	Description	Research Tool(s)	Relevant Chapters
1	Resources and Processes	What are the inputs to the lab sessions (e.g., resources, materials required, etc.) What is the quality of the intervention activities? What feedback did the participants provide about the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
2	Acquisition	Are the objectives or desired outcomes of the learning intervention met? What did the participants learn as a result of participation in the intervention?	Qualitative and quantitative analysis of intervention artifacts	Chapter 5
3	Application	Are newly acquired knowledge and skills being applied within the class? What actions are the various stakeholders taking toward improving the integration of stakeholder considerations? Who adopts what aspects of the instruction (students, student teams or instructors)? What changes are visible in the performance indicators (e.g., design project)?	Quantitative analysis of intervention artifacts; in-class evaluation; stakeholders in design rubric	Chapter 5 and Chapter 6
4	Organization and Course	What organization/learning environment barriers prevent or support adoptions? What aspects of the learning environment and intervention prove most successful for program stakeholders?	Observations of design team meetings; student focus groups; instructor interviews; stakeholders-in-design rubric	Chapter 7
5	Societal	What impacts exist outside and after the course?	Instructor interviews	Chapter 7

Additional theoretical lenses are necessary to investigate the Organization and Course level effects of the interventions. First, the education literature discusses three components of the learning environment that affect students' orientation toward particular achievement goals: *task*, *authority*, and *evaluation and recognition* (Ames, 1992). As defined by Ames (1992), achievement goals describe students' perceptions of success in the learning environment, their reasons for engaging with the course and the

material, and their understanding of themselves and the elements of the course. The learning environment components include *task*, which, as illustrated in Table 77, describes the instructor’s design of the learning activities and assessments (e.g., projects, homework, and exams). The *evaluation and recognition* component focuses on the evaluation strategy employed by the instructors, which considers the methods, frequency, and content of the assessments. *Authority* captures the approach to distributing authority and responsibility within a classroom. For example, is it student-centered or instructor-centered? With each of these three components, Ames (1992) also notes how *students’ perceptions* play a critical role. As a result, it is important to consider, for instance, how students’ perceive the tasks (e.g., as a challenge, as meaningful, as requiring little effort), the purpose of the evaluations, and the control structure within the learning environment. Ames (1992) explains how “students have different classroom experiences, but because they also bring different prior experiences with them, they may interpret a teacher-student interaction or event quite differently” (p.267). Thus, students’ perceptions are examined within each learning environment component to further explore the Organization and Course level effects of the interventions.

Table 77: Components of the Learning Environment Affecting Student Orientation Towards Achievement Goals (adapted from Ames, 1992)

Components	Description
Task	<i>The design of learning activities and assessments</i> What is the structure of the task? How is the task delivered? How does the task interact with the other structures in the classroom?
Evaluation and Recognition	<i>The approach to evaluating students(e.g., criteria, methods, frequency, and content of evaluation)</i> What is the structure of the evaluation? How are students recognized for positive or negative performance?
Authority	<i>The instructor’s orientation toward student responsibility and autonomy with the learning environment</i> To what degree do the instructors involve students’ in decision making? What responsibilities do students have based on assignments or other assessments?

The second lens used to characterize the Organization and Course level impacts applies the adaptations of the *relatedness* and *perspective* classifications developed by Richter and Paretto (2009), as used in earlier phases of the intervention evaluation (see Chapter 5). These classifications recognize students' (in)abilities and values as they relate to the connections between stakeholder considerations and aircraft design decisions (see Table 78).

Table 78: Relatedness and Perspective Classifications (Adapted from Richter and Paretto, 2009)

Relatedness/ Perspective	Positive/ Negative	Description
Relatedness	Positive	Students' ability to identify connections between stakeholder considerations and their work thus far in aircraft design.
	Negative	Students' inability to see connections between stakeholder considerations and their work thus far in aircraft design (e.g., it does not involve human factors)
Perspective	Positive	Students' ability to see an aircraft from various stakeholder perspectives and identify ways in which the stakeholder considerations enrich the overall design
	Negative	Students' inability to see an aircraft from more than a standard performance perspective and/or value the contributions of stakeholder perspectives to the overall design

Finally, the third lens applied within this analysis examines cognitive load. As discussed in Chapter 5, in design capstone courses, novices may experience significant cognitive load, i.e., the cognitive resource demands required to learn particular concepts or to solve particular problems (Chandler & Sweller, 1991; Sweller, 1988). Design capstone courses require students to approach ill-defined problems and make connections among material from many different, sometimes perceived as disparate, classes. In addition, these design courses may be the first design experience for many of the students. As such, students who appeared to be experiencing a high amount of cognitive load were tracked to determine if this cognitive load affected their integration of stakeholder considerations. Causal factors noted in the cognitive science literature were examined for their impact on students' cognitive load, including the characteristics of the student, the task or design problem, the learning environment, and the relationships among these factors (Kirschner, 2002).

7.2 Methods and Limitations

A convergent mixed method research design was used to explore the relationship among the components of the aircraft design capstone learning environment and students' integration of stakeholder considerations within the design process, using the three theoretical lenses (Creswell & Plano Clark, 2011). Over the course of the academic year, the researcher observed lectures, lab sessions, and design team meetings between student teams and the course instructors. In addition, the researcher conducted a series of interviews with the instructors, and performed informal focus groups with three of the ten student teams (see Figure 38). Qualitative analysis of this data isolated the characteristics of the learning environment, using the causal factors defined within Cognitive Load Theory and related theoretical lens. This data was then integrated with the qualitative and quantitative measures of team performance on the design project reports and design reviews, as discussed in the previous chapter, looking specifically at the teams' design understanding and their integration of stakeholder considerations into their design process.

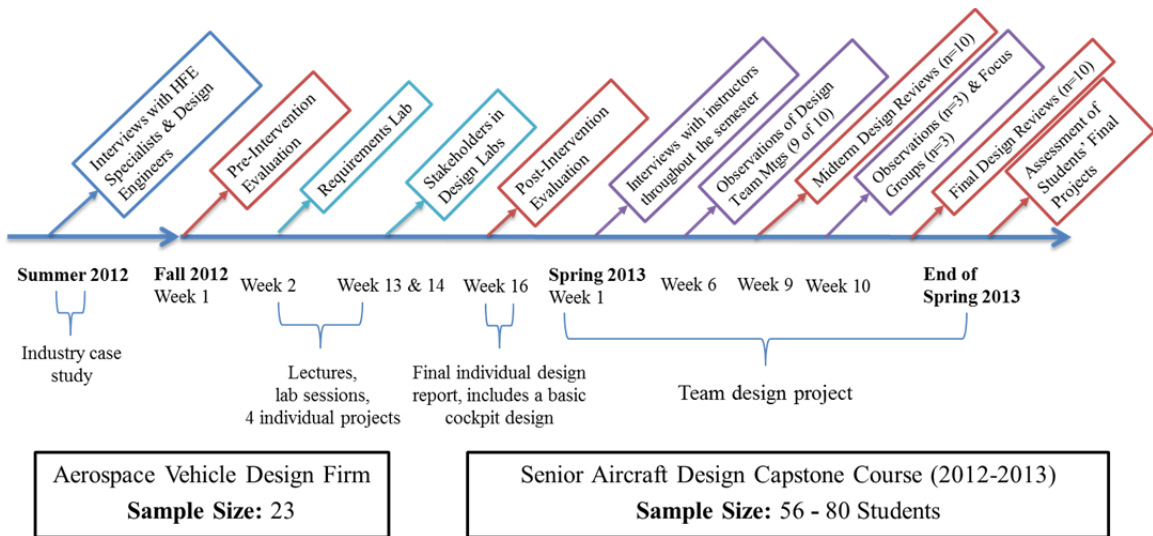


Figure 38: Complete Data Collection Roadmap

7.2.1.1 Data Sources

7.2.1.1.1 *Interviews with Design Instructors*

In the spring semester, the researcher conducted semi-structured interviews with the course instructors six times throughout the semester at two to three week intervals. One year later, the researcher conducted a final follow-up interview with the instructors to explore post-course impacts of the interventions. The purpose of these interviews was to gather information about student progress, challenges students were facing in the design process, and instructors' perspectives of stakeholder integration on the projects (see Appendix H for interview protocol). Additional questions were developed prior to each interview to take into account recent observations or unanswered questions from the previous interview. The researcher took notes during the interviews and expanded the interview accounts following the interview to facilitate the subsequent data analysis.

7.2.1.1.2 *Observations of Student Design Team Meetings*

In the second semester of the aircraft capstone design sequence, the student teams met weekly with the course instructors to update the instructors on their progress and receive feedback. These meetings typically lasted around 30 minutes. From the start of the 6th week of the spring semester until the midterm design reviews during Week 9, the researcher attended team meetings for nine of the ten design teams (Note: One team could not be observed due to a time conflict). Following the midterm design reviews, three teams (one low, one middle, and one high performing) were selected for continued observation. The assessment of team performance on the design project was completed after conferring with the design instructors during the post-midterm design review interview to support the selection of these three teams. Finally, all ten teams were observed during both the midterm and final design reviews.

Field notes and follow-up memos (Miles & Huberman, 1994) were developed for each meeting and design review. Observing students during design reviews helped identify students' perceptions reflected in the team design reports. Specifically, the researcher captured perceptions about the importance of stakeholder considerations and approaches (or lack thereof) for integrating stakeholder considerations into the design process. For the most part, the observations were made without disturbing or disrupting the students and without audio or video recordings.

7.2.1.1.3 *Informal Focus Groups with Students*

Three different teams (one high, one middle, and one low performing team) were recruited to participate in an informal focus group, one per team. The informal focus groups followed a semi-structured protocol with one main question and a series of optional follow-up questions (see Appendix I). These questions were developed following the midterm design reviews based on observations of the teams and the preliminary analysis of the midterm design reviews. The opening question asked students to complete a short card-sorting task, designed based on principles defined in Coxon (1999), where the notecards represented different tasks within the aircraft design process (e.g., configuration selection, constraint analysis, stakeholder analysis, historical research about other similar aircraft). Specifically, the students were asked to sort the cards into stacks based on three questions:

1. Which design tasks do you view as feasible (or infeasible) for students to complete over the course of a semester?
2. Which design tasks do you feel most confident (or least confident) in your ability to complete?
3. Which design tasks, if you had a choice, would you want to complete as part of a senior design project?

Students were asked to explain the reasoning behind their selections. The researcher took notes regarding students' responses and expanded those notes at the completion of the focus group. Following the card-sorting task, the researcher inquired about students'

perceptions of the progress of the course and students' recommendations for changes to the course curriculum (e.g., lecture topics, project requirements, course focus). Finally, for the middle performing team, the researcher asked clarifying questions about the teams' integration of stakeholder considerations, since their midterm design review included stakeholder considerations only at the end of their presentation. It was unclear how (or if) the team integrated these considerations during the design process.

Discussions with these students supplemented the observations and the examinations of projects with additional insight into how students' perceptions changed over the course of the semester, the challenges they faced while designing the vehicle, and their understanding of and perceptions about aircraft stakeholders and their role in design.

7.2.1.2 Data Collection and Analysis

Data were collected throughout the second semester of the senior aircraft design capstone course with the approval of the Institutional Review Board (see Appendix A.4 and A.5). Each data source was initially analyzed qualitatively and separately by a single researcher using thematic analysis techniques to uncover high-level themes within the data (Miles & Huberman, 1994). Instances of cognitive load were noted, along with discussions about relatedness or perspective, as defined in Section 7.1 This data were then integrated using the learning environment components lens (adapted from Ames, 1992). Finally, the qualitative and quantitative data from the analysis of the students' design projects, as presented in the previous chapter, were integrated into the learning environment components lens to allow for comparison between students' performance and their progress throughout the semester. Additional data from the first semester of the course were included to further understand emerging patterns and to draw conclusions across the framework, the instances of cognitive load, and the relatedness and perspective classifications.

7.2.1.3 Limitations

Limitations of this approach include the use of a single design course at a single university and the examination of that course by a single investigator. To avoid capturing only a one perspective within this study, this design utilized multiple data sources and different data collection methods (Creswell & Miller, 2000). It is also important to discuss the potential impact of “subject effects” (Weber & Cook, 1972). Subject effects, in this context, reflect how the researcher’s involvement in the course, as an observer, may have swayed students’ responses in the data collection instruments and for their team design project. Students may have perceived that, to help the researcher, they should mention the word “stakeholders” and include discussions about stakeholders and stakeholder considerations within their responses and project. Thus, the researcher’s role as a passive intervention within the course can be viewed as a limitation of the research design, which must be kept in mind when examining the overall results and conclusions.

In addition, the observations and focus groups spanned teams at differing performance levels and the instructor perspective was added to provide a richer illustration of the learning environment. The qualitative nature of the majority of the data required the researcher to be constantly aware of her own assumptions and biases during the collection and analysis of data. Through the use of multiple sources of data and the triangulation of the data in the data analysis phase, this research design helps mitigate some of the effects of “elite” bias and researcher bias (Miles & Huberman, 1994). In addition, a skeptical peer review process, where researchers unaffiliated with the project review whether sufficient evidence exists to support the claims, was used to further ensure the trustworthiness of the results presented and to identify possible rival conclusions (Creswell & Miller, 2000).

7.3 Results

The results section is divided into three parts: Task, Evaluation and Recognition, and Authority. These parts represent the learning objective components previously discussed. The impact of students' perceptions on each component is also incorporated into each of the subsections.

7.3.1 Task

To explore the tasks (e.g., learning activities, assignments) within the capstone design sequence, this section begins with a brief review of the learning activities and overall structure of the requirements lab, first semester of the course, stakeholders in design lab, and the second semester of the course. Then, this section presents the three characteristics related to tasks that emerged as affecting the students' integration of stakeholder considerations and the overall effectiveness of the active interventions: the *team design project requirements*, the *design process structure*, and the *available tools and resources* to complete the learning activities and assignments (see Table 79).

Table 79: Overview of Task-related Learning Environment Barriers

	Team Design Project Requirements	The Design Process Structure	Available Tools and Resources
Requirements Lab (<i>Active Intervention</i>)	Stakeholder-centric design case	Focus on writing requirements and stakeholder identification	Interactions with stakeholders; peers as resources
First Semester of Course	Four small individual projects used to introduce parts of design process; not explicitly stakeholder-centric	Very structured design process	Excel design tool, design textbook, other design software tools
Stakeholders in Design Lab (<i>Active Intervention</i>)	Examination of large scale case studies with many stakeholders	Students developed own design process; large-scale case studies used to illustrate different design processes	Case studies, stakeholder mapping, human-centered design methods, peers as resources
Second Semester of Course	One large team project; not explicitly stakeholder-centric	Student-driven design process	Excel design tool, design textbook, other design software tools

7.3.1.1 Overview of the Course Tasks

The first active intervention, the Requirements Lab, was structured to support students as they constructed knowledge about stakeholders and requirements during their introduction to the early stages of design. The learning environment was designed using Kolb's Learning Cycle (Kolb & Kolb, 2009), which models learning as a process of constructing knowledge. Thus, the activities were divided into sections: learning by experience, learning by reflection, and learning by experimentation. Students were given opportunities to learn from interactions with clients and other stakeholders.

The tools made available to the students during and after the Requirements Lab included: (1) reference material about requirements, (2) interactions with stakeholders during activities, and (3) student-developed standards for well-written requirements. These standards, for example, were defined on the board in the classroom and during the learning by reflection activity when the students had an opportunity to consider the characteristics of well-written requirements from their perspective. Finally, the students also worked in teams for many of the activities that allowed them to use one another as resources.

The Requirements Lab was implemented early during the first semester of the design capstone course. During the remainder of the first semester, students attended lectures and lab sessions that focused exclusively on the components of an aircraft and the mathematical tools used in conceptual design. During the lecture sessions, the instructors presented themselves as subject-matter experts who were responsible for disseminating knowledge and experience to the class. The structure of each lecture included one, or a combination, of the following elements: in-class quiz, review of quiz/project results, lecture, and discussion of project (Q&A). The lecture duration ranged from 30 minutes to the full 55 minutes. Lab sessions, which did not always occur each week, were about 1.5 hours and provided students with time to construct their

design tools with the help of the instructors. Lecture slides served as resources, along with the textbook, for completing the assignments. Lecture slides included discussions of “design significance” to help students understand the significance of the given characteristics to the overall design. From the observations, it was clear that Microsoft Excel was advocated by the instructors as the main design tool for this first semester of the course (e.g., the lab times were dedicated to developing that tool). For example, during one lab, the instructors discussed how the work in a single spreadsheet can verify the requirements are met by particular design parameters. Other tools discussed within the course such as a database for examining airfoils, XFOIL, Vehicle Sketch Pad, and AVL.

During the academic year after this study, the instructors incorporated a Gulfstream accident report into one of the lab sessions, similar to the case studies presented in the Stakeholders in Design Labs. The accident report was used to give students an opportunity to discuss what can go wrong within a design and to springboard a discussion about ethics.

In the 12th week of the semester, the second active intervention, the Stakeholders in Design Labs, was implemented. The design of these labs was based on social constructivist learning theory (Vygotsky, 1978). As such, the activities and overall design were based on the concepts of collaboration, negotiation, and communication. The aim of the labs was to support students as they defined how stakeholder requirements could be incorporated into the design process they would follow during their team design project. The activities included design process development, case studies, and an introduction to human-centered design (HCD) methods.

The design process development was meant to provide students with a tool that they could use during their team design project. Other tools were also introduced, including a Stakeholder Mapping technique and HCD methods such as Participatory Design. Finally, the case studies themselves were introduced to the students as resources

with the explanation that experienced design engineers work from previous designs and use lessons from those previous designs and their own previous design experiences when starting a new project.

The Stakeholders in Design Labs were designed with the context of the course in mind. Students' feedback from the Requirements Lab, class observations, and results of an in-class evaluation were used to develop the learning objectives and activities. Even though the student-centered, social constructivist learning theory used within these Labs was inconsistent with the instructor-centered learning environment the students had experienced up to this point in the semester, feedback illustrated that students appeared to like and benefit from the structure. In addition, the idea of constructing knowledge within a team is consistent with the work environment most students will experience in their careers. Prior to the first Stakeholders in Design Lab, the instructors returned their scores and feedback on one of the individual projects. It was clear that, for a few students, this feedback impacted their attitude at the start of the lab. In addition, during these labs, students were in the process of submitting another individual project and starting their final deliverable.

For the second semester of the design capstone course, as mentioned in the previous chapter, the students separated into teams to develop a solution to a Request-for-Proposals (RFP). The instructors utilized the RFP developed by the American Institute of Aeronautics and Astronautics (AIAA) as the specification for the team design project and as an assessment tool. The students attended lecture, if held, twice a week. Once during the semester, a guest lecture provided the students with a discussion about the integration of human factors into aircraft design. Instead of lab sessions, the instructors attended 30 minute design reviews with each team once a week. The teams were responsible for leading the meetings and could use that time to clarify questions they had about the project or present what they have done up to the point. Throughout this second semester, students performed two design reviews, a midterm and a final. For the team design

project, the students had their design textbooks, the design tools that they made previous semester, and additional software analysis tools (e.g., XFOIL, AVL) as necessary.

In the follow-up interview with the instructors one year after the study, the instructors also discussed incorporating two guest lecturers in this subsequent year of the course. The first guest lecturer provided students with a talk on the stakeholder perspective (1st guest lecture) and an introduction to human factors (2nd guest lecture). The third guest lecturer was an industry representative who introduced students to the marketing and business side of aircraft design. The instructors viewed these guest lectures as a good exposure for the students. In future years, the instructors hope to bring in maintainers and pilots. Finally, the instructors noted that they introduced the students to a few more analysis tools such as Computational Fluid Dynamics software that students could use for their team design project.

7.3.1.2 The Structure of the Request-for-Proposals (RFP)

One of the most influential factors on students' integration of stakeholder considerations and the effectiveness of the labs was the structure of the RFP, which aligns with findings from the aerospace engineering design curricula review in Chapter 3. Earlier, in the first semester, 15% of the students reflected on the general difficulties caused by project requirements. For instance, Lucas explained how the most difficult part of the course was "understanding the exact design requirement and designing an aircraft to meet the standards." Ricky specifically requested that the "list of deliverables for each project/report was little bit more detailed OR was explained a little more clearly." Georgiana spoke specifically about the report requirements:

"The instructions for reports were unclear. While following the process was simple, sometimes the exact outputs or presentation requirements were not clearly laid out."

It is important to note that the first semester individual project requirements were structured, and each project focused only on certain portions of the design process. For example, the focus of project 2 was weight sizing: “For the second part of the project, the student will perform the weight sizing process described in Roskam Part I and in-class.”

Within the team design project, many student teams were found to limit their integration of stakeholder considerations to the explicit stakeholder-related requirements included in the RFP. At the start of the second semester, the students received a single RFP for the team design project, which the instructors viewed as more difficult than the previous year’s. The objective statement of the RFP explicitly stated “considering hybrid electric propulsion and advanced modular batteries, design a regional-sized commercial airliner with the lowest operating cost per seat-mile for the economic mission of 400 NM.” Additionally, the RFP included implicit requirements for reductions in emissions and noise, and one *optional* explicit passenger-related requirement: “the value of passenger time can also be considered in the economic analysis.” This optional requirement, in theory, provided an opportunity to examine and incorporate the value of passenger time as a competitive advantage. However, even with explicit comments about passenger time from the instructors, none of the teams in this study examined it. A similar phenomenon occurred in regards to *operating cost per seat-mile*, which was defined as one of the driving factors of the design within the RFP. As discussed in the previous chapter, most teams did not complete trade studies based on operating cost until after the midterm design review, even with the explicit instructor remarks about operating costs during the design team meetings. In addition, some teams did not appropriately define this metric.

This result aligns closely with student perceptions from the first semester of the course, where over 40% of the students noted that where pilot safety and satisfaction requirements were not specifically included in an assignment description, they did not need to be considered. Adam explained how “the project requirements do not require you

to consider the safety of the pilots,” while Joshua noted, “the safety and satisfaction of the pilots was never given as a requirement, or even a preference, so it did not enter into my consideration.”

For Team C, the team design project RFP was not viewed simply as an assignment description, but as competition rules: This RFP was also the RFP for the AIAA undergraduate aircraft design competition, and student teams could enter their proposals in the competition following the end of the second semester. Only Team C chose to submit their proposal to the competition.

Team C was also the team who most successfully integrated stakeholder considerations consistently throughout their design process. In the first semester of the course, Adrian, one of the members of this team, explained how they would integrate stakeholder considerations into their team design project “even if this is not something specifically mentioned in the RFP, it may be a difference maker as to the best design.” This difference in perspective may have encouraged this team to integrate stakeholder considerations explicitly into their design.

As briefly introduced in the previous chapter, the active interventions may have influenced students’ perceptions of the appropriate design environment for integrating stakeholder considerations. In their reflections during the Stakeholders in Design Labs, many students did not believe the stakeholder “fit” within the aircraft design capstone learning environment. Specifically, students noted various challenges, including the lack of access to stakeholders and a possible lack of focus on stakeholders in the requirements. For instance, Heather explained,

“I am not sure what kind of requirements and resources will be available for the spring semester design project. Whether or not safety & satisfaction of stakeholders is considered depends on if there is contact with them.”

In a comparison of the start-of-term to end-of-term evaluations, the integration of stakeholder considerations in the case of the personal submarine design scenario

significantly increased. This scenario clearly “fit” into the stakeholder-centric design environment defined by the students, as interactions with stakeholders were possible and the design requirements had an explicit stakeholder focus. As a result, a mismatch existed between the design environment created by the team design project RFP, which included stakeholder considerations implicitly yet did not require or provide interactions with stakeholders, and the stakeholder-centric design environment generated by these students. This perception may have been further enhanced by students’ perceptions of the unrealistic nature of the RFP, specifically in regards to the hybrid electric propulsion requirements. Both Teams C and H raised this issue during their informal focus groups.

7.3.1.3 Design Process Structure: Problem-Scoping Example

The first semester of the course introduced students to the design process as defined in the course textbook. In the lectures, the design process was introduced as a linear process with iteration as a step. Each part of the process had a very specific task for the student to complete. For example, “Determine A, B coefficients from weight regression” and “Construct Class I drag polar.” Thus, over the course of the semester, the students may have developed a reliance on this design process. The initial evidence for this conclusion came from the similarity between the design process drawings generated by the students during the Stakeholders in Design Labs and the design process presented by the course instructors.

In the second semester, the mid-performing Team H discussed in the focus groups how they noticed the emphasis on the given design process, but didn’t necessarily like the overlap between the first and second semester of the course. “You just repeat the same methods in the second semester that you did in the first semester.” However, Adrian, from the high performing Team C, explained how this RFP “breaks the design process,” specifically through the addition of the batteries and electric power requirements. Team I, a team who experienced significant cognitive load throughout the design project, also

noted this emphasis, but, conversely, suggested removing the major differences between the first semester projects and the team design projects by designing an RFP specifically for this class. This new RFP would allow the students to use the tools they built in the first semester directly in their team design project in the second semester.

Another example of the impact of this design process comes from the problem-scoping phase of the process. During both in-class evaluations, students self-reported high levels of self-efficacy for problem-scoping activities and viewed these activities as the most important design activities within the design process. In the active interventions, stakeholder identification was defined as part of the problem-scoping phase of the design process. The Requirements Lab specifically included learning activities that provided students with the opportunity to practice stakeholder identification. Yet, in the second semester, instructors noted that students had trouble with problem-scoping. One of the instructors described how the students seemed to “jump in without thinking.” The other instructor explained that teams, in general, were not paying attention to the requirements and discounted planning.

Overall, the instructors both emphasized that even by the fifth week of the project most groups didn't seem to have a clear picture as to how to approach the problem. One of the instructors explained how several teams were looking at the design trade studies in the same manner as they had performed weight and sizing analysis in the fall semester. These observations are consistent with findings from the literature about the challenges of this phase for novice design engineers (Crismond & Adams, 2012; Downey & Lucena, 2003). Specifically, novice designers may not know how to approach an ill-defined, open-ended design problem (Downey & Lucena, 2003), which may lead them to make assumptions about the problem statement and generate solutions before adequately understanding the problem (Atman et al., 2007; Crismond & Adams, 2012). Experienced designers, on the other hand, focus on understanding the problem and defining the solution space without making design decisions too early within the design process

(Ahmed et al., 2003; Atman et al., 2007; Crismond & Adams, 2012; Smith & Leong, 1998).

For the students in this study, these challenges with the problem-scoping phase of design could be attributed to students' cognitive load as they tried to transfer a design process they learned in the first semester to a different design problem. For instance, the only learning activity based on the requirements analysis phase of design was the Requirements Lab, which focused on writing requirements rather than evaluating requirements. Recommendations from the previous two dissertation chapters suggested a greater focus on problem-scoping activities in design courses, since, for example, the summative evaluations of students' design projects indicated that only half of the teams identified stakeholders as being within the problem scope at any point in the design process. When it did occur, the teams integrated stakeholders most thoroughly in the concept generation phase which has elements of problem-scoping (e.g., defining figures of merit), and the student teams defined a greater number of stakeholder-related considerations than performance considerations. However, cost considerations were not included explicitly in the first semester design process and many of the teams incorrectly prioritized the *operating cost* design driver. During the academic year following the study, the instructors discussed changing the approach for framing configuration selection to incorporate the stakeholder perspective more explicitly. The purpose was to encourage students to develop Figures of Merit purposefully and appropriately based on the stakeholders' perspective.

7.3.1.4 Tools and Resources

In each of the active interventions, students had an opportunity to reflect on their experiences. These reflections provided some information about students' perceptions of the interventions and a capstone design learning environment. The time spent in the requirements lab session, for example, was the aspect students disliked the most: The lab

was either too long or too short. This issue arose again in the Stakeholders in Design Labs. In the focus groups, Team H discussed that lack of time available to complete their project as a constraint to integrating stakeholders. Thus, time may have been a limiting factor for these students, perhaps due to some combination of not having enough time and not knowing how to approach their tasks in a time-efficient manner.

During the second semester, the students had access to their Excel design tools from the first semester of the course and their textbook. The instructors further expected students to also use textbooks from previous courses and additional resources, as needed. Yet, from the instructor interviews, the instructors discussed how students didn't know how to go back to texts from previous classes when they didn't understand a concept. One instructor noted that the students were "not really taught to find their own resources or how to make assumptions that make sense." Even for teams, such as Team D, who completed an integrated and iterative design process as determined by the evaluation of the design projects, they were constantly reminded by the instructors to examine old lecture slides or the book. In the twelfth week, the instructors had to point out that one of the students had misused a cost analysis report, which described suggested values for military aircraft rather than regional or commercial aircraft. Thus, for some teams, this task of finding their own resources may have required significant cognitive load. For example, when students reflected on their difficulties in finishing the first semester individual design projects, Samuel mentioned how

"Using complex Excel calculation (e.g., goal seeking) is kind of difficult to understand. Also tons of formulas on each lectures [*sic*] are too much to digest and understand. Also, having to look at both slides and Roskam book just confuses the heck out of me. I wish there was just one standard text book or slides that we can all just stick to."

For this student and others in the course, the tools may have already been too complex for students to even consider incorporating additional tools into their team design project.

As with sizing and the different types of analysis, the instructors and the design textbook provide students with design tools, but these tools did not support the integration of stakeholder considerations. Following the Stakeholders in Design Lab, students discussed how access to tools and greater awareness of stakeholder considerations were some of the main enablers for the 63% who reported they would consider stakeholders in their team design project. These tools included the Stakeholder Mapping technique, which was used by half the teams in their team design projects. However, like the sizing and the different types of analysis design tools provided to the students, these tools did not explicitly support the integration of stakeholder considerations. Thus, tools which incorporate stakeholder considerations directly need to be integrated into the main design tool (i.e., Excel), especially for the teams experiencing high cognitive load. Team I, for example, noted that they perceived the infeasible portions of the project to be cost analysis, stakeholder analysis, and market analysis, due to the lack of available resources and time. Team B, the other team who experienced noticeable amounts of cognitive load throughout the design process, also did not incorporate the stakeholder mapping technique into their design process.

Students perceive that a design environment that integrates stakeholder considerations must provide an explicit, stakeholder-centric set of requirements and interactions with stakeholders. This concept of interactions with stakeholders was introduced first in the Requirements Lab and reiterated in the Stakeholders in Design Lab. Within the Stakeholders in Design Labs, 12 of the 20 teams discussed “interactions with stakeholders” as one way they would incorporate stakeholder considerations into their team design project. Student reflections also indicated some students (15%) foresaw an inability to consider stakeholders within their project because there would be no means to communicate with those stakeholders. Zachary expressed,

“No, I do not believe we will have an accurate idea of stakeholder satisfaction. The RFP will define requirements but communication with stakeholders can't happen.”

Connor explained that stakeholders could be considered but not comprehensively:

“Consider', yes, however, we may not be able to fully encompass all needs/satisfaction of the stakeholder without true stakeholders to evaluate the design.”

In the context of this RFP, however, access to stakeholders was not required, nor was it necessarily possible. As a result, the discussions about, and opportunities to interact with, stakeholders in the active interventions may have suggested to some students that stakeholder considerations cannot be effectively included in a design without these interactions. On the other hand, Team C created stakeholder interactions themselves by speaking with airline representatives and surveying college-aged passengers to gather information about passenger preferences.

The instructors also tried to support students' “access to stakeholders” by giving them hypothetical situations to consider as they prepared their design reviews and final design reports. For example, in a design team meeting with Team B, one of the instructors suggested the students think about the type of questions which would be raised “if you were presenting to someone at Boeing.” These hypothetical situations were also given to other teams, such as Team F. In describing the reason why it is necessary to consider life cycle costs, one of the instructors explained how “as a company [you're] going to care about [acquisition costs].” Yet, by the time of the final design reviews, the teams were only presenting in front of the instructional team and the researcher, rather than airline or other relevant stakeholders.

7.3.2 Evaluation and Recognition

To explore the evaluation and recognition strategies used within this learning environment, this section begins with a brief review of the formative and summative assessments used within the requirements lab, first semester of the course, stakeholders in design lab, and the second semester. Then, two aspects of the evaluation strategy are discussed in detail, specifically the *interactions with an external audience* and the *instructors' team project evaluation strategy* (see Table 80).

Table 80: Overview of Evaluation-related Learning Environment Barriers

	Interactions with External Audience	Evaluation Strategy
Requirements Lab (Active Intervention)	Presentation to peers/ instructors in class discussion small group work	Formative assessments only, immediate feedback
First Semester of Course	Projects & quizzes to instructional team only	Project grades and quiz grades
Stakeholders in Design Lab (Active Intervention)	Presentation to peers/ instructors in class discussion small group work	Formative assessments only, immediate feedback
Second Semester of Course	Midterm design review included outside audience; design meetings & final design review to instructional team & researcher; project reports to instructors only	RFP "checklist" with some additional requirements

7.3.2.1 Review of Evaluation and Recognition Strategies

It is important to note that students were not formally evaluated in either active intervention. The previous chapters included discussions of the formative assessments used to evaluate the overall effectiveness of the interventions and determine if students met the learning objectives. These formative assignments included class-wide and small-group discussions. One of the in-class activities in the Requirements Lab, the design case, was collected for further examination. With the case study activity, half of the teams were asked to present their case study evaluation to the class. They were also asked questions about their evaluation by their peers and the instructors. Finally, anonymous feedback forms were used to gather information about students' understanding of the purpose of

the lab, the aspects they liked and disliked, and students' perceptions of the importance of the content of the lab for their team design project.

In the first semester, students completed four projects and a final design deliverable, which accounted for 90% of that semester's grade. The final 10% was comprised of in-class quizzes about aircraft and aircraft design. After each quiz, the instructors went through the answers with the students during lecture. When returning the projects and quizzes, the instructors discussed major trends in the assessments. For instance, when discussing the second project, the instructors noted how the projects were "disappointing" and they "don't know how much more they can go over this." The main instructor explained how they went over the process and the only difference between the in-class examples and the project requirements were a few segments of the mission profile. The students, from his perspective, may not have realized that context drives reasonable numbers. The final design deliverable was used as a summative assessment and allowed the students to resubmit the previous four projects within the one final design report. The students could make modification to those projects to correct any mistakes from the initial submission.

Student evaluations during the second semester were centered entirely around the team design project. The design team meetings and design reviews served as ungraded formative assessments. The final design report was graded by the instructors using the RFP as a "checklist." In addition, they defined additional requirements for each project; for example, a weight and balance analysis is not included in the RFP explicitly, but is necessary to achieve a feasible final design. The instructors noted that if a student team completed all of the RFP requirements, the team could receive an A in the course, with the caveat that the report need also be correctly formatted. During the semester, the design team meetings were comprised of only a single team, the instructors, the course teaching assistants and the researcher. The midterm design reviews were advertised as open to the department; however, only the instructors, course teaching assistants,

researcher, and a small group of interested faculty and graduate students attended. The final design reviews were not advertised as open to the department due to a scheduling conflict. As a result, only the instructors, the course teaching assistants, and the researcher attended. Students from other teams were not invited to attend their peers' design team meetings or design reviews.

7.3.2.2 Evaluation Through Interactions with External Audience

The researcher was part of the students' external audience in that she observed both semesters of the design capstone course. Thus, it was necessary to use unobtrusive measures to gather information about the course and students' experiences to reduce the effects of the researcher on the students' behavior (Miles & Huberman, 1994). However, in this case, the research was perceived to be a "stakeholder advocate" and her presence served as a passive intervention reminding students unobtrusively about stakeholders throughout the course. One hypothesis for the discrepancy between the students' integration of stakeholder considerations in the final design review, as compared with the final design report, was based on the fact that the students knew the researcher would be attending the design reviews, but was not one of the graders for the course. For example, Teams G and H both included stakeholder mappings within at least one of their design reviews, but neither integrated it within their design report.

Evidence of the researcher's possible effect was also observable at the design team meetings and in the informal focus groups. In one of the informal focus groups, Group H mentioned how they started thinking about stakeholders during configuration selection and then again a week or two before the midterm design review. This second instance aligned with the researcher's first observation of their design team meetings. During the design team meetings, students made comments about the researcher's presence and one team noted to the researcher, prior to their midterm design reviews, how they included a stakeholder mapping. A member of Team D, for instance, pointed

out at the end of the researcher's second meeting with this team that "they still need to talk about stakeholders."

With the closed off nature of the design reviews, students received limited feedback from a broader external audience. The use of an external audience might have encouraged the students to further incorporate stakeholder considerations. In the case of Team C, they arrived at the final design review wondering whether the same external audience from the midterm reviews would be in attendance, because they had made specific stakeholder-relevant slides for that one member of the audience who had asked some questions from a stakeholder perspective.

During the active interventions, the students noted that peer interactions helped the students learn from each other. From the Requirements Lab, students mentioned in the anonymous feedback how they enjoyed "working in the teams to get other perspectives on how to write good requirements/what constitutes a requirement" and how "it was fun to talk to others and hear opinions based on different experiences." Taylor mentioned during the Stakeholders in Design Labs that he learned from his communications with other group members and individuals with "different points of view." Heather, on the other hand, noted how surprised she was "just how differently people in the same class can interpret a problem & [sic] set up a design process." While the students may not have necessarily served as "stakeholder advocates" for one another, students may have gathered ideas about stakeholder integration from their peers, if required to attend other teams' design reviews.

In the academic year following this study, the instructors, as previously mentioned, invited outside guests to speak with the class throughout the second semester. One of the guests was the CEO of an aircraft company, who came to discuss his perspective of the design process. He spoke about the marketing aspects of aircraft design and the importance of understanding the customer. He talked about the business perspective and why we need to care about that perspective. The instructors mentioned

the benefit of having the students seeing this perspective from an outside guest of his stature.

7.3.2.3 Evaluation Based on the RFP

From the discussion earlier, the RFP was found to impact students' integration of stakeholder considerations. As a result, the use of the RFP as the main reference when evaluating students' team design projects perpetuates that impact. In interviews with the instructors immediately following the completion of the course, both returned to the issue of the RFP and the fact that, as instructors, they even emphasized to the students to look at the RFP as the minimum of what was needed for a good grade in the course. When the instructors were asked what tangible tool would help them encourage the students to consider stakeholders or to evaluate their understanding of stakeholders as it relates to the project, one instructor talked about requirements that could either be included in or added to the RFP. With these requirements, the instructors could incorporate some points on their project rubric for including stakeholder requirements or concerns.

For the students in this study, the RFP-based evaluation strategy may have affected not only their integration of stakeholder considerations in the final design report, as described previously, but also the integration of stakeholder considerations in any part of the project. Throughout the design reviews, the instructors made *explicit relatedness* comments about where stakeholder considerations could and should be integrated. The *explicit relatedness* descriptor identifies statements by the instructors that explicitly connect stakeholder considerations with students' design decisions and the project trade studies. For instance, Team F presented a fuselage with a flat bottom at their midterm design review. After the presentation, the instructors discussed the negative effect of that flat bottom on cabin pressurization and stated that the students needed to change their design accordingly. In Team A's final design review, one of the instructors mentioned how "a cherry picker" would be needed for maintenance because the engines were placed

so high (with the intent of reducing cabin noise). The instructor explained how “that’s a big deal and really needs to be fixed.” While these comments, and some others, led to design changes by the students, others (i.e., connections between passenger time and design decisions) did not.

Instructors attributed some of the negative aspects of the team design projects to students’ motivation, as there were many students who “wanted to just squeak by.” As an example, in Team E’s midterm design review, the students first mentioned stakeholders when discussing weight sizing (i.e., “crew and payload weights were given” – slide 5) and the next mention was on slide 18 (i.e., “Payload: 16,870 lbs (~70 [passengers])”). During the design team meetings, the instructors had made explicit comments about the impact of stakeholder considerations on their trade studies and overall design (e.g., the impact of a turn constraint on passenger comfort). Yet, even during configuration selection, the phase where teams most commonly integrated stakeholders, the students translated the stakeholder-related mission requirements into technical design requirements. For instance, “low operating cost” became “high fuel efficiency and optimized propulsion system.” Thus, the team limited the scope of the operating cost consideration to fuel efficiency and propulsion, potentially omitting other critical considerations. Overall, the team integrated stakeholders at isolated points within the midterm design review, but only within a limited scope of the design (i.e., fuselage design, cost analysis, “flying qualities”). At the final design review, Austin explained how they “[threw] on the cockpit, [made] sure enough room for pilot and there [was] an appropriate visibility angle.” When scoring Team E’s design report, the SMEs on average described the team as having completed a fairly integrated and iterative design process, but all three SMEs agreed that the team lacked appreciation for stakeholders (i.e., scored a 0 for stakeholder integration) (See Chapter 6). As one of the SMEs explained, “This group never explicitly mentioned the stakeholder in their report. They had a completely absent regard for the impacts that their design decisions would make on the stakeholders

of this aircraft.” Therefore, where the RFP can make clearer that the project will be evaluated based on criteria that include stakeholder integration, it will thus address some aspects of the students’ behavior attributable to motivation.

7.3.3 Authority

This section begins with a review of the instructors’ orientation toward student responsibility and autonomy within the learning environments defined for the two active interventions and across the two semesters. Then, the *transition from the instructor-centered individual-based learning environment* in the first semester to the *student-centered team-based learning environment* in the second semester is examined, particularly for its effects on cognitive load and students’ integration of stakeholder considerations.

7.3.3.1 Review of Authority within the Learning Environments

Control of the Requirements Lab stayed mostly with the instructor. However, students worked together at multiple points within the class and shared perspectives during class-wide discussions. During the learning by reflection section, the students had an opportunity to define well-written requirements from their perspective, giving them authority to develop standards for one another. However, as discussed when examining the task structure of the design capstone course, these student-developed standards were not then used within the team design project because students were not required to write requirements. In the design case study, students were responsible for their own design process. They were provided with some resources and they had to work with their teammates to pace themselves during the activity and make decisions about how to approach the task.

The first semester of the course was an instructor-centered, lecture-based course, as evidenced by the minimal class discussions or Q&A sessions. The instructors

presented mostly from lecture slides, including some explicit connections to stakeholder-related requirements and considerations. For example, when introducing students to wing design principles, the lead instructor discussed the effect of the dihedral angle on passengers. He presented the following example to the students: if you are designing an aircraft for deploying combat soldiers into battle, you need to be careful of the dihedral angle they select due to the potential passenger discomfort during flight. In addition, the instructors discussed the importance of making assumptions, justifying design decisions, and evaluating the reasonableness of final values. During the academic year following the study, the instructors made efforts to increase student participation during the labs and lectures. They attributed this to the interventions, which were very participatory and a “nice change of pace” for the students.

The control of the Stakeholders in Design Labs stayed mostly with the instructor; however, students worked together throughout the two lab sessions. The instructor presented material to the students in mini-blocks at two points within the session (introduction to stakeholder mapping and case study evaluation). The case study evaluation and design process development were completed in groups with students controlling the pace. While students were provided with a presentation template as a tool to aid their case study evaluation, they controlled the initial Q&A portion of the presentations. Later, the students also evaluated methods for use within their upcoming team design project. This evaluation allowed them to decide which methods they would prefer to use or would integrate “best” with the constraints of the project.

The second semester’s structure for authority was distinctly different from the first semester: As previously noted, the students were responsible for selecting their own design teams and for running the design team meetings. The instructors discussed how they wanted to let the students drive the process themselves. One instructor noted the pedagogical debate of balancing how to support students and how to let them go their own way. From a learning perspective, the other instructor noted that they need to let the

students “do their own thing.” As part of this, the instructors purposefully let the students discover their own mistakes. Throughout the term, as within the first semester, the instructors made explicit comments about connections between aircraft design and stakeholder-related considerations.

7.3.3.2 Transition from Instructor-Centered Individual-based to Student-Centered Team-based

In the instructor-centered learning environment in the first semester, the students may have developed a reliance on the structured process. While both of the active interventions were more student-centered with an emphasis on group work, these interventions comprised only 9 of the 120 contact hours in the first semester. The change in the learning environment introduced a learning curve for students at the start of their team design project in the second semester. The educational literature explains how faculty expectations that students will know how to work effectively in groups or teams can be unfair to students (Ambrose et al., 2010). In addition, this transition from an instructor-centered learning environment to a student-centered learning environment can create student resistance initially (Blumberg, 2009; Felder & Brent, 1996; Weimer, 2002). As Felder and Brent (1996) explain, “The students, whose teachers have been telling them everything they needed to know from the first grade on, don't necessarily appreciate having this support suddenly withdrawn” (p. 43). The student-centered, team-based environment of the second semester required a “new way of thinking” for these students (Barr, 1998, p. 19). As a result, some students may have viewed this environment as “threatening” or the environment simply may have been beyond their level of intellectual maturity at that point (Weimer, 2002). Thus, for teams with students who experienced high cognitive load in the first semester, this change in the learning environment, along with the complexity of the RFP, may have had a negative impact on their progress during the problem-scoping phase.

As an example, Stephanie from Team I discussed the differences between the two semesters of the course during the informal focus group. In the first semester, the students worked on projects “by ourselves.” In the second semester, the teams were made up of more people, so in theory they should have been able to do all of the major design process components and “then some.” However, according to Stephanie, several things were “holding them back.” It was clear to her that her team didn’t fully understand everything from the first semester and they all went about the different individual projects differently. This assessment by Stephanie aligned with many of the problems the team faced over the course of the team design project, as they struggled to understand the RFP and the relationships among different design variables. At the final design reviews, Team I scored the lowest of the teams in *Design Understanding* and *Stakeholder Integration*, and the instructors considered this team as one of the lowest performing in the class. Overall, this transition between instructor-centered and student-centered learning environments may have forced some teams to face more challenges during the problem-scoping phase of design, which ultimately limited their time to work on later phases of the design and may have limited their overall integration of stakeholder considerations.

In the interviews, the instructors discussed how they tried hinting at stakeholder considerations when meeting with the students. Yet, according to the instructors, the teams, in general, did not pay much attention to the requirements or these hints. When reflecting back on the term in the summer, both instructors were disappointed in the small number of teams that considered ground operations (e.g., method for unloading and loading of the batteries). One instructor attributed this to the complexity of the RFP which limited the teams’ time to complete other aspects of the design. The other instructor noted that neither instructor provided the teams with explicit feedback on these issues in particular. However, the observations of the design team meetings demonstrated how the instructors made many *explicit relatedness* comments. For example, when

meeting with Team H, one of the instructors connects operating costs per seat-mile to number of batteries, defining additional trade studies in between those parameters. Still, this explicit relatedness did not successfully prompt all of the student groups to consider stakeholders, as observed in the case of the optional passenger time requirement.

The student-driven authority structure in the second semester of the course gave students the authority to work within the constraints of the learning environment based on their discretion (e.g., RFP, evaluation strategy). As a result, other factors likely contributed to their decisions to follow up with *explicit relatedness* comments such as a positive *perspective* of stakeholder considerations or perceptions of misalignment between the stakeholder-centric design environment and the aircraft design environment. For other students, such as those on Team F, their desire to “squeak by” resulted in integrating stakeholder considerations only as explicitly specified in the RFP. Team C, on the other hand, wanted to win the AIAA Undergraduate Aircraft Design Competition and thus leveraged the stakeholder considerations in attempts to create a more innovative design solution. Team J was the other team, besides Team C, to consider the impact of design on ground operations (see Figure 36). Yet, the integration of this consideration was due to one team member, Leslie, who used the open-ended authority structure to add stakeholder considerations to the design process. After the Stakeholder in Design Labs, she explained,

“It’s pretty simple & a fun challenge thinking through everyone who might be affected practicality is an awesome thing to get practice w/so I'd love to see a stakeholder's need during design -> it's a neat challenge that I haven't really thought of before.”

7.4 Discussion and Summary

In response to Research Question 4.3 and the Organization and Course level questions from the evaluation framework (see Table 81), this mixed methods analysis

demonstrated how particular aspects within the aircraft design learning environment hindered or supported students' integration of stakeholder considerations and overall effectiveness of the active interventions. The lack of explicit stakeholder requirements within the team design project's RFP may have influenced students' decision to incorporate stakeholder considerations. As discussed in Chapter 3, the project description or mission specifications affect the ability for stakeholder integration to occur both at the start of the design process, and within later phases. The impact of the RFP was further strengthened due to its role in evaluating the final design reports.

Differences between task and authority structures in the first and second semester negatively affected those students who experienced high cognitive load in the first semester. Their reliance on the structured and compartmentalized design process introduced in the first semester created challenges for teams as they tried to approach the complex, ill-structured, holistic RFP in the second semester. The change from an instructor-centered, individual-based learning environment to a student-centered, team based learning environment created a large learning curve for some teams during the early problem-scoping phase of design. This learning curve during the problem-scoping phase is especially detrimental for the integration of stakeholder considerations, as this phase is a critical phase for stakeholder identification and the establishment of stakeholder-related requirements (Chua & Feigh, 2011; Jain & Sobek, 2006).

Table 81: Overview of Organization, Course, and Societal Level Evaluations

Level	Active Interventions (Requirements Lab & Stakeholders in Design Lab)
Organization and Course	<p><i>What organization/learning environment barriers prevent or support adoptions? Who adopts what aspects of the instruction (students, student teams or instructors)? What aspects of the learning environment & interventions prove most successful for program stakeholders?</i></p>
	<p>Positives: Some learning environment barriers were found to positively impact the effectiveness of the interventions:</p> <ul style="list-style-type: none"> • the Request-for-Proposal (if stakeholder-centered), • the student-centered learning environment in second semester, • the stakeholder-related tools, and • the use of an outside audience, especially stakeholder advocates. <p>Instructors also provided students with <i>explicit relatedness</i> comments during design team meetings.</p> <p>Negatives: Some learning environment barriers may have negatively impacted the effectiveness of the interventions:</p> <ul style="list-style-type: none"> • the Request-for-Proposal (where it lacks explicit stakeholder requirements), • the RFP as the evaluation strategy (where it lacks explicit stakeholder requirements), • the high cognitive load on students within a design capstone course • the transition from an instructor-centered, individual-based to a student-centered, team-based learning environment (especially for those experiencing high cognitive load), • student reliance on structured design process, tools and resources (e.g., time), and • lack of outside audience. <p>These barriers created additional cognitive load for some teams (especially Teams B and I), which may have prevented them from incorporating stakeholders.</p> <p>Improvements: Development of tools which integrate with students' current design tools and introduction of scaffolding for problem-scoping process within interventions. Clear inclusion of stakeholder requirements in the evaluation strategy, made available to the students</p>
Societal	<p><i>What impacts exist outside and after the course?</i></p>
	<p>The instructors modified instructional activities to increase student engagement and support students' understanding of the impacts of design decisions. The role of the stakeholder was explicitly incorporated into part of the design process (i.e., configuration selection). The instructors also included additional outside guests into the course schedule who could provide students with a stakeholder perspective and discuss the importance of stakeholder considerations within the design process.</p>

Tools (e.g., design tools, stakeholder integration techniques) and resources (e.g., time, information about stakeholders) were also found to influence students' integration of stakeholder considerations. The stakeholder mapping technique provided half of the teams with a tool to define Figures of Merit or evaluate their design from a stakeholder perspective. Tools that integrate with students' current design tools may further support stakeholder integration, especially for students experiencing high cognitive load during the design process. Finally, an outside audience provided students with additional

perspective about their designs and the simple presence of a stakeholder advocate may have influenced students to consider stakeholders at different points in the design process.

From the instructor interviews and the observations of design team meetings, it was clear that the instructors adopted some of the principles from the interventions. Their use of *explicit relatedness* comments and stakeholder hypotheticals, along with their desire to incorporate stakeholder-related requirements in future semesters of the course, demonstrate their overall adoption of a *positive perspective*. Overall, the aspect of the interventions and learning environment which proved most successful for program stakeholders were the introduction of the stakeholder mapping technique. In addition, the student-centered approach in the second semester, combined with the students' *positive perspective* (perhaps due to one or both of the interventions), allowed students to explore the integration of stakeholder considerations if they so desired. This behavior was especially apparent from Teams C and J.

The Societal level of the evaluation framework inquires about the impacts which exist outside and after the course. From a follow-up interview with the instructors approximately one year after the study, the instructors were found to have adopted some of the pedagogical techniques from the active interventions (i.e., use of accident reports, addition of opportunities for student participation in lab and lecture) and continued to demonstrate their *positive perspective* about stakeholders. Rather than simply explaining the connections between aircraft design and stakeholder considerations, the instructors explicitly incorporate the importance of stakeholder considerations into the problem-scoping phase of the design process (i.e., through configuration selection and figure of merit definition). Finally, the instructors have recruited outside guests to support student understanding of stakeholder considerations and provide students with additional experienced perspectives about the design process.

CHAPTER 8 - Conclusions, Future Work & Implications

8.1 Summary of Findings

Over the next few decades, technology will continue to advance at a rapid pace. Today's engineering students will need to consider critical design issues, such as the implications of fully automated machines and vehicles, or of renewable energy. They will need to make design decisions and compromises between technical considerations and their economic and human considerations (Haupt, 1977). Despite proposals for substantive changes in the field of aerospace systems design, there is a need to better prepare aerospace engineering students to overcome future challenges within the field (Chaput, 2010; Haupt, 1977). Given the importance of stakeholder considerations to the design of aircraft and other aerospace engineering vehicles, the aim of this dissertation is to (1) understand how stakeholder considerations are currently integrated into aircraft design practice and education, and (2) determine how to support student integration of stakeholder considerations through the design and evaluation of in-class educational interventions.

A case study conducted at one large aircraft design firm addressed Research Question #1: *What conditions enhance or inhibit the integration of stakeholder considerations into the practice of aerospace vehicle systems design?* A diverse group of designers was interviewed about their design experiences and their experiences integrating stakeholder considerations into the design process. Qualitative analysis of these interviews revealed six conditions affecting the integration of stakeholder considerations in the practice of aerospace vehicle systems design, at least at this firm. The first two relate to the structure of a design team or group in terms of the benefit of (1) a common goal addressing stakeholder considerations and (2) a group structure that supports addressing stakeholder needs. The next two conditions affected the ability of individual designers from different disciplines to form a 'trading zone' for their design,

specifically (3) the use of ‘boundary objects’ (e.g., storyboards, prototypes, etc.) among the group members and (4) the existence (or lack of existence) of a shared language to support the exchange of ideas. Individual characteristics of designers also influenced the integration of stakeholder considerations, specifically in regards to (5) each individual’s perspective about how to work on cross-disciplinary teams and (6) the training and learning experiences of these individuals regarding approaches to working on cross-disciplinary teams.

A review of Aerospace Engineering design capstone course syllabi and textbooks was used to examine Research Question #2: *To what extent and how does the aerospace engineering design curricula take into account stakeholder considerations?* Overall, within aerospace design education, stakeholder considerations are commonly limited to quantitative measures as surrogates for those stakeholder considerations that can be clearly defined and quantified. Many students, then, are not introduced to stakeholder considerations that are challenging to quantify, such as metrics for maintainer’s performance or pilot fatigue. Aerospace design capstone courses with a broader focus on design provide students opportunities to consider the customer and the end-user more directly, but cannot consider other stakeholders due to the constraints on the design project (e.g., conceptual design-focused capstones, inability to perform field testing, etc.). This differs from courses in service learning or product design that require students to focus on usability from the start.

An in-class evaluation, grounded in existing survey questions and a context-specific design task, was used to respond to Research Question #3: *To what extent do aerospace engineering students understand and take into consideration the effects of design decisions on stakeholders?* The students, within this study, self-reported a moderate-to-high confidence in their abilities to design. They were most confident in their ability to complete problem-scoping activities (e.g., identifying a design need and researching a design need) and to communicate a design solution. These activities aligned

with the students' beliefs as to which design activities are most important. At this stage within their curriculum, most students did not view iteration and making trade-offs as critically important design activities. The students' understanding of context considered the effects of the customer, the type of aircraft being designed, the mission, and/or the economic constraints on the mission. The students, however, did not see the impact of the broader context, such as political and ethical considerations, or of stakeholders outside of the customer, such as maintenance personnel or non-users. When asked to develop a design team and requirements for a single manned submarine, the students may have included a customer or user, but most selected engineers who are able to focus on the technical and logistical considerations of the submarine. The majority of the design considerations they discussed focused on the technical aspects of the design, with a few contextual or stakeholder-related considerations. Industry experience was found to be particularly important, as patterns emerged between industry experience and students' considerations of stakeholder and context considerations, specifically in the context question.

Research Question #4, *what educational interventions can enhance students' understanding of and ability to integrate stakeholder considerations into the design of an aerospace vehicle*, motivated the design and implementation of empirically-informed and theoretically-grounded educational interventions. Two active interventions (i.e., Requirements Lab, Stakeholders in Design Labs) were created based on the findings from Research Questions #2 and #3. The researcher was an observer within the design course and thus served as a passive intervention, an ever-present "stakeholder advocate." Finally, a future intervention was developed in the form of a Stakeholders in Design rubric. The rubric evaluates students' design understanding and integration of stakeholder considerations and, as such, can be used as a summative assessment tool. In addition, if this rubric is provided to the students prior to submitting any deliverables, it can support their understanding of how to design with stakeholders in mind.

To isolate the characteristics of the interventions and learning environment which support students' integration of stakeholder considerations, Chapters 5, 6, and 7 examined the interventions. Overall, the interventions were found to increase students' awareness of stakeholder considerations. Specific aspects of the interventions were found to support students' integration of stakeholder considerations: the introduction of the stakeholder mapping technique, the stakeholder-centric focus of the Stakeholders in Design Lab, the design process development activity, and the case study activity. Chapter 5 examined students' experiences during, and immediately following, the active interventions. Student feedback demonstrated an overall satisfaction with the pedagogical techniques used within the lab. An examination of artifacts from the interventions illustrated that many of the learning objectives were met by most of the students. In the case of the Requirements Lab, the examination showed that the stakeholder-centric focus was not clear, while in the Stakeholders in Design Labs, students may have developed misconceptions about the HCD methods. Overall, many students demonstrated an understanding of how the design could impact different stakeholders, either at this phase or in future phases. Students also perceived the Requirements Lab content as fairly important to their team design project.

A post (i.e., end of term) in-class evaluation and an assessment of students' team design projects supported a summative assessment of the effectiveness of the interventions in Chapter 6. Within the interventions, students were introduced to a variety of stakeholders beyond the main customer. In the post-evaluation, students demonstrated an awareness of a diverse set of stakeholders and the relationship between requirements and design. Students also identified the stakeholders for their team design project for at least one of the deliverables and incorporated stakeholder-related regulations. Introduction of HCD methods and the Requirements Lab's design case appeared to influence students' understanding of the characteristics of a design environment that is supportive of the integration of stakeholder considerations. The post-evaluation results

indicated that students proposed integrating stakeholder considerations when interactions with stakeholders would be possible and the design requirements have an explicit stakeholder focus. The case study activity and the design process development appeared to influence students' beliefs of the importance of iteration within the design process. The interventions also supported students' abilities to balance performance and stakeholder considerations during configuration selection and concept generation in their team design project. Still, many design decisions were not in the end impacted by stakeholder consideration, and many teams incorrectly prioritized the requirements and didn't correctly apply an important design driver (i.e., operating costs) explicitly called out in the RFP.

In Chapter 7, a mixed methods analysis demonstrated how particular aspects within the aircraft design learning environment hindered or supported students' integration of stakeholder considerations and overall effectiveness of the active interventions: (1) lack of explicit stakeholder requirements or focus within team design project requirements, (2) evaluation strategy, (3) differences between the first and second semester task and authority structures, and (4) availability of tools (e.g., design tools, stakeholder integration techniques) and resources (e.g., time, information about stakeholders, etc.). In addition, the student-centered authority structure in the second semester, combined with the students' *positive perspective*, which could be attributed to one or both of the interventions, allowed students to explore the integration of stakeholder considerations if they so desired.

8.2 Future Work: Recommendations for the Interventions

8.2.1 Modifications to the Active Interventions

The evaluation of the interventions suggests improvements to enhance their overall effectiveness and support their implementation in aerospace engineering design capstone courses. Future iterations of the Requirements Lab, for example, should focus

on how to evaluate a design problem or set of requirements to identify what they mean for the subsequent design process. Lab activities can specifically support students' incorporation of stakeholder considerations from that point in the design process and assist students in prioritizing or determining the value of the different stakeholders. Instructors could also consider scaffolding the problem-scoping process within the class or this scaffolding could be incorporated into both interventions. Both labs should also encourage students to value design decisions that are based on stakeholder considerations.

The lab activities can also be better aligned with their learning objectives. In the case of the Stakeholders in Design Labs, for examples, the students perceived additional learning objectives that could simply be added to the lesson plan. Future iterations of the Stakeholders in Design Labs could include additional scaffolding with the design process negotiations and the HCD methods activity. Finally, additional tools can be developed which integrate more seamlessly into students' current design tools. Thus, the Stakeholders in Design Labs can introduce these tools and resources to support the integration of stakeholder considerations, especially for the teams experiencing high cognitive load with the existing design tools.

8.2.2 Modifications to the Rubric

The initial evaluation of the Stakeholder in Design rubric as a summative assessment tool and future intervention highlights both benefits and possible areas of improvement. To improve interrater reliability, the literature suggests considering how the variation in the scores may result from the descriptions and scoring strategy (Plumb & Sobek, 2008). In this case, the SMEs' varied definitions of what constituted implicit stakeholder integration could have negatively affected the consistency of the scores. For instance, all of the projects were required to include an evaluation of aircraft emissions and noise, which are implicit stakeholder considerations. Some of the SMEs perceived

this requirement as students implicitly considering stakeholders; other SMEs perceived that the students didn't consider stakeholders in this case unless they considered stakeholders beyond the scope of the RFP or explicitly recognized the role of the stakeholder in these requirements. As a future intervention, questions could be added to the rubric typifying how (ideally) students should consider stakeholders at each stage of the design process.

Another option for improving interrater reliability is to include anchor papers with the rubric and to discuss those anchor papers during rubric training. With this initial sample of design projects, the anchor papers could be executive summaries from these design projects that showcase high and low performing teams.

While this initial evaluation only applied the rubric as a summative assessment tool, the rubric can and should be used as a formative assessment tool as well. For example, students can be provided with the rubric at the same time as the project's RFP to emphasize the expectation that integrating stakeholders is important. The use of the rubric as a formative assessment tool would also serve to improve the validity of the rubric by clearly mapping its criteria to task requirements (or in this case, design project requirements). For the design projects examined in this study, the design project requirements only included stakeholder considerations implicitly, which likely deterred some students from considering stakeholders more explicitly during the design process.

The holistic nature of the rubric also permits its use during oral design reviews throughout the semester. This repeated use of the rubric would strengthen students' perception of the importance of considering stakeholder considerations and, as such, could result in a broader perspective by students on the role of stakeholder considerations in complex system design. Additional efforts over the coming year will improve the rubric and evaluate it with a larger sample of design project ratings. Future work will also include a comparison of the relationships found through the use of the rubric and the relationship defined within the outcome space developed by Zoltowski (2010). Overall,

this rubric provides a tool for the engineering design learning environment to encourage students to consider the impact of complex system design decisions on stakeholders.

8.3 Implications

8.3.1 Implications for Industry

The industry case study provided empirical evidence of six conditions which enhance or inhibit the integration of stakeholder considerations into the aircraft design process. These results have implications for firms designing complex systems. First, this research demonstrated the positive impact of ensuring functional groups have a common goal addressing HF and/or stakeholder considerations to help overcome challenges due to differences in disciplinary languages and worldviews (Adams et al., 2009; Mansilla et al., 2012). In particular, Adams and colleagues (2009) determined, during an examination of a product design group of design engineers and an HF specialist, that discussions about the user of the product triggered cross-disciplinary discussions among the group members. Thus, to foster the integration of stakeholder considerations, management could consider establishing a mission or goal for their design team centered on a particular stakeholder(s) and encouraging discussions about the stakeholder(s) within team meetings.

Second, one of the industry functional groups demonstrated the effectiveness of having stakeholders embedded into the structure of the group. Thus, design groups can be structured include relevant stakeholders, such as pilots, maintainers and manufacturing personnel, similar to participatory design and user involvement design models (Damodaran, 1996; Hussain et al., 2012). Management can also consider how to structure the group and associated design teams to incorporate relevant stakeholders more prominently.

To develop robust and sustainable trading zones among designers, aerospace vehicle design firms can also create and promote the use of boundary objects and a

shared language. For instance, design checklists were perceived to be useful for integrating stakeholder considerations into the design of a recent aircraft. Other types of boundary objects, such as storyboards, templates, or flow models may also further enhance the integration of stakeholder considerations throughout the design process (Beyer & Holtzblatt, 1998; Pew, 2008). As discussed earlier in this work, communication has been cited as a large-scale issue in that designers may not “speak the same language” given their disciplinary background (Chapanis, 1996). Instead, they may value different aspects of the design and apply different abstractions in their models and analyses. The formalization of a shared language, or inter-language, within complex system design organizations is not a novel concept (Militello et al., 2010; Pew, 2008; Vaughan, 1999) and would support the exchanges of information among designers and design teams using a formalized set of acronyms, procedures, and documentary requirements.

Finally, these results illustrate the impact of having design team members capable of cross-disciplinary work. Aerospace engineering design teams can be comprised of not only engineers from multiple disciplines, but also technicians, psychologists, and business managers with little or no understanding of engineering fundamentals. Studies of professionals’ experiences with designing across disciplines also highlight key areas where collaborative efforts can breakdown due to differences in goal direction and design thinking, situation complexity and team members’ self-perceived roles in the collaboration (Adams et al., 2011; Adams et al., 2010). To further the integration of human factors and stakeholder considerations in aircraft design, it is necessary to first train design team members on cross-disciplinary work. Whether through the creation of a training course, the establishment of a mentorship program, or the support of related programs within the aerospace engineering undergraduate curricula, the design workforce can be further developed and prepared to integrate stakeholder considerations early and throughout the design process.

8.3.2 Implications for Engineering Education Practice

The products of this doctoral work can be used by aerospace design instructors, including two labs and a rubric for examining stakeholder integration in students' projects and design reviews. These products were designed considering the context of an aerospace engineering design capstone course (e.g., constraints due to allowable contact hours, design competition project requirements, students' time management). Overall, these products and their evaluations provide a framework for faculty to understand how they can support student integration of stakeholder considerations early and throughout the design of an aerospace vehicle.

Beyond the labs and rubric developed here, this research also revealed conditions within the learning environment that impact students' integration of stakeholder considerations into a complex systems design process. For instance, the project requirements given to the students drive their decisions to incorporate stakeholder considerations, especially when these requirements also serve as the evaluation and scoring criteria. Additionally, students may view certain design environments as more open to the integration of stakeholder considerations such as environments where designers can have direct contact with stakeholders. As a result, design competitions through aerospace organizations such as AIAA and NASA should explicitly include stakeholder requirements within their RFP each year. For example, the RFP could require students to identify the impacts of their design on a variety of stakeholders (Feigh & Chua, 2011; Landsburg et al., 2008; McDonald, 2013; Pew, 2008).

The differences between the first and second semester's learning environment intensified the cognitive load for several students to such a degree that some teams focused on the minimum requirements for the team design project. To scaffold students through this transition, instructors could consider incremental changes in the first semester, allowing students to experience a student-centered and/or team-based environment prior to the start of the second semester (Blumberg, 2009). This scaffolding

can provide students with more time to focus on the problem-scoping phase of the design process, which, as previously mentioned, is critical for the integration of stakeholder considerations in complex system design.

To improve the availability of tools (e.g., design tools, stakeholder integration techniques) and resources (e.g., time, information about stakeholders), instructional activities could engage various stakeholders in the local community (e.g., pilots, air traffic controllers, flight attendants, aircraft designers, government personnel). These stakeholders could visit the class and speak with students about how they impact or are impacted by the design of an aircraft. Also, faculty could invite industry personnel to attend design reviews as “customers,” serving as the external audience discussed in Chapter 7 and thus encouraging students to justify design decisions and consider the realism of their assumptions. Another option would be to motivate students to seek out stakeholders on their own (e.g., class assignment, part of grading rubric). For example, one of the teams in this study gathered information and sought design feedback by surveying a group of airplane passengers and interviewing an airline mechanic. These interactions with stakeholders may provide students with an opportunity to achieve a higher level of appreciation for stakeholders and an understanding of the challenges and rewards of integrating stakeholder conditions into their design project (Zoltowski, 2010). Design instructors could utilize existing frameworks for supporting students during specific parts of this process such as information gathering (Nelson, 2013; Stanford University Institute of Design, 2014) and prototyping (Stanford University Institute of Design, 2014).

The results from the industry case study demonstrated a need for engineering graduates who are capable of working in a cross-disciplinary collaborative environment. To support student preparation for this type of design environment, aerospace engineering departments could, for example, modify senior-level design capstone courses to incorporate multidisciplinary projects spanning more requirements than those related

to vehicle performance. This type of course would allow students to experience the challenges related to communication and collaboration within multidisciplinary problems and begin to appreciate the value other disciplines can bring to a design problem (Heise et al., 2010; Militello et al., 2010; Pew, 2008). In addition, students could be introduced to the process of developing a business case or communicating a design to an audience from a different discipline to gain a level of comfort with the types of boundary objects and shared language they will need to employ within the aircraft design industry (Feigh & Chua, 2011; Militello et al., 2010; Pew, 2008). By exposing students to the types of domain knowledge, tools, and challenges they will experience in industry during their undergraduate curriculum, these students will be more prepared to engage in the complex integration process of aircraft design and to consider stakeholders in the design process.

While this research was aimed at improving design education in an aerospace engineering curriculum, the findings can be generalized to other engineering disciplines. The results of this study can inform design education in other disciplines where stakeholder considerations can be integrated into the design process for any complex system, and the interventions from this study can be adapted for use in other design capstone courses. Similar work in Human-Centered Design (Titus et al., 2011; Zoltowski et al., 2010) and sustainability research (Watson, 2013) could also be integrated with this work to support engineering design education today.

Finally, exposure to stakeholder considerations early and throughout the engineering curriculum would encourage students to see value in these considerations in their design capstone course and when they transition into industry (Dym et al., 2005; Oehlberg & Agogino, 2011). Even though the senior aerospace engineering design students appeared to enjoy the interventions, the two interventions designed in this study may more effectively promote students' integration of stakeholders if conducted with students at earlier stages of their collegiate career (Watson, 2013).

8.3.3 Implications for Future Research in Engineering Design

8.3.3.1 Consider the Implications of this Work on Engineering Graduates' Experiences in Industry

By examining the effect of these interventions on students' team design projects, this research provides insights about the short-term impact of the interventions. Future work should consider the effect of these interventions and changes to the overall learning environment design on engineering graduates' experiences and performance within industry. Through a longitudinal study, changes within students' perceptions during and after the undergraduate program could also be tracked to capture critical incidents or patterns of students' development.

8.3.3.2 Explore the Integration of Stakeholder Considerations within Graduate-Level Design Course and Programs

The work within this doctoral thesis closely examines undergraduate students' understanding of and ability to integrate stakeholder considerations into complex systems design. Within graduate programs in aerospace engineering and other fields, the student population includes students from many different disciplines and with diverse design, industry, and academic experiences. Future work should explore students' perceptions of the role of stakeholders in design at the graduate level. In addition, the multidisciplinary learning environment, along with students' previous experiences, suggests that changes could be made to the interventions to focus more on students' understanding about how to work within a cross-disciplinary environment, the prioritization and quantification of stakeholder considerations, and approaches for interacting with stakeholders during the design process.

8.3.3.3 Develop New Resources and Tools to Support Students' Integration of Stakeholder Considerations

Student feedback from both low and high performing teams indicated a need for more information to support their ability to integrate stakeholder considerations into design. Students shared a desire for market analysis information but feared it may be proprietary, yet students did not appear to consider other important available sources of information. One such resource could be accident and incident reports, which are also mentioned in Roskam, and could be incorporated into the active interventions. Additionally, future work could include the development of checklists, as discussed in the industry case study, for students to use during the design process that articulate the proper consideration of stakeholders at each design phase. However, this research demonstrated that, within conceptual design focused capstone courses, students utilize only visual representations (sketches or computer-generated drawings), along with mathematical and computational models. Thus, future work may need to focus on the development of tools that can support the quantification of stakeholder considerations and be integrated into these existing mathematical and computational models. These tools could also incorporate power/interest matrices or influence/importance matrices, utilized in civil and environmental engineering, to provide students with an approach for prioritizing stakeholder considerations alongside other performance requirements (Watson, 2013).

8.3.3.4 Improve Assessment of Students' Perceptions and Understanding of Human-Centered Design

This work provided empirical results regarding engineers' and engineering students' perceptions of how stakeholder and context considerations are integrated into the vehicle design process. However, future work is necessary to improve the usefulness of the outcomes of the in-class evaluation. For example, changes to the submarine design scenario could include requiring students to write out a design process plan, similar to the

work by Melton and colleagues (2010; 2012), or having students complete the submarine design scenario using a think-aloud protocol in a laboratory setting, similar to studies by Atman and colleagues (2007; 2008). Ultimately, one aim would be to use the Stakeholders-in-Design rubric to explore the results of students' responses to the submarine design scenario. Future studies could then examine students' understanding of and appreciation of stakeholder considerations at the start of a senior design experience by evaluating their responses to the submarine design scenario and predict students' readiness to integrate stakeholder considerations in their design projects. Also, future work could explore stakeholder integration within disciplines outside of aerospace engineering to compare students' perceptions and uncover any differences that could impact the effectiveness of the active interventions for these disciplines.

Finally, additional research could explore how to support the use of the submarine design scenario by instructors, which is currently not possible based on the time burden of the data analysis process. One option would be to transform the submarine design scenario into a situational judgment task. This assessment method is currently used within business to assess integrity, problem-solving and interpersonal skills and is being developed for use in engineering education to assess higher-level skills like global competency (Jesiek & Woo, 2011). The assessment requires students to choose among options (i.e., forced-choice assessment, rather than having students develop their own design), but is based on an authentic design scenario.

8.3.3.5 Explore the Relationship between Cognitive Styles and Stakeholder Integration

The positive perspective of some of the students positively impacted their integration of stakeholder considerations. Student perceptions can be shaped by instruction: students were found to think more globally about design by the end of the first semester and some of that global thinking was seen within their design reports as students considered maintainers and ground operations. However, the relationship

between this global perspective on design, students' positive perspective of stakeholder considerations, and students' overall integration of stakeholders in the final projects warrants further evaluation. In the literature, an individual's cognitive style describes their "preferred way of thinking, organizing, and representing information within [their] mind" (Roberts, 2006, p. 167). Using Roberts' (2006) definitions of the dimensions of cognitive styles, the global perspective of design can be related to the global and holistic cognitive style, while the local perspective could be related to the more analytic, cognitive style. In other words, some students may have preferred to examine and understand a vehicle design problem by examining the big picture and thinking holistically. Other students, however, may have preferred a more analytic approach by breaking the problem down and thinking through the design process sequentially. Future work could leverage previous work on these cognitive styles, such as studies completed within the architectural design learning environment (Roberts, 2006), and examine how cognitive styles affect students' integration of stakeholder considerations within the design process.

8.3.3.6 Examine the Relationship between Students' Course Goals and the Integration of Stakeholder Considerations.

Ames (1992) defines two sets of goal orientations in educational settings: mastery goal orientation and performance goal orientation. Performance goal orientation is associated with "avoidance of challenging tasks, negative affect following failure, accompanied by judgment that one lacks ability, positive affect following success with little effort, and use of superficial or short-term learning strategies" (Ames, 1992, pg. 263). Mastery goal orientation, on the other hand, is aligned with the perception that effort leads to success; examples of behavior associated with mastery goal orientation include "developing new skills, trying to understand [one's] work, improving [one's] level of competence or achieving a sense of mastery based on self-referenced standards"

(Ames, 1992, pg. 262). This doctoral work examined the impact of project requirements and project assessment strategy on students' integration of stakeholder considerations. However, research has not examined the relationship between a student's goal orientation and their ability to, or desire to, integrate stakeholder considerations into the design of a complex system. Thus, future work could examine how understanding a student's goal orientation could help instructors determine strategies to invoke within their design course to encourage students' integration of stakeholder considerations.

8.3.3.7 Learn from On-the-Job Training

Within the aerospace engineering curriculum, students should be exposed to designing across multiple disciplines (Chaput, 2010) and be capable of deriving achievable and measurable requirements that also fulfill those of the customer (Tam, 2004). These desired attributes of engineering graduates, however, do not completely align with the attributes of the current generation of graduates (Butler, 2012). In addition, there is a disconnect between the skills and abilities necessary to excel in analysis courses, which comprise the largest portion of an aerospace engineering curricula, and the skills and abilities needed to succeed in a design curricula (Chaput, 2010; Hall & Cummings, 2007). The culture within the industry case study research site was centered around on-the-job training. For instance, many of the recommendations to improve the integration of stakeholder considerations in the aircraft design process were based on different approaches that had been implemented by designers in the industry case study through on-the-job training, rather than trying to find college graduates with the requisite skills. On-the-job training is an educational approach that captures changes in knowledge, attitude, or skills due to implicit and explicit learning within the work environment (Berings et al., 2008). With this in mind, future work could further explore the on-the-job training that occurs in the aerospace engineering industry and contrast it with the approaches used within undergraduate and graduate engineering programs to identify

gaps between the university learning environment and the work environment. Additionally, these findings could help researchers better understand the impact of a curriculum's content and pedagogy on industry preparedness.

8.3.3.8 Further Investigate the Integration of Stakeholder Considerations within the Aerospace Vehicle Design Industry

Within aerospace engineering specifically, researchers have examined the dynamics of concurrent engineering teams (Hihn et al., 2011) and teamwork, adjustment to change, and knowledge management among design team members (Baird et al., 2000). The results of the industry case study in this doctoral work add to this literature by identifying the role of boundary objects within aircraft design collaborations. Future work should expand upon the descriptions provided by this industry case study and to further build a theory around the integration of stakeholder considerations in complex systems design (Eisenhardt, 1989a). The next steps would be to incorporate quantitative data collection and analysis methods to examine stakeholder integration at more than one aerospace vehicle design firm and across aerospace vehicles (i.e., spacecraft and rotorcraft). Situational judgment tests, field surveys, or design tasks are just some of the methods that could be used to further uncover critical relationships (Eisenhardt, 1989a). Additionally, multiple investigators could be used to examine the research sites from different perspectives and increase the overall validity of the findings (Eisenhardt, 1989a).

APPENDIX A - IRB Consent Forms

A.1 Industry Case Study Consent Form

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Investigators: Dr. Amy Pritchett and Alexandra Coso, School of Aerospace Engineering
Protocol and Consent Title: Study of Project Development Design Teams (05/09/12v1)

You are being asked to be a volunteer in a research study.

Purpose:

The purpose of this study is to observe design teams within a product development sector of a commercial aircraft firm to improve the integration of requirements addressing the interactions between humans and the aircraft and develop related training materials for design engineers assigned to product development design teams.

Exclusion/Inclusion Criteria:

Only those individuals who are, or have been, members of product development design teams at [COMPANY NAME REMOVED] are eligible to participate.

Procedures:

If you decide to take part in this study, you give the researcher permission to observe the design team and record notes about how the design process works. You will also be asked questions about your training experiences, your experiences on design teams, and your current design projects. This will either occur informally, before or after design team meetings, or in an interview.

Interviews will last between thirty minutes and one hour and will be conducted during a six-week period. Observation periods will vary, as they will depend on the length of the various team meetings. The observations will be completed over the course of six weeks.

Risks or Discomforts:

The research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required outside of the research context.

Benefits:

By participating in this study, you can provide valuable insights for improving the aircraft design process and the development of training materials for new hires and other design engineers.

Compensation to You:

No compensation is provided for your participation.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study. No data collected about you will include personal information. The data collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in password-protected files and only study staff at Georgia Tech will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. Your privacy will be protected to the extent allowed by law. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records.

Costs to You:

There are no costs to you, other than your time, for being in this study.

Participant Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:

If you have any questions about the study, you may contact Alexandra Coso at acoso@gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact
Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Compliance, at (404) 894-6942.
or
Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Compliance, at (404) 385- 2175.

If you do not agree to participate in the study or would like to withdraw from the study, please email Alexandra Coso at acoso@gatech.edu at any time.

Otherwise, it means that you have read (or have had read to you) the information contained in this document, and would like to be a volunteer in this research study.

A.2 IRB Approval: First Semester Study



Protocol Number: H12275
Funding Agency: NSF Graduate Research
Fellowship Program
Review Type: Exempt, Category 1 & 2
Title: Incorporating Stakeholder Considerations into
Fixed Wing Design Education: An Exploratory Study
Number of Subjects: 100

August 24, 2012

Amy Pritchett
AE
0150

Dear Dr. Pritchett:

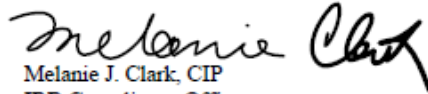
The Institutional Review Board (IRB) has carefully considered the referenced protocol. Your approval is effective as of August 17, 2012. The proposed procedures are exempt from further review by the Georgia Tech Institutional Review Board.

Project qualified for exemption status under 45 CFR 46 101b. 1 & 2.

Thank you for allowing us the opportunity to review your plans. If any complaints or other evidence of risk should occur, or if there is a significant change in the plans, the IRB must be notified.

If you have any questions concerning this approval or regulations governing human subject activities, please feel free to contact Dennis Folds, IRB Chair, at 404/407-7262, or me at 404 / 894-6942.

Sincerely,


Melanie J. Clark, CIP
IRB Compliance Officer

cc: Dr. Dennis Folds, IRB Chair
OSP

A.3 First Semester Student Consent Form and Associated Amendment

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Investigators: Dr. Amy Pritchett and Alexandra Coso, School of Aerospace Engineering
Protocol and Consent Title: Incorporating Stakeholders Considerations into Fixed Wing
Design Education – An Exploratory Study (07/23)

You are being asked to be a volunteer in a research study.

Purpose:

The purpose of this study is to explore students' understanding of and perceptions about how stakeholder considerations can be incorporated into the design of a fixed wing vehicle.

Exclusion/Inclusion Criteria:

Only those individuals who are students within the Fixed Wing Design course at Georgia Tech in the fall 2012 semester are eligible to participate.

Procedures:

As part of your senior design course, you will be asked to complete in-class evaluations related to design and stakeholder requirements. If you decide to take part in this study, you give the researcher permission to use your responses in her study and also to observe your participation in lectures and lab sessions related to this topic and record notes about your experiences.

Please remember while you must complete the evaluations and attend the lectures and lab sessions for the course, your participation in the study is completely voluntary and will not affect your final grade.

Risks or Discomforts:

The research presents no more than minimal risk of harm to subjects.

Benefits:

By participating in this study, you can provide valuable insights for improving aerospace engineering design curricula.

Compensation to You:

No compensation is provided for your participation.

Confidentiality:

The information that you give in this study will be handled confidentially. Your name will not be used in any report (pseudonyms will be used). Data collected will be kept in password-protected files and only study staff at Georgia Tech will be allowed to look at them. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB and the Office of Human Subject Research Protection may review study records.

Costs to You:

There are no costs to you, other than your time, for being in this study.

Participant Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:

If you have any questions about the study, you may contact Alexandra Coso at acoso@gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact
Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Compliance, at (404) 894-6942.

or

Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Compliance, at (404) 385- 2175.

If you do not agree to participate in the study or would like to withdraw from the study, please email Alexandra Coso at acoso@gatech.edu at any time.

Agreement: I agree to participate in the research study described above.

Signature: _____ **Date:** _____

You will receive a copy of this form for your records.

Incorporating Stakeholders Considerations into Fixed Wing Design Education –
An Exploratory Study
Dr. Amy Pritchett and Alexandra Coso
School of Aerospace Engineering

ADDENDUM TO CONSENT

This addendum to the consent form is to tell you about new information regarding the study in which you are participating. (Please See Italicized Text.)

Procedures:

As part of your senior design course, you will be asked to complete in-class evaluations related to design and stakeholder requirements. If you decide to take part in this study, you give the researcher permission to use your responses in her study and also to observe your participation in lectures and lab sessions related to this topic and record notes about your experiences. *The researchers will also examine your course submissions, related to requirements, stakeholders, and design, to supplement the observations.*

Please remember while you must complete the evaluations and attend the lectures and lab sessions for the course, your participation in the study is completely voluntary and will not affect your final grade.

All other sections of the original consent form still apply. Please refer to it for any questions you might have.

Contact Names and Numbers

If you have questions about the research, call or write: Alexandra Coso (acoso@gatech.edu) or Dr. Amy Pritchett (amy.pritchett@ae.gatech.edu).

If you have any questions regarding research participants' rights, please contact the Melanie Clark, Office of Research Integrity Assurance, Georgia Institute of Technology at (404) 894-6942.

Conclusion

SIGNATURES

A copy of this form will be given to you.

Your signature below indicates that the researchers have answered all of your questions about the addendum.

Consent to Research

Signature: _____ Date: _____

Printed Name: _____

Person Obtaining Consent - Signature: _____ Date: _____

A.4 Second Semester Student Consent Form

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Investigators: Dr. Amy Pritchett and Alexandra Coso, School of Aerospace Engineering

Protocol and Consent Title: Incorporation of Stakeholders in Fixed Wing Design: An
Observational Study

You are being asked to be a volunteer in a research study.

Purpose:

The purpose of this study is to understand students' perceptions about how stakeholder considerations should be incorporated into the design of a fixed wing vehicle.

Exclusion/Inclusion Criteria:

Only those individuals who are students within the Fixed Wing Design course at Georgia Tech in the spring 2013 semester are eligible to participate.

Procedures:

If you decide to take part in this study, you give the researcher permission to examine your course submissions related to your capstone project, and to observe your participation in the project design reviews and record notes about your project solution. The researcher may also meet with you or your instructors during the semester to inquire about the progress of your project or to assist you with integrating stakeholder requirements into your design. This will occur informally at mutually agreeable times and your participation in any such meetings is voluntary; the researcher will record notes from these meetings.

Risks or Discomforts:

The research presents no more than minimal risk of harm to subjects.

Benefits:

By participating in this study, you can provide valuable insights for improving aerospace engineering design curricula.

Compensation to You:

No compensation is provided for your participation.

Confidentiality:

The information that you give in this study will be handled confidentially. Your name will not be used in any report (pseudonyms will be used). Data collected will be kept in password-protected files and only study staff at Georgia Tech will be allowed to look at them. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB and the Office of Human Subject Research Protection may review study records.

Costs to You:

Most aspects of your participation involve allowing the researcher access to data that is already generated as part of this course. Thus, there are no extra costs to you for being in this study except for any time that you agree to volunteer to meet with the researcher.

Participant Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:

If you have any questions about the study, you may contact Alexandra Coso at acoso@gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact
Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Compliance, at (404) 894-6942.

or

Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Compliance, at (404) 385- 2175.

If you do not agree to participate in the study or would like to withdraw from the study, please email Alexandra Coso at acoso@gatech.edu at any time.

Agreement: I agree to participate in the research study described above.

Signature: _____ **Date:** _____

You will receive a copy of this form for your records.

A.5 Second Semester Instructor Consent Form

CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY

Georgia Institute of Technology

Investigators: Dr. Amy Pritchett and Alexandra Coso, School of Aerospace Engineering

Protocol and Consent Title: Incorporation of Stakeholders in Fixed Wing Design: An
Observational Study

You are being asked to be a volunteer in a research study.

Purpose:

The purpose of this study is to understand students' perceptions about how stakeholder considerations should be incorporated into the design of a fixed wing vehicle.

Exclusion/Inclusion Criteria:

Only those individuals who are the instructors within the Fixed Wing Design course at Georgia Tech in the spring 2013 semester are eligible to participate.

Procedures:

If you decide to take part in this study, you give the researcher permission to ask you questions about the progress of the class as a whole and the individual students' projects and record notes about the processes being used by the different groups and the different ways stakeholders are being considered. (*Note:* Permission will also need to be attained from the students to inquire about their progress within the course as per FERPA regulations). These conversations will occur at mutually agreeable times either informally in brief conversations before or after class or team meetings, or in scheduled interviews lasting between thirty minutes and one hour.

Risks or Discomforts:

The research presents no more than minimal risk of harm to subjects.

Benefits:

By participating in this study, you can provide valuable insights for improving aerospace engineering design curricula.

Compensation to You:

No compensation is provided for your participation.

Confidentiality:

The information that you give in this study will be handled confidentially. Your name will not be used in any report (pseudonyms will be used). Data collected will be kept in password-protected files and only study staff at Georgia Tech will be allowed to look at them. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB and the Office of Human Subject Research Protection may review study records.

Costs to You:

There are no costs to you, other than your time, for being in this study.

Participant Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:

If you have any questions about the study, you may contact Alexandra Coso at acoso@gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact
Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Compliance, at (404) 894-6942.

or

Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Compliance, at (404) 385- 2175.

If you do not agree to participate in the study or would like to withdraw from the study, please email Alexandra Coso at acoso@gatech.edu at any time.

Agreement: I agree to participate in the research study described above.

Signature: _____ **Date:** _____

You will receive a copy of this form for your records.

APPENDIX B – Industry Case Study: Semi-Structured Interview

Protocol

At the beginning of the session, I will:

- Introduce myself to the student and thank him/her for taking time to participate.
- Review the informed consent:
 - *Before we begin, I would like to inform you that all information from this interview will be held confidential and there are no risks to this study. Additionally, your participation in the study is voluntary; therefore, you may withdraw from the study at any point. Here is the consent form. Please take a few moments to read through it. Thank you for agreeing to participate. I have planned this session to last no longer than 45 minutes.*

The following questions will be used as a guide. Some may not be asked if the answer is gleaned from a previous response. Follow-up probes may be used in the context of each interview to elicit greater detail and information.

Introductory Questions

For these first questions, I want to ask you about how the design process works within the firm from your perspective.

1. Is there a specific set of steps that you follow as a design engineer?
 - If so, could you describe them?
 - For a given project, what is the timeline for completing these steps?
 - Follow-ups will be related to order of steps, frequency of iterations, which steps are completed in parallel, etc.
2. When a new project starts, what happens exactly?
 - Are there meetings or training sessions?
 - How do people get acquainted with the new project?
3. Describe some projects where you followed this design process.
4. Describe a project where you did not exactly follow this design process.
 - How did this design process differ from the design process you previously described?
 - Why the difference?
 - Was there a noticeable impact?
5. Could you tell me a little about the design teams who are assigned to these different projects?
 - What are the typical compositions of the teams, in terms of disciplinary affiliation, work experience, and gender?
 - How are the design engineers assigned to design teams?
6. What is the typical week for someone on x design team?
 - Are there several group meetings a week?
 - Do design engineers work more on their own or in collaboration with others on the team?

Design Team Questions

This set of questions is about your previous experiences on design teams.

7. Over the lifetime of a commercial aircraft, many individuals will interact with the design, including, but not limited to, manufacturers, pilots, flight attendants, ground handlers, maintainers, and passengers.
 - For a given project, are there dedicated requirements addressing the considerations of these or other stakeholders?
 - If so, can you describe them and when they are addressed during the design process? Who is responsible for addressing these requirements?
 - If not, why not?
8. Have you had a design team experience where you felt that stakeholder considerations were integrated very well into the final design?
 - Could you tell me a little more about the type of project it was?
 - What were the backgrounds of the individuals on that design team with you?
 - Was there a specific reason you felt that the integration was especially effective on this project?
9. Have you had a design team experience where you felt that stakeholder considerations were poorly integrated into the final design?
 - Could you tell me a little more about the type of project it was?
 - What were the backgrounds of the individuals on that design team with you?
 - Was there a specific reason you felt that the integration was especially ineffective on this project?

Challenges/Interventions Questions

This set of questions is about the challenges that may be faced in attempting to integrate stakeholder considerations into the aircraft design process and any previous interventions used at the firm.

10. What challenges do individuals with specializations in human systems integration face in attempting to address these requirements within the overall design process?
11. What challenges do design engineers with other specializations face?
12. What challenges does management face in supporting this integration?
13. Has the firm tried any types of interventions to attempt to improve the effectiveness of the integration?

Training/Intervention Questions

This set of questions is about the types of training individuals receive when they start at the firm.

14. Thinking about the incoming engineers this summer, what type of training do they receive before starting their first design project?
15. What type of challenges do incoming engineers face when participating on their first few design teams?
16. What type of training do you think would be most helpful to improve a design engineer's ability to identify and meet stakeholder requirements?
17. Are there certain skills or abilities that you would like to see when selecting/hiring engineers to improve the overall aircraft design process and the effectiveness of the design teams?

Wrap-up Questions

17. Is there anything else about your experiences on design teams or stakeholder requirements at the firm that you would like to share? Or that you think might help me in my project this summer?
18. Do you have any questions for me?

At the end of the interview: I will thank the participant for his/her time and insight.

APPENDIX C - In-Class Evaluation

C.1 In-Class Evaluation Instrument

SECTION I

DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.

A. Rate your degree of confidence to perform the following tasks by recording a number from 0 to 100. (0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Identify a design need	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Research a design need	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Develop design solutions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Select the best possible design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Construct a prototype	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Evaluate and test a design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Communicate a design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Redesign	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

B. Indicate your knowledge/ability in each area using the scale provided.

	Little or None	Some	Adequate	High	Very High
Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc) that might affect the solution to an engineering problem.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ability to recognize how different contexts can change a solution	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

C. Describe how *the ability to recognize how different contexts could change a solution* might relate to fixed wing aircraft design.

SECTION II

Please select and list the six most important and six least important concepts for design from the list below.

Abstracting	Identifying constraints	Seeking information
Brainstorming	Imagining	Sketching
Building	Iterating	Synthesizing
Communicating	Making decisions	Testing
Decomposing	Making trade-offs	Understanding the problem
Evaluating	Modeling	Using creativity
Generating alternatives	Planning	Visualizing
Goal setting	Prototyping	

Most Important

-
-
-
-
-
-

Least Important

-
-
-
-
-
-

For one of the 6 you listed as the most important for producing a high quality design, please explain why you believe it is important.

For one of the 6 you listed as the least important for producing a high quality design, please explain why you believe it is least important.

SECTION III

For this problem, imagine you are an employee at AeroAquatics, Inc, a submarine design firm. Based on a recent design challenge, upper management has tasked you with heading up the conceptual design of a new personal submarine. The submarine will be used by researchers (and other customers) to perform solo deep dives in the ocean.

- a. Your first task is to put together a team to begin the design process. Please select a team of 6 individuals from the list below and briefly explain why you chose each individual.
(NOTE: You can have more than one person from a given discipline, just be sure to indicate that)

[List will be randomized]

- Aerospace Engineer
- Biomedical Engineer
- Civil Engineer
- Cognitive Engineer
- Computer Engineer
- Computer Scientist
- Electrical Engineer
- Environmental Engineer
- Financial Analyst
- Human Factors Expert
- Industrial Engineer
- Industrial Designer
- Marine Biologist
- Marketing Expert
- Materials Science Engineer
- Mechanical Engineer
- Medical Physician
- Potential Customer
- Potential User
- Project Manager
- Systems Engineer

- b. Prior to the first team meeting, upper management asked you to prepare a list of requirements for the project. Please list the requirements you would bring to the meeting.

SECTION IV Demographics

Gender: ___ Male ___ Female

Citizenship: ___ US Citizen ___ Permanent Resident ___ International (Country):

Undergraduate Major: _____

Have you participated in any other undergraduate design-related courses? ___ Yes ___ No
If so, please list those courses.

Have you participated in any problem-based learning courses? ___ Yes ___ No
If so, please list those courses.

Have you had any aerospace engineering industry experience? ___ Yes ___ No
If so, please list those experiences below, noting what your functions were.

C.2 In-Class Evaluation: Submarine-Design Scenario Coding Scheme

Submarine Design Prompt Coding Scheme (Revision: 09/04/2013)

Design Consideration	Frame of Reference	Description	Keywords
SUB	Technical	The "what" of the sub	Requirements
		Design aspects of the sub, including physical properties, features, and other specifications	Dimensions, type, weight, system architecture, interfaces w/out explicit about integration or multiple systems
		Materials needed, properties of materials (not cost)	Materials
		Other design considerations (with no mention of ocean/water/human)	Forces, stress, strain, fluids, hydraulics, power generation, control systems, electrical systems, structures
		Equipment needed for research (with no mention of human researcher)	Storage, payload
		Technology	
		Performance requirements	Range, speed, endurance, etc.
		Personnel related to the technical aspects of the design/design in general	Engineers, etc.
SUB	Logistical	The "how" of the sub; management, feasibility of technical systems	Scope, management personnel (i.e., a project manager, financial analyst), all teamwork/collaboration related discussions, understand problem
		Where to send the submarine and for how long (i.e., the mission requirements)	Depth requirements, location of dives; dive duration (not specific to human)
		Integration/construction/manufacturing; how many subs are we making	Project duration, systems integration/interfaces between systems, layout
		Cost-related considerations (includes material cost & availability, funding, etc.) Selling the product (without explicit discussion of customers or market)	
		Maintenance and failure, reliability, testing of components	Does not refer to maintainers directly
		Alternative design ideas (rather than a submarine)	
		Transportation, Deployment, and Recovering of submarine	Recoverability, deployment, sub transportation to and from locations
		Certification considerations/government policies relating only to submarine design (not humans or environment)	
		Life-cycle considerations (i.e., disposal)	
		Review of past solutions	
SUB	Natural	Environmental information on dive sites/mission related discussions	
SUB	Social	Sub's effect on safety [does not mention the human]	Safety , emergency plans - used when student is not explicitly talking about a particular type of safety requirements
		Government regulations related to safety	Does not refer to humans directly.
		Sub's effect on use of ocean by transportation/people/other research submarines	Transportation systems, military, etc.

Design Consideration	Frame of Reference	Description	Keywords
Surroundings	Technical	Effect of surroundings on submarine (no mention of human)	Pressure and Depth effects on submarine; talks about visibility without explicitly mentioning human
		Research requirements as they relate to biological and environmental surroundings	biological research, sample retrieval
		Dynamics and Design considerations due to ocean	hydrodynamics
		Physical properties of water/surroundings	force, pressure, friction, speed, current, flow rate,
Surroundings	Logistical	Government Regulations/Certification requirements related to surroundings	
		Personnel related to the surroundings	Marine Biologist, environmental engineer, etc.
Surroundings	Natural	ecosystems, environmental surroundings, aquatic life (if submarine is not mentioned)	
		impact of submarine (and subsystems) on surrounding environment	pollution
		General or broad environmental impact of sub	
Surroundings	Social	Impact of submarine on people or communities near but not directly associated with the sub	travel, recreation, tourism
		People's opinion on use of submarine to explore ocean	
		Impact of submarine on human-related ocean sites (e.g. ship wrecks, etc.)	
		Effects of water/surroundings on human body (in general)	

Design Consideration	Frame of Reference	Description	Keywords
STK	Technical	the "what" of the interior - Design aspects of the interior quarters and work stations for the researcher	Comfort, communication requirements
		Dynamics and Control Systems (relating directly to user)	ease of use of controls, maneuverability
		Design parameters (related to stakeholders)	# of passengers, interfaces (explicitly mentioning user)
		Life-support systems; Limits of human body; safety systems	Oxygen required, safety of cabin
		Aesthetics	
		Effect of surroundings on human [as it relates to submarine]	pressure and depth effects
STK	Logistical	Relevant personnel	E.g., HFE, cognitive engineer, marketing expert, medical physician, customer, user, industrial designer
		Stakeholders Analysis (who are the stakeholder and what are their needs)	
		Design for maintainability (talks about maintainers)	
		Design for manufacturability (talks about manufacturers)	
		Design for people	user-centered design, human-centered design
		User-testing	
		Engagement with user or customer/client for this design	
		Market Research (Market size, determination of what market)	
		Certification/Government regulations (as it relates to stakeholders)	
STK	Natural	Effect of human based system and/or the proposed research on marine life	
STK	Social	People's opinions on user-focused/user-based systems, using a human diver vs. automated systems	
		Effect of design on economics systems	
		Effect on competitors or information about competitors	
		User-based systems effect on safety of user/safety of others; Safety requirements related to human but does not include explicit discussion of safety-related systems on sub	emergency plans (if human systems mentioned)

Notes:

Remember that you can assign "no code" to either or both coding dimensions, if the segment and its context do not provide enough information to base a coding.

If the segment is not explicit or considers two frames of reference, always select the code that is farther "out" in terms of frame of reference (for instance, if a systems engineer was included for both logistical and technical reasons, code as logistical)

Based on coding scheme by Kilgore and Atman, Adapted by Alexandra Coso

C.3 Pre-Evaluation: Validity and Reliability of Design Self-Efficacy and Contextual Competence Scales

C.3.1 Design Self-Efficacy Scale

The items are designed to measure design self-efficacy, thus it is necessary to assess whether students' responses to these questions are consistent. Using Cronbach's alpha, a common test for internal consistency among the items, the result indicated a good level of internal consistency for the eight design self-efficacy items ($\alpha = 0.861$), where a good level of consistency is between .8 and .9. Items 2 through 8 on this scale represent observations of students' design self-efficacy. The next necessary analysis was to determine if these observations could be re-expressed as a single design self-efficacy score. Principal component analysis was utilized to understand the relationships among the observations. For the design self-efficacy scale, the analysis initially suggested the existence of two factors based on the Kaiser-Guttman Rule (two of the eigenvalues were greater than 1 – 4.110 and 1.05). However, upon correspondence with the scale developer and examination of the scree plot, the second factor was discarded from further analysis (Carberry, 2012).

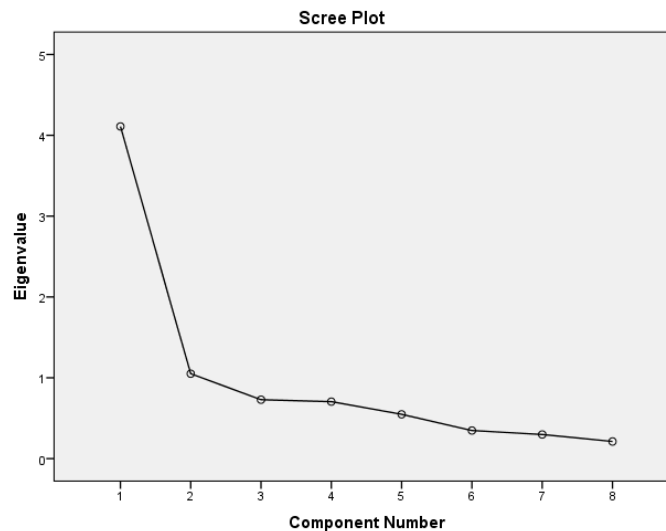


Figure 39: Design Self-Efficacy Scree Plot - Pre-Evaluation

The items all loaded onto the first factor with loadings above 0.6 (see Table 6). Final factor scores were calculated using a least squares regression approach. Finally, the correlation between the resultant factor scores and item #1 within the scale, *conduct engineering design*, were found to be significant, $r = .8$, $p < .001$.

Table 82: Factor Loadings for Design Self-Efficacy Items

#	Item	Factor Loading
2	Identify a design need	0.631
3	Research a design need	0.655
4	Develop design solutions	0.731
5	Select the best possible design	0.632
6	Construct a prototype	0.712
7	Evaluate and test a design	0.789
8	Communicate a design	0.694
9	Redesign	0.859

C.3.2 Contextual Competence Scale

The reliability analysis for the four contextual competence items was acceptable ($\alpha = 0.771$) and when conducted for items 2-8 of the design self-efficacy scale and the contextual competence scale, the result demonstrated good internal consistency ($\alpha = 0.826$). The factor analysis resulted in a single factor with loadings greater than .69 (see Table 83). A statistically significant correlation was found between the resultant factor scores and which lab section the students were in when completing the evaluation, $r = -.265$, $p < 0.05$. Thus, it was necessary to use the lab section in future analysis with these factor scores. The correlation between the design self-efficacy factor scores and the contextual competence factor scores was found to be significant, $r = .268$, $p < 0.05$.

Table 83: Factor Loadings for Contextual Competence Items

#	Item	Factor Loading
1	Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc) that might affect the solution to an engineering problem.	0.755
2	Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	0.831
3	Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	0.812
4	Ability to recognize how different contexts can change a solution	0.696

C.4 Post-Evaluation: Validity and Reliability of Design Self-Efficacy and Contextual Competence Scales

C.4.1 Design Self-Efficacy Scale

As previously discussed, it is necessary to assess whether students' responses to these questions are consistent. Using Cronbach's alpha, the result indicated a good level of internal consistency for the eight design self-efficacy items ($\alpha = 0.837$), where a good level of consistency is between .8 and .9. The next necessary analysis was to determine if the observations for items 2 through 8 could be re-expressed as a single design self-efficacy score using principal component analysis. For the design self-efficacy scale, the analysis initially suggested the existence of two factors based on the Kaiser-Guttman Rule (two of the eigenvalues were greater than 1 – 3.978 and 1.397). However, upon correspondence with the scale developer and examination of the scree plot (see Figure 40), the second factor was discarded from further analysis (Carberry, 2012).

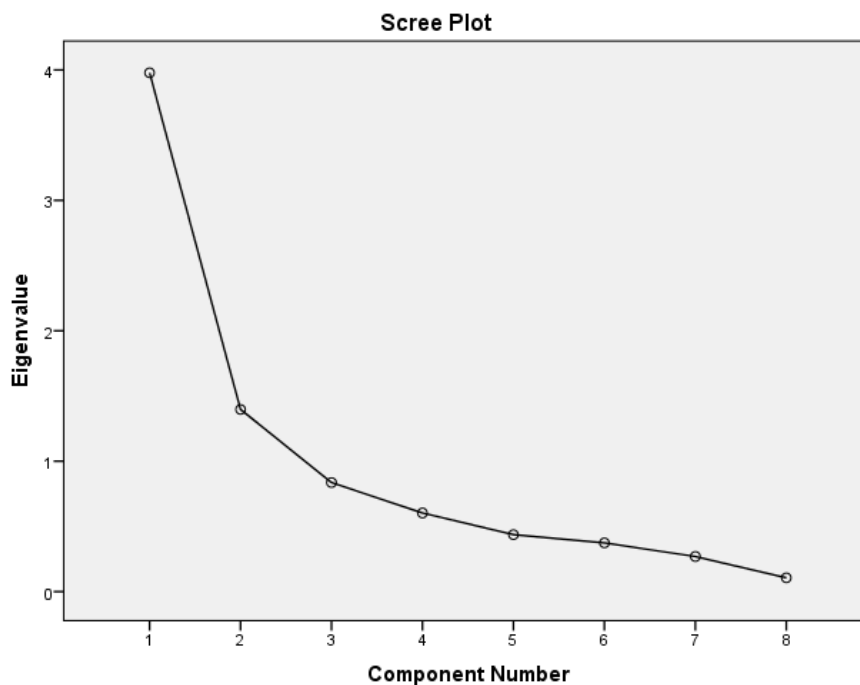


Figure 40: Design Self-Efficacy Scree Plot - Post-Evaluation

The items all loaded onto the first factor with loadings above 0.5 (see Table 84). Final factor scores were calculated using a least squares regression approach. Finally, the correlation between the resultant factor scores and item #1 within the scale, *conduct engineering design*, were found to be significant, $r = .808$, $p < .01$.

Table 84: Factor Loadings for Design Self-Efficacy Items – Post-Evaluation

#	Item	Factor Loading
2	Identify a design need	0.632
3	Research a design need	0.541
4	Develop design solutions	0.803
5	Select the best possible design	0.748
6	Construct a prototype	0.633
7	Evaluate and test a design	0.719
8	Communicate a design	0.726
9	Redesign	0.799

C.4.2 Contextual Competence Scale

The reliability analysis for the four contextual competence items was acceptable ($\alpha = 0.720$) and when conducted for items 2-8 of the design self-efficacy scale and the contextual competence scale, the result demonstrated good internal consistency ($\alpha = 0.803$). The factor analysis resulted in a single factor with loadings greater than .6 (see Table 83). Unlike with the pre-evaluation, the correlations between the responses by section were not found to be significant. However, as with the pre-evaluation, the correlation between the design self-efficacy factor scores and the contextual competence factor scores was found to be significant, $r = .281$, $p < 0.05$.

Table 85: Factor Loadings for Contextual Competence Items

#	Item	Factor Loading
1	Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc) that might affect the solution to an engineering problem.	0.696
2	Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit	0.818
3	Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions	0.794
4	Ability to recognize how different contexts can change a solution	0.638

APPENDIX D – Requirements Lab

D.1 Lesson Plan and Handouts

Course: Aircraft Design I
Duration: 1.5hrs to 2.5hrs
session

Implementation: Lab Sessions
Estimated Number of Students: 40-45 per lab session

Overview:

This lab session replaces the requirements lecture from the previous year and incorporate additional information about stakeholder-related requirements. The focus of last year's lecture was requirements and their relationship to performance, verification and validation of requirements, and how requirements fit into the design process. The overall goal of this new design is to introduce students to requirements, their importance, and how stakeholder-requirements should be incorporated into the requirements definition phase of the design process.

The structure of the lesson is based on the idea of experience, reflection, and experimentation. The first part of the lesson focuses on giving the students a relatable experience to begin to understand requirements. The second part of the lesson focuses on reflection on and discussion about requirements. The final part of the lesson provides the students with an opportunity to experiment with what they have just learned about requirements with a business jet example. Stakeholder considerations and discussions of stakeholder requirements are integrated into all the parts of the lesson.

Learning Objectives:

- Students will be able to describe the purpose of writing requirements and recognize characteristics of well-written requirements. (*Comprehension*)
- Students will be able to explain why validation and verification are critical in the requirements definition process and give examples of different validation and verification techniques. (*Comprehension*)
- Students will be able to identify different stakeholders affected by a design problem. (*Comprehension*)
- Students will be able to discuss how requirements affect design and the design process. (*Comprehension*)
- Students will be able to formulate well-constructed high level requirements and 2nd level requirements. (*Application*)
- Students will be able to breakdown a problem and write requirements for performance and stakeholder considerations. (*Application & Analysis*)

Materials and Instructor Preparation:

- Modify the existing powerpoint for use as reference material for the students following the lecture and a powerpoint with all the prompts for use during the lab session
- Read through Raymer, Roskam, and Nicolai texts to understand what is currently taught about requirements.
- Develop/Find examples for the introduction and conclusion of the session

Agenda:

Framing the Class:

Duration: approx. 10 minutes

Students will be asked to write down an experience where they designed something and the steps they went through. I will ask for one or two volunteers to discuss their examples.

Mode of Transportation/Bike Example: (learning by experience)

Duration: approx. 20 to 30 minutes

- Upon arrival to the class, students will be handed notecards and asked to take a couple of minutes to write two or three requirements for the following scenario
 - *I am moving out to the far side of midtown and piedmont park area. It will now take too long for me to arrive to campus by walking. I need your help determining what mode of transportation will get me to campus quickly and safely. Take a few minutes and on your notecards write down a couple of requirements for my mode of transportation. (pedagogical transparency)*
 - Partner up and discuss your requirements with your partner. *Were you missing any?*
- **REPORT OUT:** I will write up on the board some of the requirements (show hierarchy if exists).
- *Based on these requirements, I would like to pursue the idea of getting a bicycle. I have the opportunity to get a custom-made bike for almost nothing from a friend, but need to supply him with a list of design requirements that capture my needs and limitations.*
 - Combine into groups of four and write up the design requirements that you think need to be included in the RFP. Give them 3 min.
 - Then explain that if they have any questions to ask me, the client/the user, they can at that point (3 more minutes)
- *While you all were working on your proposals for a bike design, ABC Bicycles, Inc. sent me their requirements lists for me to review.*

- **See attachment.** Have students compare their requirements to those in the example and discuss what they see. Which requirements are written well? How do you know?
- **What would a more specific requirement?**

Discussion and Reflection: (learning by reflection)

Duration: approx. 30 to 45 minutes

The discussion will begin by talking about the learning objectives for the rest of the lesson. The questions will be addressed as they come up in the discussion.

- Why might we need to write requirements? What's their purpose?
- Who do requirements affect?
 - Anecdote time: other design groups
 - Anecdote time: Passenger experience/Flight Attendants L-1011
- Where do you get information for writing requirements?
- How do you write requirements?
- How do you ensure your requirements are the right requirements?
 - Anecdote time: door example
- What is a process for requirements writing?

Business Jet Example: (learning by experimentation)

Duration: approx. 45 minutes to 1 hour

[Can be implemented in a subsequent class period if necessary]

The prompt is included below. The structure of this exercise is to have the students first consider the prompt individually, then to get back into their groups of four and negotiate the requirements, the stakeholders, and the necessary verification and validation techniques.

The output of the discussion is a write-up due at the end of the lab which includes (1) list of stakeholders, (2) proposed requirements, and (3) verification and validation plan.

After about 10 minutes of discussion in groups, four stakeholders/characters will be available for questions for 30 minutes: (1) marketing study person, (2) a future pilot for the jet, and (3) the team's managers/mentors with 20 years of experience in business jet design.

There will be an opportunity (10 to 15 minutes) after the stakeholder interaction period for reporting out about the group's particular requirements. This will provide time to reiterate important points from the lesson and the importance of well-written requirements.

Then the students will be given 15 to 20 minutes to revisit their requirements and make changes before submitting them.

Prompt: EliteFlights, Inc. has just received a unique opportunity to design a business jet for a niche market of international business travelers. The company has completed a market analysis, which demonstrated the need for a jet for this passenger group. The design must meet the preferences of the international business traveler, which includes locations for sleeping over long night flights, smooth travel so as not to disturb working/sleeping conditions, room for staff & baggage, and a high level of comfort and service. In addition, many of the business travelers prefer to hold business meetings in the air. The jet must be able to fly in all weather conditions both during the day and at night. The jet must also be able to leave at least one engine running for a reasonable amount of time at an airport, so to expedite leaving a particular city or country. An example of a common trip for this class of business traveler is Los Angeles, CA to Abu Dhabi, UAE. Yet, these travelers also are known to use the jets to go to remote locations with smaller airports and landing strips.

Marketing Notes:

- Cost is an important component, because we need to stay competitive with the rest of the business jet manufacturers.
- We would like to offer our customers the most comfortable flight with the least amount of turbulence and the most protection from the low outside air pressure. We heard that the Bombardier Global Express business jet features 4500ft equivalent effective cabin altitude when cruising at 41,000 ft. In addition, the FAA mandates the cabin altitude may not exceed 8,000ft.
- Cruise performance is definitely important for our customers.
- The larger the fuselage diameter the more space for our customers.
- We would also like to market to our customers an airplane with low noise, so as not to cause a disturbance when arriving and leaving from more remote airports.

Technical & Stakeholder-related Trade-offs:

- Parasite drag vs. wetted air/fuselage diameter
- Fuselage length, fineness ratio and the resulting effect on form factor drag
- Cruise altitude certification
- Number of engines or trades with take-off/field length
- Wing loading on a small airplane/gust stability

Conclusion & Check for Understanding: At the end of the lab, students will submit one copy of the business jet example write-up per team (see attachment). Students will also be asked to fill out a short feedback form (see attachment). *The instructor will review students' responses to provide students with feedback during future lectures.*

ABC Bicycles, Inc.

Requirements for Alexandra's Custom-made Bike!

1. From the U.S. Consumer Product Safety Commission's regulations on bicycles, the bicycle shall not have unfinished sheared metal edges or other sharp parts that may cut a rider's hands or legs.
2. The bicycle pedals shall have threads on both sides.
3. The bicycle pedals can have reflectors.
4. The bicycle shall have front suspension.
5. The bicycle frame shall be painted for protection from corrosion.
6. The bicycle shall have brakes.
7. The bicycle shall be at least a 5-speed bike.
8. The bicycle should be reasonably comfortable.
9. The ends of the handlebars shall be capped or covered.
10. The bicycle shall have front and rear brakes.
11. The bicycle shall have a basket at the front.
12. The bicycle will weigh some weight that Alexandra can lift.
13. The bicycle shall be easily repairable.
14. The bicycle shall have more than 18 gears.
15. The bicycle frame shall be aluminum.
16. The tires shall be treaded to help the bike stay on stable on muddy terrain or wet roads.

EliteFlights Business Jet Design Case

EliteFlights, Inc. has just received a unique opportunity to design a business jet for a niche market of international business travelers. The company has completed a market analysis, which demonstrated the need for a jet for this passenger group. The design must meet the preferences of the international business traveler, which include locations for sleeping over long night flights, smooth travel so as not to disturb working/sleeping conditions, room for staff & baggage, and a high level of comfort and service. In addition, many of the business travelers prefer to hold business meetings in the air. The jet must be able to fly in all weather conditions both during the day and at night. The jet must also be able to leave at least one engine running for a reasonable amount of time at an airport, so to expedite leaving a particular city or country. An example of a common trip for this class of business traveler is Los Angeles, CA to Abu Dhabi, UAE. Yet, these travelers also are known to use the jets to go to remote locations with smaller airports and landing strips.

1. Who are the different stakeholders for this design problem?
2. What requirements do you propose for the new business jet design?
3. What verification and validation procedures will be required?

Student Feedback Form

1. In your opinion, what was the purpose of this lab session?
2. What did you like about the lab session?
3. What did you not like about the lab session?
4. What is the most important feedback you want the instructor to hear about today's lab?
5. On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from this lab session are to your senior design project for this upcoming spring semester?

D.2 Reference Presentation for Students

The slides are included on the next 10 pages.

Requirements

Supplementary Notes

Learning Objectives

- Students will be able to describe the **purpose of writing requirements** and recognize **characteristics of well-written requirements**.
- Students will be able to explain **why validation and verification** are critical in the requirements definition process and give examples of different validation and verification techniques.
- Students will be able to **identify different stakeholders** affected by a design problem.
- Students will be able to discuss **how requirements affect design** and the design process.
- Students will be able to **formulate well-constructed high level requirements** and 2nd level requirements.
- Students will be able to breakdown a problem and **write requirements**.

Requirements

- **Definition:**
 - A specification of what we need the vehicle or system to do, which for Aircraft Design means*
 - (1) What mission the aircraft will be called upon to perform
 - (2) How much the aircraft should cost
 - (3) How the aircraft should be maintained and supported
 - (4) The schedule for the aircraft
- Requirements are organized into levels, flowing down from the highest level (Level 1) to the subsystems as system architecture and design decisions are made

*From Nicolai 2010

Where do design requirements come from?

- Stakeholders
 - **Clients**, through consultation with clients (e.g airlines, military, government, etc.)
 - **Users**, through market assessment, analysis of user experience, consultation with users (e.g. passengers, flight crew, flight attendants, ground personnel, etc.)
 - **Government**, through examination of regulations (FAR 23 or 25), certification requirements, etc.
 - **Manufacturers**, through examination of previously used requirements, discussions with manufacturers, research about manufacturing human factors, etc.
 - **Maintainers**, through examination of previously used requirements, discussions with maintainers, research about maintainability human factors, etc.
- Safety Analysis & Requirements
 - Previous incidents and accidents can influence government regulations and also the requirements for future aircraft, as defined by the design companies.
- The Operational Environment
 - Government regulations for the safe operation of the aircraft in different airspaces
 - Purpose of airplane design (consider required range, required speed, required take-off and landing distance, landing terrain, mission)

Writing requirements

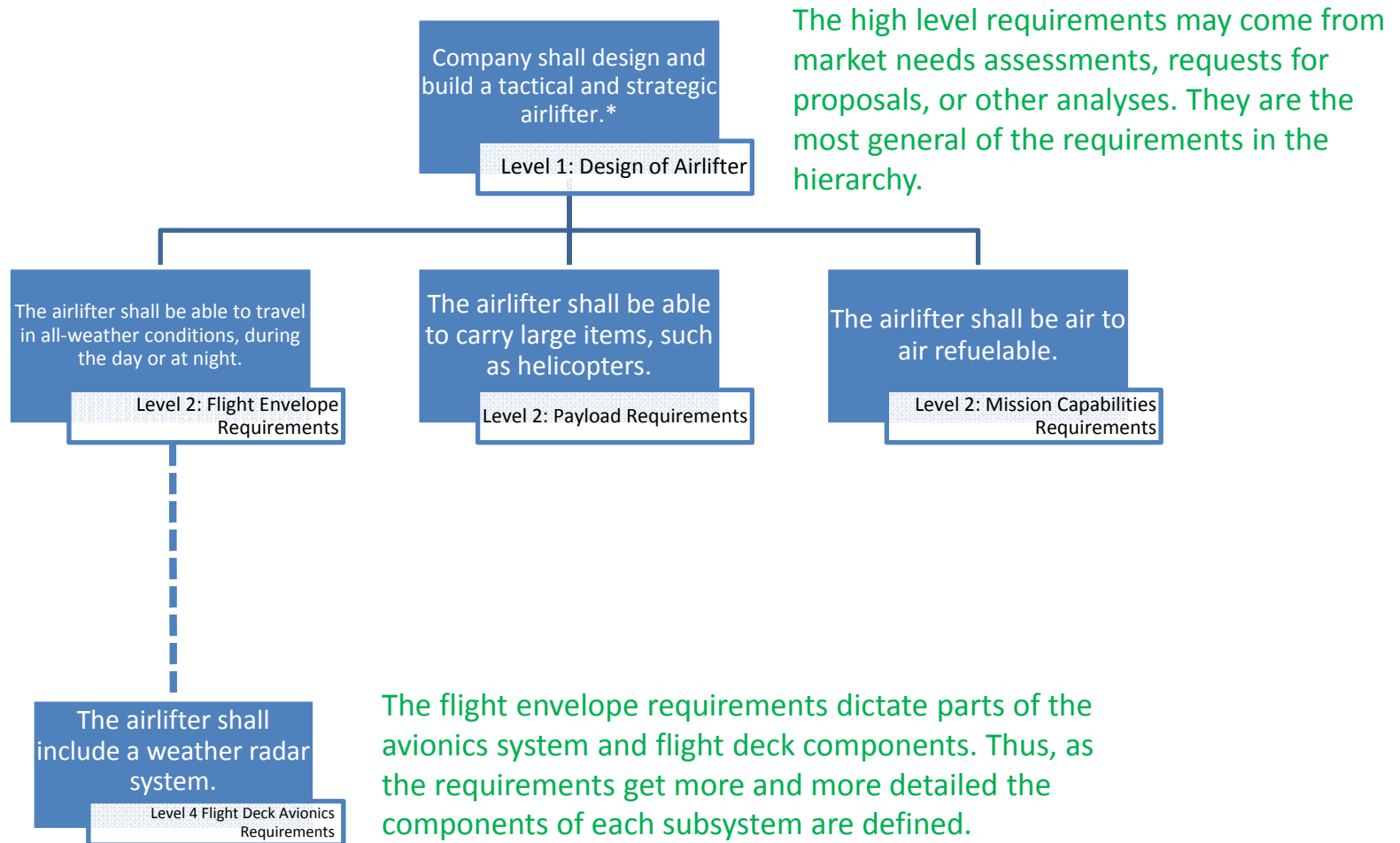
- Requirements *shall* have the word *shall* in the statement.
 - E.g. *The airplane shall have a maximum speed of no less than 350 kph at sea level at its maximum weight.*
- Lower-level requirements *shall* flow down from higher level requirements.
- Requirements *shall* become more specific and detailed in the lower levels.
- Requirements *shall* reflect the needs and limitations of the stakeholders.
- Requirements *shall* be clear and consistent.
- Requirements *shall* be specific enough so they can be verified and validated.

Requirements Examples

- For the Next Generation Strategic Bomber*,
 - The bomber shall have an entry into service date in the 2020-2025 timeframe. **GOOD!**
 - It shall be design to have a reasonable service life. **NOT SPECIFIC ENOUGH – what is reasonable?**
 - The bomber shall be a manned aircraft with two crew members. **Will now have to consider government regulations for manned aircraft.**
 - Unrefueled combat range shall be no less than 4,000nm. **GOOD!**

*Adapted from AIAA 2011-2012 Grad Team Aircraft Competition RFP

Requirements Hierarchy



*Adapted from http://www.n-w-c.de/files/RBE-Handout-DAY1_.pdf

Requirements Definition Process

- Iterative process
- Components include*
 - *Requirements elicitation* – consultation with stakeholders, examination of government regulations and previous aircraft from a similar class
 - *Requirements analysis and negotiation* – The requirements are analyzed and some formal negotiation takes place involving different stakeholders to decide which requirements are to be accepted.
 - *Requirements Validation* – Careful check of requirements for consistency and completeness.

*From Sommerville 1997

Verification & Validation (V&V)

- Validation: Used to answer the questions
 - Are these the RIGHT requirements?
 - Are the requirements correct?
 - Are they specific enough to be shown that they have been met?

Remember to ask WHY!

- Verification: Shows that the requirements have been met, using techniques like
 - Analysis, ground demonstration, flight demonstration, inspection, relevant previous experience

References

- Requirements, Lecture 24 – August 2011 (*Neil Weston*)
- Nicolai, L. & Carichner, G. (2010). *Fundamentals of Aircraft and Airship Design*, volume 1. AIAA Education Series.
- Sommerville, Ian; Sawyer, Pete. (1997). *Requirements Engineering – A Good Practice Guide*. John Wiley & Sons.
- https://www.aiaa.org/uploadedFiles/Events/Other/Student_Competitions/2011-2012%20Grad%20Team%20Aircraft.pdf
- http://www.n-w-c.de/files/RBE-Handout-DAY1_.pdf

Other recommendations for reading:

- Hooks, I. F., and Farry, K. A.: *Customer-Centered Products: Creating Successful Products Through Smart Requirements Management*, American Management Association, New York, 2001. (More than you probably want to know now about requirements.)
- Brooks, C. G., Grimwood, J. W., and Swenson, L. S.: *Chariots for Apollo: A History of Manned Lunar Spacecraft*, NASA SP-4205, 1979.
- Knacke, T. W.: *The Apollo Parachute Landing System*, NASA CR-131200, 1968.

APPENDIX E – Stakeholders in Design Lab

E.1 Lesson Plan

Course: Aircraft Design I

Implementation: Lab Sessions

Duration: Two three-hour sessions

Estimated Number of Students: 40-45 per lab session

Overview:

The intention of this lab session is to provide students with the opportunity to consider how stakeholder requirements and concerns can be integrated into the design of a fixed wing vehicle. These lab sessions will focus on important characteristics of engineering design, specifically collaboration, negotiation, and communication. The students will also engage in reflective activities to prime them for the lab activities and content. These reflective activities include the opportunity for students to consider what design activities they have been utilizing in their individual design projects this semester. In addition, the students will be introduced to tools and methods for integrating stakeholder requirements and concerns that they can choose into incorporate into their understanding of the design process for designing a fixed wing vehicle. The overall goal is to have students define how stakeholder requirements will be incorporated into the design process they will follow in the spring semester.

The labs are designed with a social constructivist perspective, which contends that knowledge is constructed through social interaction. In a learning environment, this theoretical perspective has four main implications. The first is the necessity for social interaction and thus collaborative activities to help students build knowledge about a particular concept. The second implication is that collaborative learning should be mediated by a “more knowledgeable other”. The focus in this case is less on direct instruction and more on facilitation. The third implication is the importance of scaffolding, which comes from the Vygotsky’s theory known as the Zone of Proximal Development, which is “the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving with a more knowledgeable other”¹. The final implication is that learning activities are grounded in authentic, real-world contexts. Thus, these labs are designed to provide students with the opportunity to work collaboratively on real-world cases, with me serving as a facilitator who is scaffolding the lesson appropriately.

Learning Objectives:

- Students will be able to identify relevant stakeholders of a fixed wing design and explain how their concerns affect (or affected) the design solution (*Comprehension & Application*)
- Students will be able to assess methods for integrating stakeholder considerations into the design process (*Analysis*)

Materials and Instructor Preparation:

¹ http://projects.coe.uga.edu/epltt/index.php?title=Social_Constructivism

- Sufficient copies of pre and post evaluations and student feedback forms
- Blank paper and small sticky notes for individual design process activity
- Large poster paper, markers, and sticky notes for group design process activity (also tacks if necessary to put on walls in the room)
- PowerPoint presentation with information about stakeholder mapping and HCD methods examples
- PowerPoint template for Case Study Presentations
- Copied versions of the case studies for the student groups

Lab I Agenda

Framing the Class:

Duration: approx. 25 minutes

Class begins by giving the students an idea of the direction we are going and explaining that they will be completing a two-part reflection activity to help prepare them for the group work we will be doing the rest of the lab session.

- Evaluation #1 – 2 questions (*duration: 10 minutes*)
- Design Process Drawing (*duration: 10 minutes*)
 - Put up the list of 23 design activities which were part of the evaluation on the following question on PowerPoint. Then read the question allowed to the students: *Think about the process you have been following in this course so far, use the activities above to describe the different steps in that process. Provide explicit examples where possible: if you write **GENERATING ALTERNATIVES** as step 3 – add, for example, **Search on NACA for different airfoil design alternatives**. Feel free to draw, write, and use the sticky notes to describe the design process on the piece of paper distributed.*

Group Design Process Negotiation:

Duration: approx. 30 minutes

At this stage, frame the next activity by discussing how design in industry is based heavily on collaboration from many different groups. Many corporations have design processes which help everyone work towards similar goals and milestones. For the next activity, split the students into groups randomly. Then give them all poster paper, markers, and sticky notes and ask them to develop a group design process based on the design processes they created individually.

After about 20 minutes, ask two groups to communicate their processes to the group and talk about why they chose different steps.

Introduction to Stakeholder Mapping:

Duration: approx. 20 minutes

Using PowerPoint and a couple of examples, talk to the students about stakeholder mapping. First, remind them about the importance of stakeholders and the discussions we had earlier in the semester. Then talk to them about how there are different ways of considering stakeholders in the design process. One process used commonly in Civil and Environmental Engineering as part of

Social Sustainability efforts is called Stakeholder Mapping. The mapping we are going to discuss today has been adapted for use in aerospace vehicle design.

- Then show them using the example of a 787 (or similar aircraft) how to:
 - Categorize the stakeholders
 - Map stakeholders to design requirements
 - Consider how information about stakeholders can be collected
 - Brainstorm the different impacts these stakeholders can have on the design solution
- Finally, show them a second example – using the design project from the previous year’s capstone and talk about how even designers of a UAV need to consider stakeholders.

Introduction to the Case Study Task

Duration: approx. 10 minutes

We will likely take a five minute break before starting this section. For this stage, first talk to the students about why we are going to work with a case study.

- *“For your first project this semester, you had the opportunity to think about previous aircraft designs and how they may be similar or different to other aircraft designs. Experienced design engineers work from previous designs such as these and use lessons from those previous designs and their own previous design experiences when starting a new project. As novice design engineers in aerospace, you will likely not have as many previous design experiences in your back pocket as more experienced engineers. So today, we are going to have each group engage with a case that describes the design process of a fixed wing aircraft. This activity is meant to provide you an opportunity to think about how the design process works in industry and also evaluate how stakeholders were or were not considered within each design.”*
- Go over the five slide template and the format of the presentation (Four groups will present – 10 min presentations – those groups will be announced at the start of the next class)
 - Summary
 - Design Process
 - Stakeholder Mapping I & II
 - Evaluation of Case
- Finally, talk for a few minutes about how the teams could go about the process – then ask if there are any questions before finally handing out the cases. Each case will include the five-slide template printed out so they have instructions to guide them as they go through the case.

Case Study Evaluation

Duration: approx. 75 minutes

Go around to the student groups during this time to check in and prompt their thought processes with additional questions (as applicable).

Wrap-Up

Duration: approx. 5 min.

Revisit briefly about what they did today and what they will do next week.

Lab II Agenda

Framing the Class

Duration: approx. 5 minutes

Welcome the students back and remind them what we did last week.

Case Presentations

Duration: approx. 1 hr.

Four groups will each present (1 for each case). They will have 7 to 10 minutes to present and 5 minutes for Q/A with the groups. For each case, one group will present, while the other group will serve as an “expert panel” for the presenting group. The panel will be responsible for asking the first round of questions to the group presenting. To discourage students sitting idly, the expert panel will always sit in the middle of the room. Thus, student groups will be required to get up and move between presentations.

Case Presentations Wrap Up discussion

Duration: approx. 15 minutes

This time slot will either be used as spill over in case some Q&A sessions go long – or as a chance for me to tie everything together from the presentations. *What were the key outcomes, trends, etc.?*

Can We Integrate Human-Centered Design Processes in Aircraft Design?

Duration: 45 minutes

The purpose of this section is to introduce students to other methods for incorporating stakeholders into the design process. For the first part of class, students will be sitting while their colleagues presented. Even though there will be a fair amount of engagement (e.g. students asking other students questions and students moving around the room to be the “expert panel” for each presentation), rather than having students listen to me discuss the different methods, students will work with two of the methods in their groups.

First, discuss stakeholder mapping as it is used for social sustainability, introducing ideas such as a power/interest matrix and providing an example a design which used this method. Then I will distribute two of the following methods to each of the groups:

- Human-Centered Design in Service Learning/Product Design
- Value Driven Design as used in Aerospace Engineering
- Context Sensitive Design in Civil and Environmental Engineering
- Participatory Design in Product Design

Each method will be explained briefly, using text and images on one sheet of paper, and an example of the method being used will be included on a second sheet of paper. [10 minutes]

On the board, five columns will be written, one for each of the four methods and one for stakeholder mapping. Students will be given post-its and asked to answer the following for each method:

- 1) What are the merits and disadvantages to the method?

2) How could this method be utilized for aircraft design?

The students will write the merits (in red) and the disadvantages (in black) on the post-its and then they will put the post-its up on the dry erase board under the appropriate column. [15 minutes]

After 15 minutes with this, groups will be asked to briefly present each of the methods – it's merits and it's disadvantageous. Then students will then be asked to vote (via post it) on which method they would advise using if they were the program manager for an aircraft design. I will call on a couple of students to tell me their reasoning behind their vote. [20 minutes]

Final Design Process Negotiation

Duration: 20 minutes

Now give the students about 20 minutes to think about these methods, the cases, and the stakeholder mappings we have already discussed and to modify their design process to incorporate where they would explicitly take into account the stakeholder considerations in their design process. When introducing this activity, remind the students that *the idea is for them to have a design process they can use as a road map for their projects in the spring*. So they need to think about what they learned when completing the case study and during the discussions in these two labs.

If time, have two groups present their design process (so every group presents once).

Conclusions

Duration: 25 minutes

Students will be asked to complete evaluation #2 and the student feedback form. Provide some closing remarks and thank them for their time the last two weeks. Also let them know the design process drawings will be collected and copies will be made available for each group the following week.

E.2 Reference Presentation for Students

The slides are included on the next 22 pages.

Aircraft Design I

Stakeholders in Design Labs

Documenting the Design Process

Design Activities

Abstracting	Identifying Constraints	Seeking Information
Brainstorming	Imagining	Sketching
Building	Iterating	Synthesizing
Communicating	Making Decisions	Testing
Decomposing	Making Trade-Offs	Understanding the Problem
Evaluating	Modeling	Using Creativity
Generating Alternatives	Planning	Visualizing
Goal setting	Prototyping	

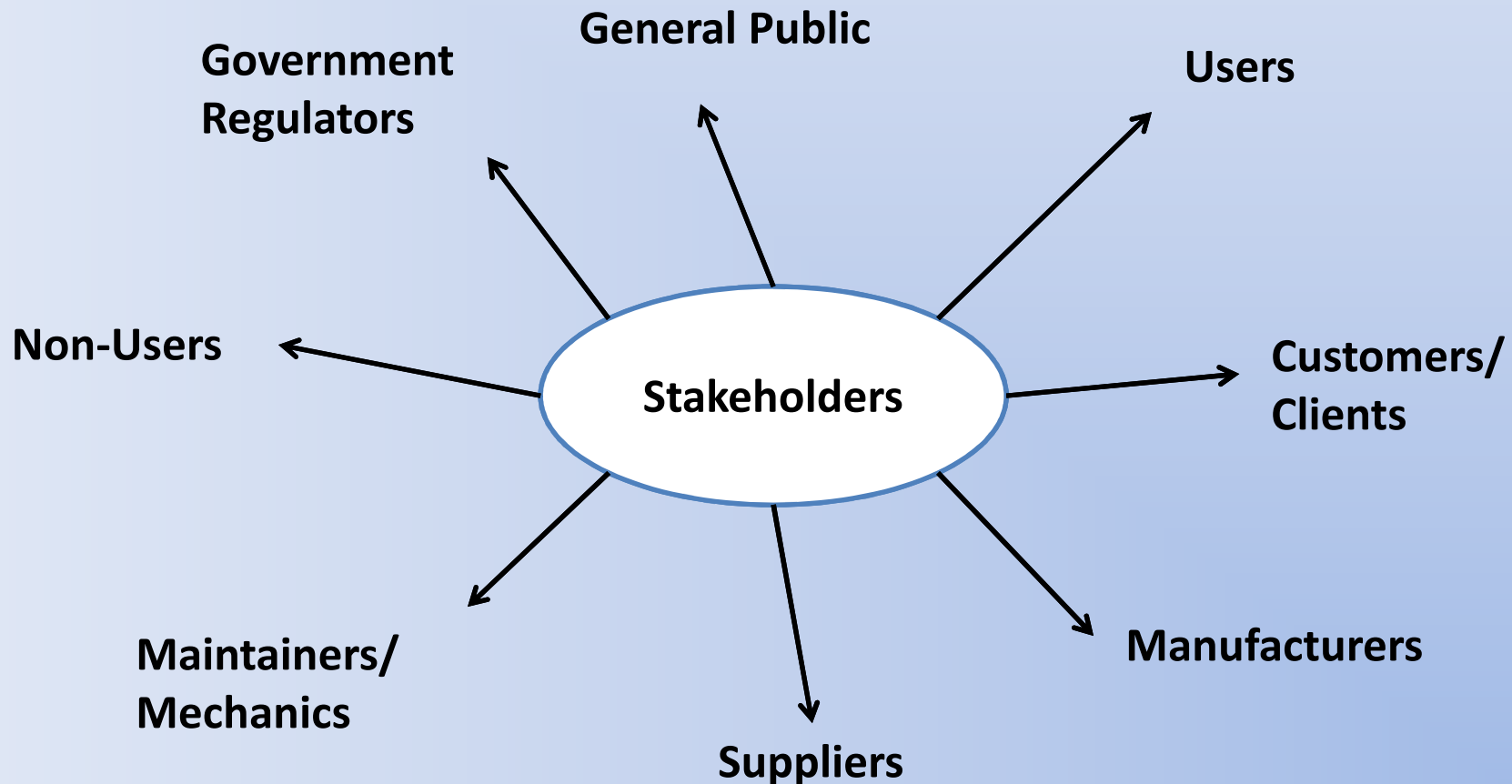
Think about the process you have been following in this course so far, use the activities above to describe the different steps in that process.

Provide explicit examples where possible: *if you write **GENERATING ALTERNATIVES** as step 3 – add, for example, **Search on NACA for different airfoil design alternatives.***

Feel free to draw, write, and use the sticky notes to describe the design process on the piece of paper distributed.

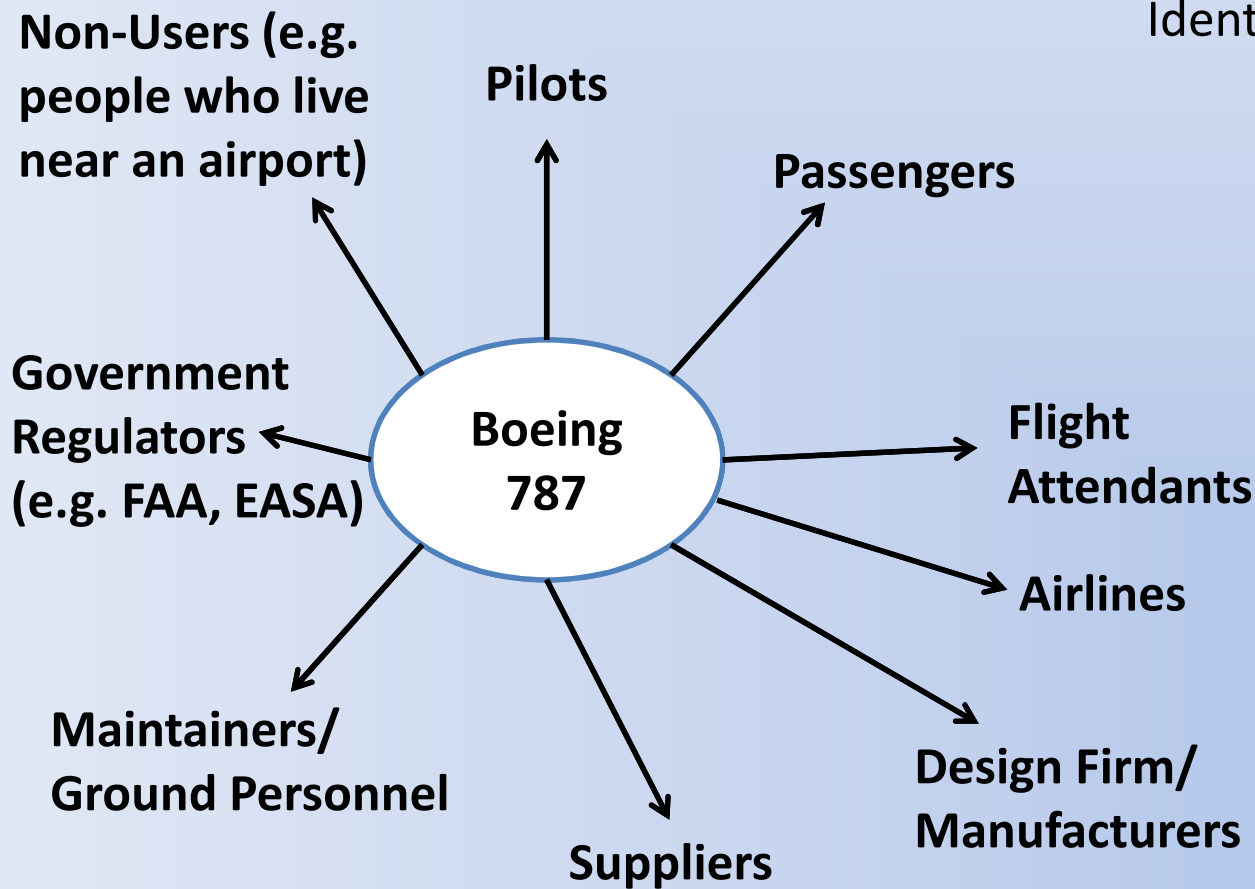
Stakeholder Mapping

“Stakeholders are all those affected by the system. They may be users or non-users. They need not be clients or decision-makers. Stakeholders may be major or minor, and the ways in which they interact with a large-scale system are myriad.” (Gibson et al., 2007, p.315)



Stakeholder Mapping

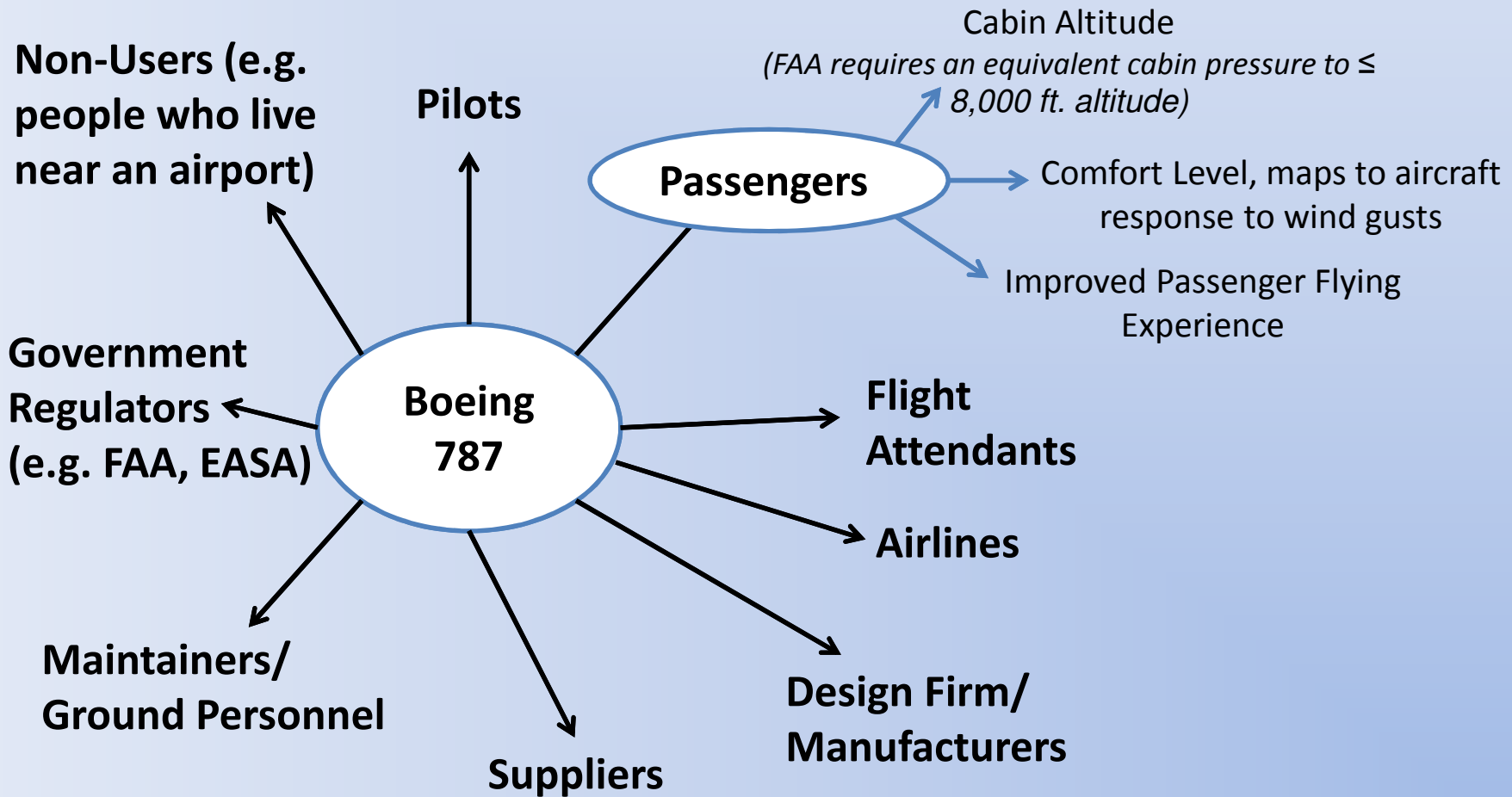
Step 1:
Identify and Categorize the Stakeholders



Stakeholder Mapping

Step 2:

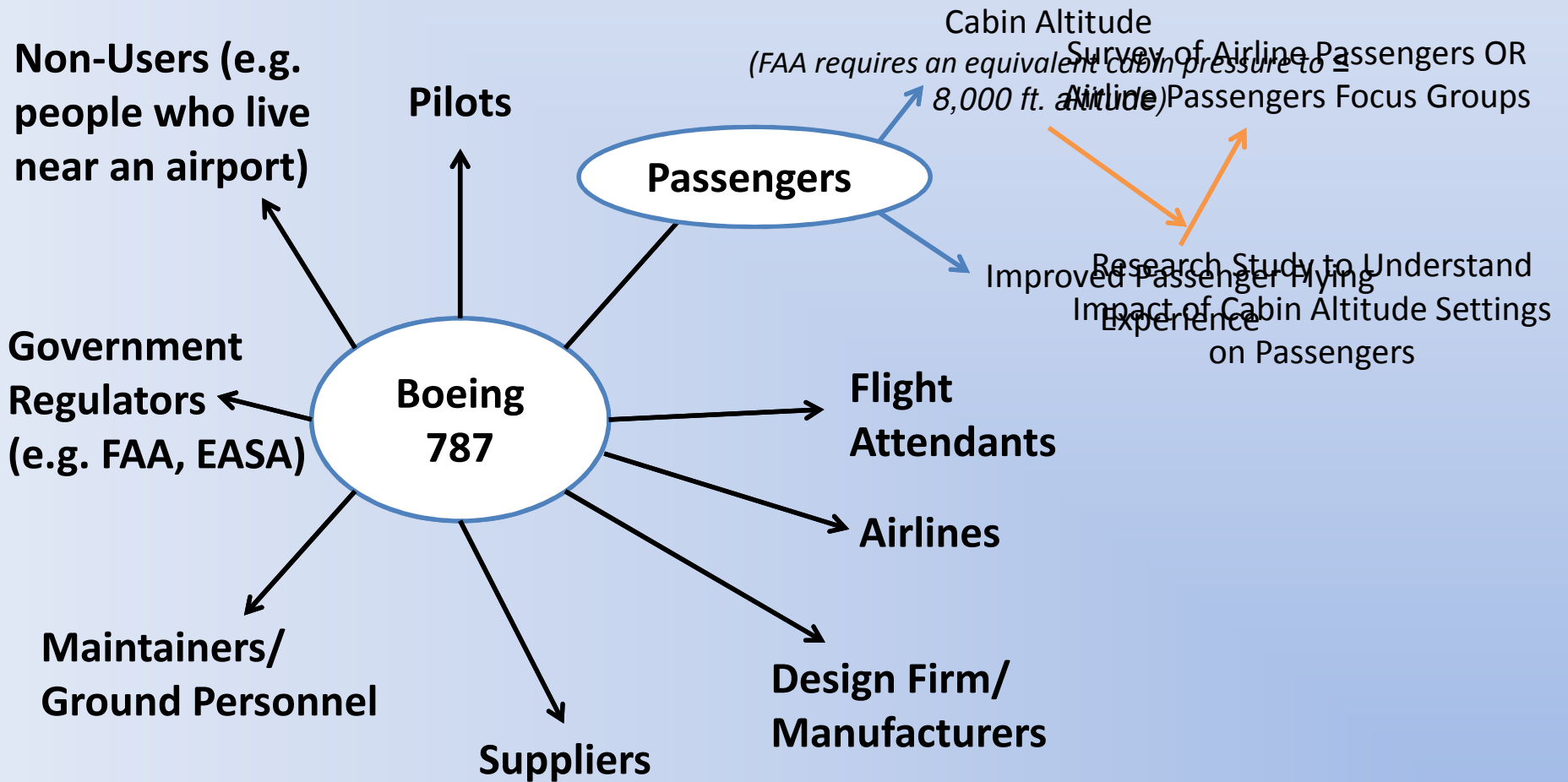
Map to Design Requirements



Stakeholder Mapping

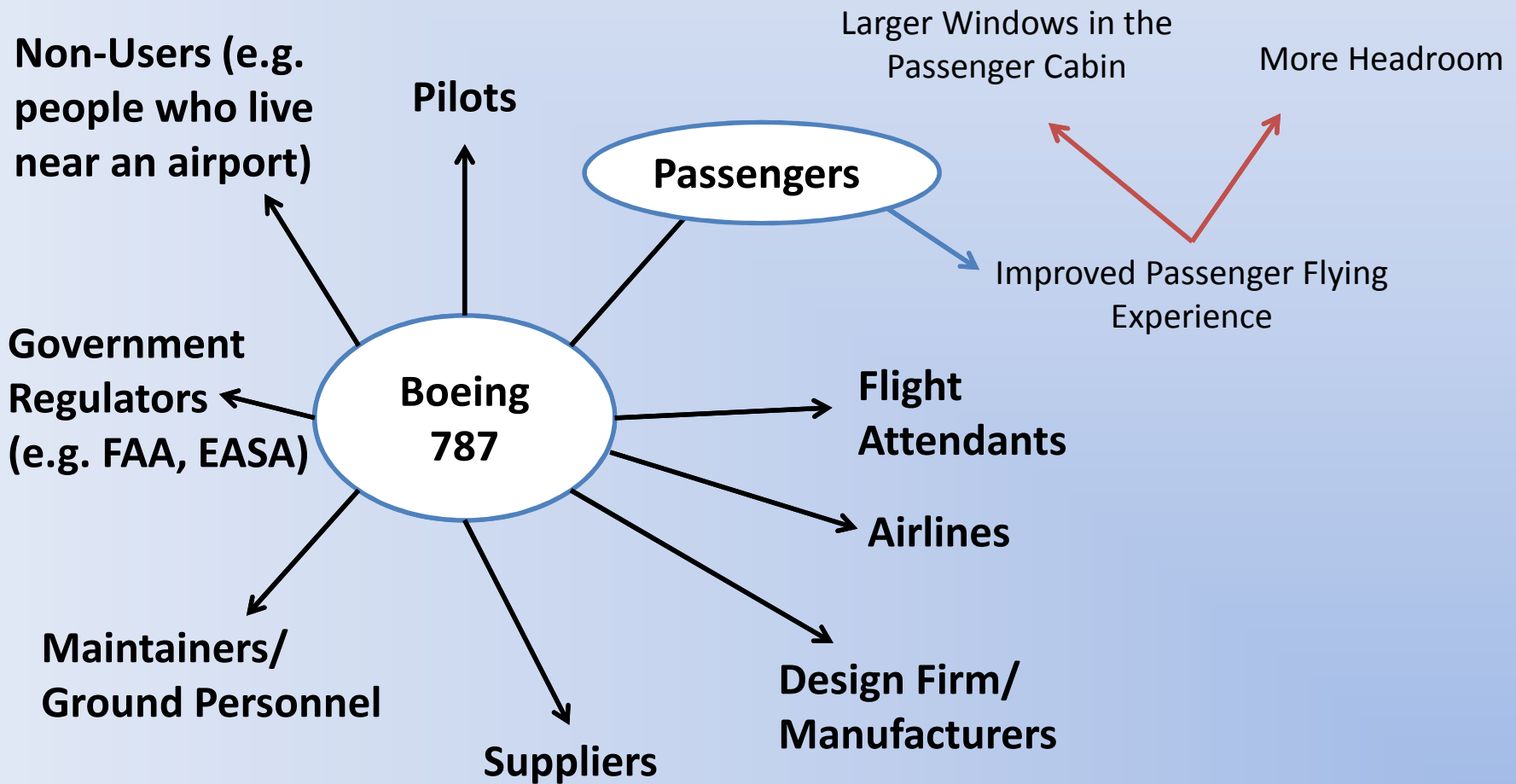
Step 3:

Determine How to Gather Information about Stakeholder Preferences and Needs



Stakeholder Mapping

Step 4:
Define Impacts of Stakeholders on
Design Solution



Stakeholder Mapping Process

Step 1:
Identify and
Categorize
Stakeholders

Step 2: Map to
Design
Requirements

Step 3:
Determine
How to Gather
Necessary
Information

Step 4: Define
Impact of
Stakeholders
on Design
Solution

One more example...



AIAA 2011-2012 Undergraduate Aircraft Design Competition

There is a need for an affordable, **humanitarian response aircraft system** that can provide **aid to the populations of both developed and under-developed nations** worldwide when natural disasters occur. Assisting those affected by earthquakes, tsunamis, hurricanes, etc. requires immediacy but these calamities can also cause logistical challenges that can hamper the response effort. Precision, unmanned resupply could help alleviate some of these challenges. 'Precision' would permit the **delivery of critical supplies to remote, discontinuous areas** where terrain and environment have limited the access of current assets, such as Chile or Haiti in 2010. Use of an **'Unmanned' vehicle** could reduce the potential for casualties and also allow for humanitarian assistance in areas that may be politically sensitive.

http://www.boston.com/bigpicture/2010/02/earthquake_in_chile.html#photo4

Required System Capabilities

Able to operate on short landing areas	<ul style="list-style-type: none"> • Takeoff and Land in ≤ 500 ft ground roll (at sea level standard day conditions)
Autonomous Flight during day or night	<ul style="list-style-type: none"> • Capable of autonomous flight using GPS (including waypoint navigation and in flight waypoint, speed and altitude changes) • Terminal area operations (taxi, warm-up, takeoff, landing, climb & descent) can be autonomous but the option for pilot-in-the-loop control via a ground station must be available • Ground station equipment necessary for autonomous control, handoff and manual control must weigh ≤ 50 lbs and be backpack transportable by a person • You are not required to design a mission control system (air vehicle avionics, ground station, antennas, computer equipment) for the vehicle. All equipment would be acquired "off the shelf." The air vehicle must allocate weight and volume for the selected air vehicle avionics.
Payload Carriage & Useful Load of Military Utility	<ul style="list-style-type: none"> • Useful Load (total payload + useable fuel) $\geq 3,000$ lb • The air vehicle must have an available cargo volume to allow the carriage of two 36 in. x 36 in. pallets loaded 42 in. high (including pallet height) • Payload should be able to be easily loaded and unloaded by personnel at a remote resupply area • Cargo handling system should facilitate cargo unloading/loading times of 30 minutes
Speed and Altitude of Military Utility	<ul style="list-style-type: none"> • Cruise Speed ≥ 140 knots, true airspeed • Service Ceiling $\geq 15,000$ ft MSL
Payload / Range Mission Performance	<ul style="list-style-type: none"> • Transport 1,800 lb to 300 nm and return 300 nm (unrefueled) with 1,800 lb payload retained
Affordable & Supportable	<ul style="list-style-type: none"> • Off the shelf components, especially engines and mission control system, can be utilized in the design to reduce overall development and acquisition cost • The air vehicle must allow for ease of operation, repair, maintenance, and support in the field
Transportable	<ul style="list-style-type: none"> • In a shipping configuration, the entire unmanned cargo vehicle must fit completely within the cargo bay of a C-130J-30 (10 ft W x 9 ft H x 55 L) and be easy to assemble to a flying configuration

Stakeholder Mapping

Step 1:
Identify and Categorize the Stakeholders

Non-Users (e.g. people who need the humanitarian aide)

Pilots at Ground Station

Customer

Government Regulators (e.g. FAA, EASA)

UAV

Ground Payload Personnel

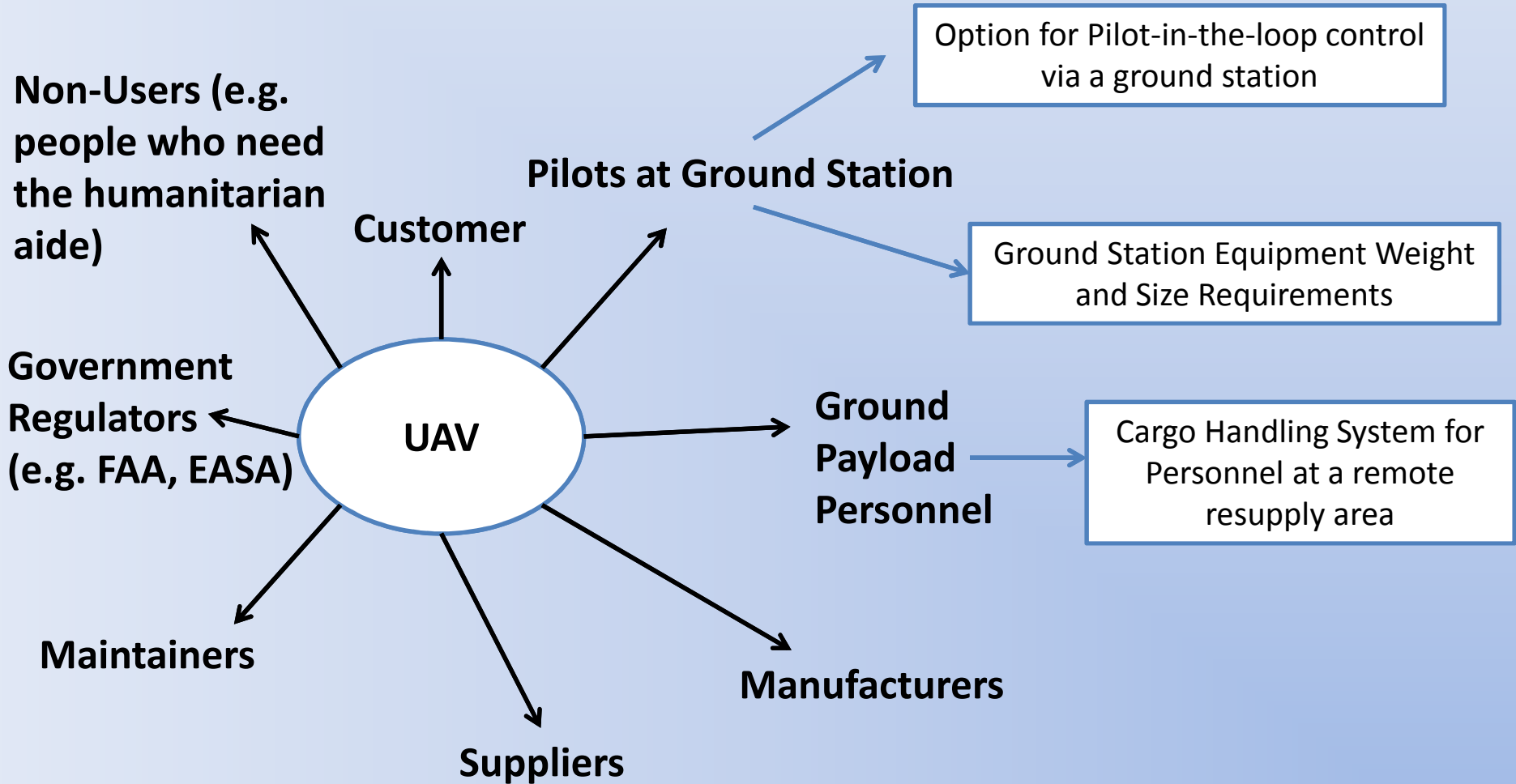
Maintainers

Manufacturers

Suppliers

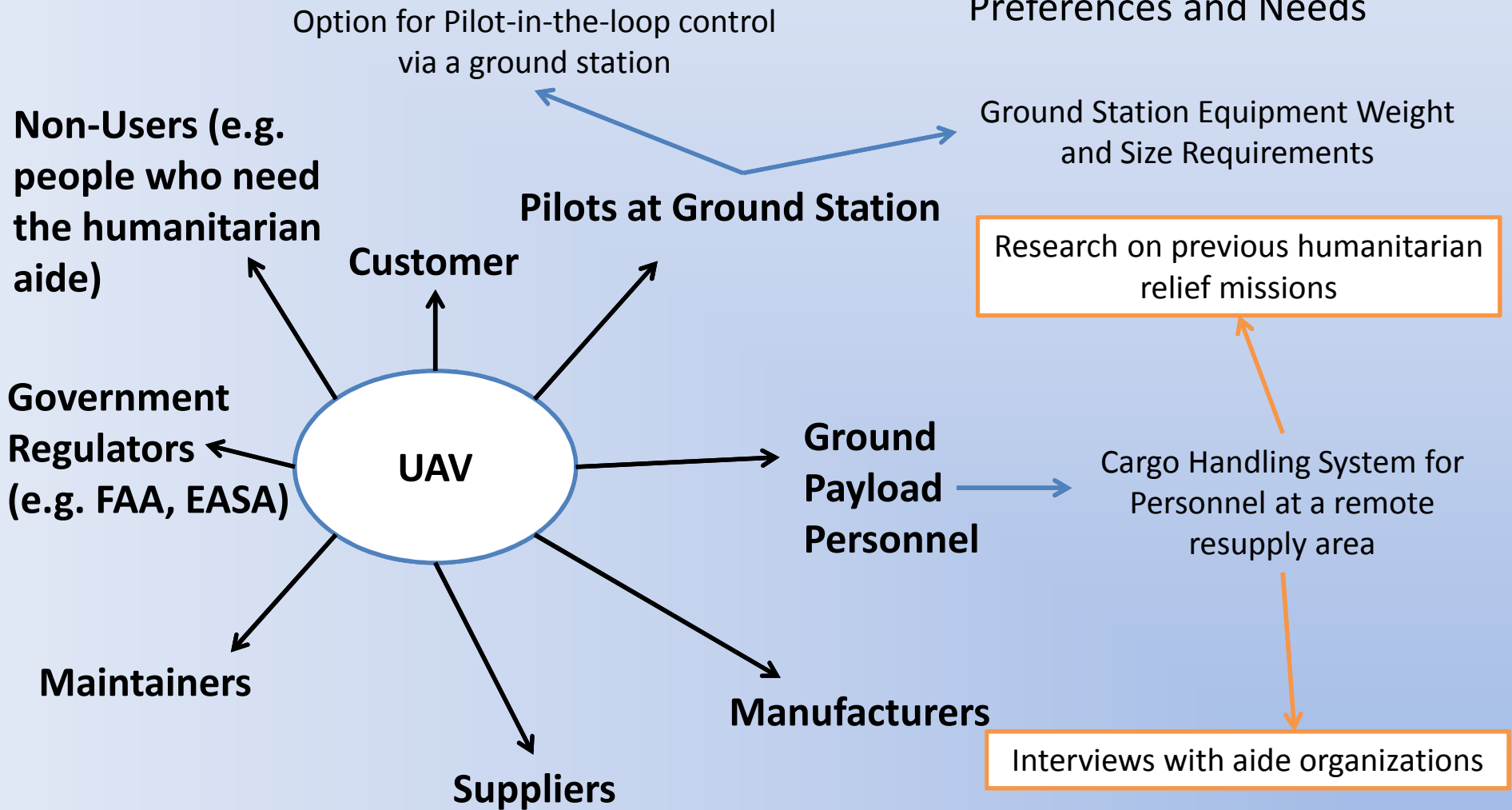
Stakeholder Mapping

Step 2:
Map to Design Requirements



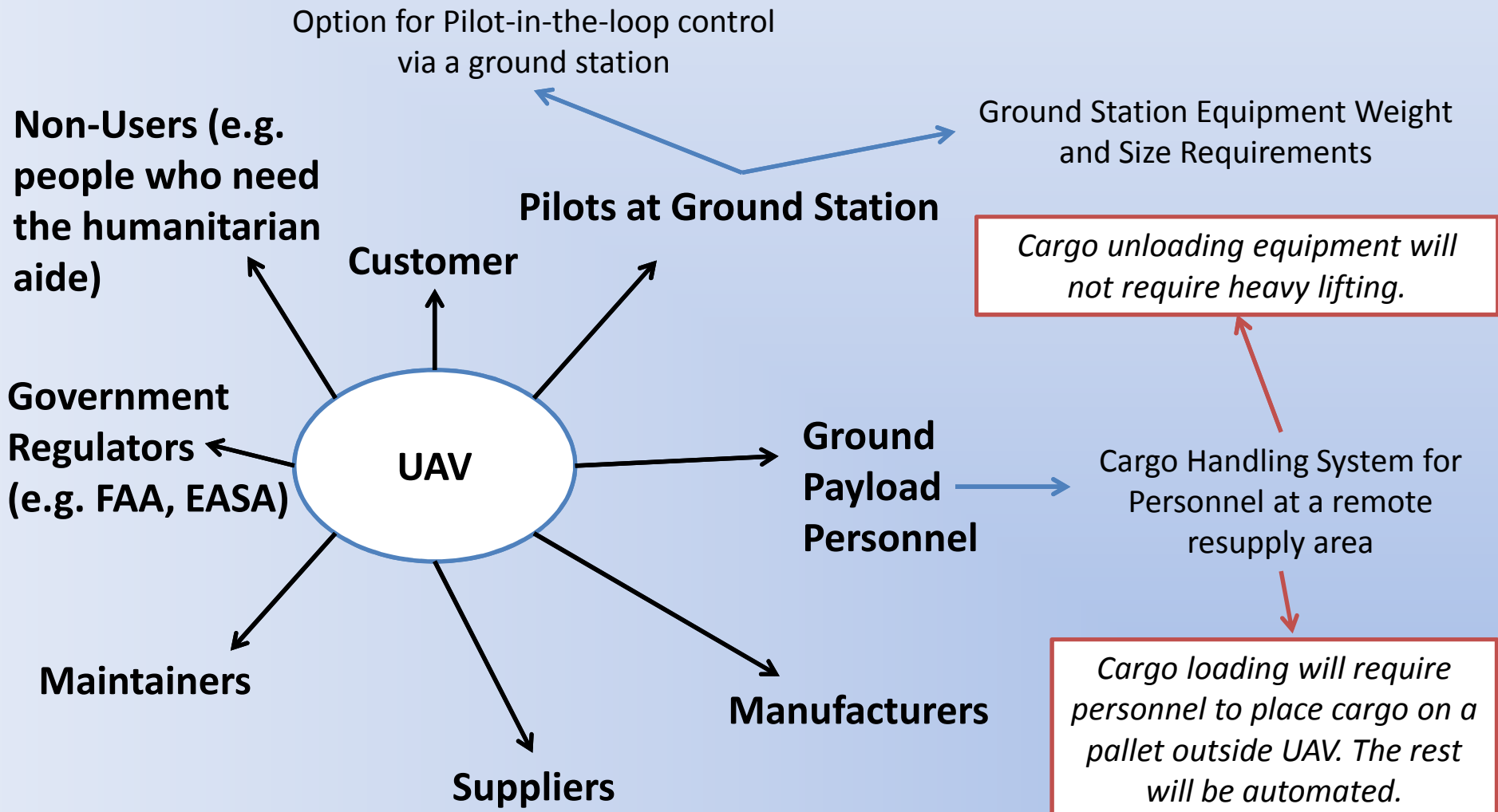
Stakeholder Mapping

Step 3:
Determine How to Gather Information about Stakeholder Preferences and Needs



Stakeholder Mapping

Step 4:
Define Impacts of Stakeholders
on Design Solution



Case Study Activity Overview

TODAY:

- + Collaborative Case Study Activity
- + Each group will receive a case, which will contain
 - An introduction to serve as a guide for reading through the case
 - Supporting documents
- + Goal of session today is to read through case and begin evaluating the design process for the aircraft and the considerations made by the designers in regards to stakeholders

NEXT WEEK:

- + Case Presentations
 - Use case presentation templates that are posted on Tsquare
 - Submit the presentation prior to lab next Monday
 - Groups will be asked to present their analysis and evaluation of the case (*Presentations will last about 7 to 10 minutes*)

Case Study Presentation Template

Date

Aircraft Design I

Team Member Names

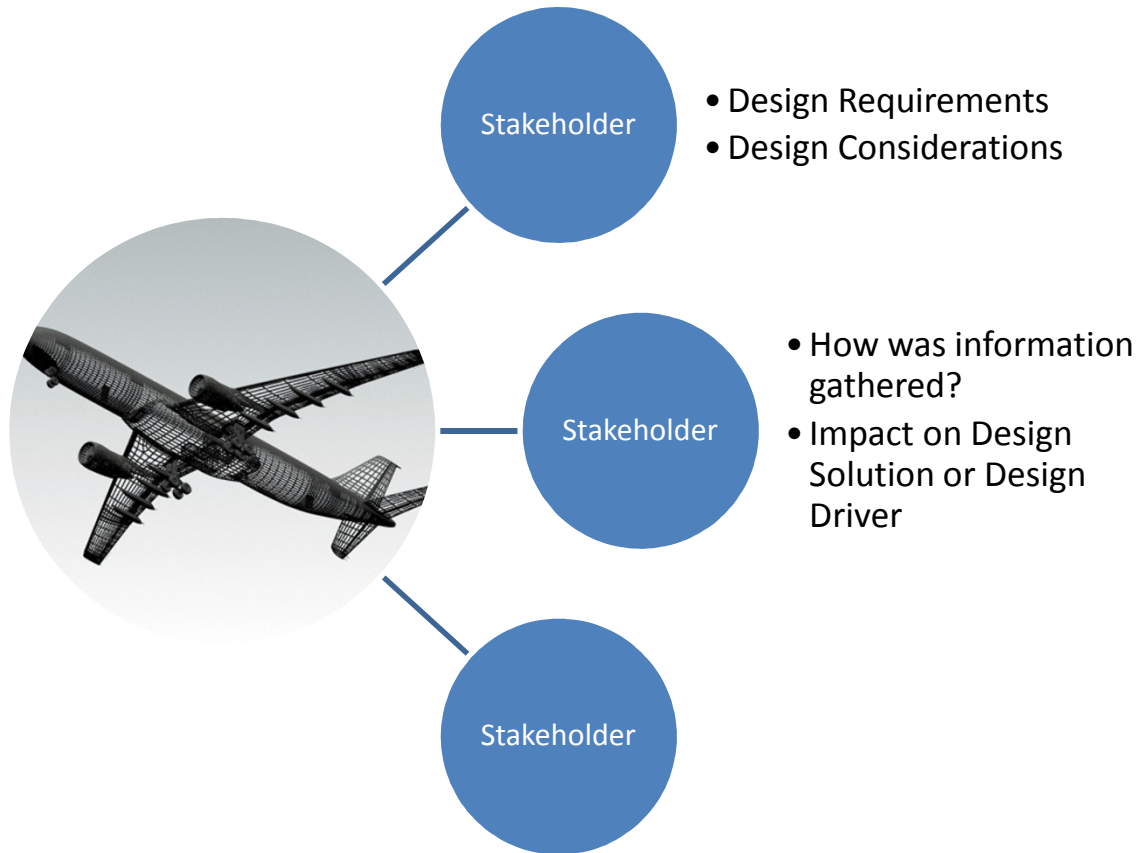
Summary of the Case

- **What aircraft was designed?**
- **When?**
- **What were some special features of the design?**
- **What other components of the design or the case do you think make this case/design unique?**

Design Process

- Scan a drawing of the design process your group drew for this case OR
- Create one in PowerPoint
- **Discuss:** How is your group's design process different from theirs? Why?

Stakeholder Mapping



- Include a stakeholder mapping for this case (again feel free to hand draw and scan it or use ppt tools)

Evaluation of the Stakeholder Mapping

- Was the mapping complete?
- Did your group feel that any stakeholders were missing? If so, who?
- What about design requirements?
- Would your group have done anything differently in regards to stakeholder considerations?

Evaluation of the Case

- **Rate the case and justify your rating:**
 - **Design Process** (Poor, Acceptable, or Excellent)
 - **Ability to take into account stakeholder requirements** (Poor, Acceptable, or Excellent)

Case Studies

Gulfstream III

Boeing 747

B-2

F-111

E.3 Reflection Questions

E.3.1 Pre-Lab Reflections

DIRECTIONS: Please answer all of the following questions by reflecting on your experiences in this aircraft design course and your previous design experiences. There are no right or wrong answers to these questions.

1. What has been most difficult part about the fixed wing aircraft design process so far?

2. Considering your most recent design project, to what extent did you consider the safety and overall satisfaction of the pilots in your design? Why or why not?

E.3.2 Post-Lab Reflections

DIRECTIONS: Please answer all of the following questions by reflecting on your experiences in this aircraft design course and your previous design experiences. There are no right or wrong answers to these questions.

1. What was the most surprising part about what you learned in these lab sessions the past two weeks?
2. What was the most difficult part about the lab sessions the past two weeks?
3. Considering your design project for the spring semester, do you believe that you and your teammates will be able to take into consideration the effect of your design on the safety and overall satisfaction of the stakeholders? Why or why not?

E.3.3 Student Feedback Form

1. In your opinion, what was the purpose of this lab session?
2. What is the most important feedback you want the instructor to hear about today's lab?
3. On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from **the requirements lab session (presented in August)** are to your senior design project for this upcoming spring semester?
4. On a scale from 1 (least relevant) to 10 (most relevant), how relevant do you believe the topics from **the lab sessions from these last two weeks** are to your senior design project for this upcoming spring semester?

E.4 Case Study Example Introduction Forms

E.4.1 B-2

This case study presents detailed information about different components of the B-2¹. The authors performed numerous interviews with those individuals involved in the design process in order to construct this case study, including system engineers, program managers, a structures engineer and a flight control manager. This packet contains four supporting documents:

- **SYSTEM DESCRIPTION**
- **CONCEPT EXPLORATION**
- **CONTRACT AWARD**
- **FULL SCALE ENGINEERING DEVELOPMENT**

It is recommended that every student in your group reads through the System Description. The remaining documents can be split up among everyone in the group to provide for more in-class time to work on the case. (NOTE: You are only required to read through Section 3.3.3 – Programmatic Decisions – the remaining sections are included in the case that you are interested in reading about the final design reviews and flight test.)

When reading through the different documents, keep track of

- the various design activities discussed by the authors (*If you could map out a design process, which reflects their work on the B-2, what would it look like?*)
- the stakeholders impacted by the design solution (*What requirements were impacted by the stakeholders? How did the engineers and designers gather information about the various stakeholders?*)

For the presentation, your group will be asked to provide

- A Case Summary, (e.g. *Important details about the B-2, when it was designed, and why*)
- A Design Process ,
- A Stakeholder Mapping,
- An Evaluation of the Stakeholder Mapping, and
- An Evaluation of the Case.

¹Griffin, J.M. and Kinnu, J.E. (2005) “B-2 Systems Engineering Case Study.” Air Force Center for Systems Engineering.

E.4.2 Boeing 747

This case study presents detailed information about different components of the Boeing Model 747 designs from the perspectives of design engineers, propulsion research specialists, product development engineers, and a pilot. This packet contains five supporting documents¹⁻⁵:

- **BOEING MODEL 747 OVERVIEW**
- **FACTORS INFLUENCING NACELLE DESIGN ON 747**
- **PERFORMANCE AND ECONOMIC DESIGN ASPECTS OF THE 747 FAMILY OF AIRPLANES**
- **FLYING THE 747**
- **AIRPORT REQUIREMENTS**

It is recommended that every student in your group reads through the Boeing Model 747 Overview. The remaining documents can be split up among everyone in the group to provide for more in-class time to work on the case.

When reading through the different documents, keep track of

- the various design activities discussed by the authors (*If you could map out a design process, which reflects their work on the 747, what would it look like?*)
- the stakeholders impacted by the design solution (*What requirements were impacted by the stakeholders? How did the engineers and designers gather information about the various stakeholders?*)

For the presentation, your group will be asked to provide

- A Case Summary, (e.g. *Important details about the 747, when it was designed, and why*)
- A Design Process ,
- A Stakeholder Mapping,
- An Evaluation of the Stakeholder Mapping, and
- An Evaluation of the Case.

¹Sutter, J.F. and Anderson, C.H. (1967) "Boeing Model 747." *Journal of Aircraft*. 4 (5). p. 452-456

²MacKinnon, M.I.K. and Mehta, B.K. (1979) "Factors Influencing Nacelle Design on 747." *Proceedings of the AIAA/SAE/ASME 15th Joint Propulsion Conference*. Las Vegas, NV.

³Olason, M.L. (1969) "Performance and Economic Design Aspects of the 747 Family of Airplanes." *Journal of Aircraft*. 6(6). p. 520–524

⁴Waddell, J. (1967) "Flying the 747." *Proceedings of the AIAA Commercial Aircraft Design and Operation Meeting*. Los Angeles, CA.

⁵Horan, J.F. (1967) "Model 747 Airport Requirements." *Proceedings of the AIAA Commercial Aircraft Design and Operation Meeting*. Los Angeles, CA.

E.4.3 F-111

This case study presents detailed information about different components of the F-111. The authors developed this case using the General Dynamics F-111 History¹. This packet contains six supporting documents:

- **SYSTEM DESCRIPTION**
- **REQUIREMENTS DEFINITION AND MANAGEMENT**
- **SYSTEMS ARCHITECTURE AND DESIGN TRADE-OFFS**
- **COMMUNICATIONS AND SYSTEMS MANAGEMENT**
- **VALIDATION AND VERIFICATION**
- **PROGRAM MANAGEMENT**

It is recommended that every student in your group reads through the System Description. The remaining documents can be split up among everyone in the group to provide for more in-class time to work on the case.

When reading through the different documents, keep track of

- the various design activities discussed by the authors (*If you could map out a design process, which reflects their work on the F-111, what would it look like?*)
- the stakeholders impacted by the design solution (*What requirements were impacted by the stakeholders? How did the engineers and designers gather information about the various stakeholders?*)

For the presentation, your group will be asked to provide

- A Case Summary, (e.g. *Important details about the F-111, when it was designed, and why*)
- A Design Process ,
- A Stakeholder Mapping,
- An Evaluation of the Stakeholder Mapping, and
- An Evaluation of the Case.

¹Richey, G.K. (2005) "F-111 Systems Engineering Case Study." Center for Systems Engineering. Air Force Institute of Technology.

E.4.4 Gulfstream III

This case study presents detailed information about different components of the Gulfstream III Executive Jet design from the perspectives of Vice-Presidents of aerospace corporations, who worked as project engineers for Gulfstream aircraft, and the engineering manager of the Gulfstream III¹. This packet contains three major sections:

- **GULFSTREAM III REQUIREMENTS**
- **EARLY DEVELOPMENT INFORMATION (ENDS ON PAGE 8)**
- **FIRST CONCEPTUAL DESIGN DEFINITION SUMMARIES (PAGES 8, 15, 29 – 32)**
- **CONCEPTUAL RE-DESIGN (AKA “THE NEXT AND FINAL STEP”)**

It is recommended that every student in your group reads through the Gulfstream III requirements. The remaining documents can be split up among everyone in the group to provide for more in-class time to work on the case. Supplemental pages were added to this case to help keep the story coherent, if you have questions please talk to the instructor.

When reading through the different documents, keep track of

- the various design activities discussed by the authors (*If you could map out a design process, which reflects their work on the Gulfstream III, what would it look like?*)
- the stakeholders impacted by the design solution (*What requirements were impacted by the stakeholders? How did the engineers and designers gather information about the various stakeholders?*)

For the presentation, your group will be asked to provide

- A Case Summary, (e.g. *Important details about Gulfstream III, when it was designed, and why*)
- A Design Process ,
- A Stakeholder Mapping,
- An Evaluation of the Stakeholder Mapping, and
- An Evaluation of the Case.

¹Mead, L.M., Coppi, C., and Strakosch, J. (1993). *The Grumman Aerospace and Gulfstream American Gulfstream III Case Study in Aircraft Design*. AIAA Professional Study Series.

E.5 Human-Centered Design Methods

E.5.1 Context Sensitive Design

Core Concept: Context Sensitive Design is a collaborative, interdisciplinary approach that involves all stakeholders in the development of a solution that fits in the physical setting, preserves environmental resources, and maintains safety as a key design requirement.

Context Sensitive Design (CSD) is an approach to design commonly used in the design of transportation improvements, whether road design or the design of other transportation facilities. These types of design solutions need to be integrated with the local environment and be consistent with the needs of the local communities. The key elements of CSD are (1) Purpose and need, (2) Environment, (3) Public participation, (4) Safety and mobility, and (5) Characteristics of transportation.

The process of applying CSD to a design project includes

- Identifying an interdisciplinary design team
- Evaluating and analyzing the context that might be affected by the project, including cultural, historic, economic, social, and environmental contexts
- Synthesizing information and articulating a statement about the context, which defines the needs of the design solution
- Developing design alternatives and discussing potential project impacts, through consultation with stakeholders
- Displaying and communicating proposals and ideas
- Evaluating design strategies, including funding, regulatory and environmental considerations and community feedback.
- Evaluating the CSD process and outcomes

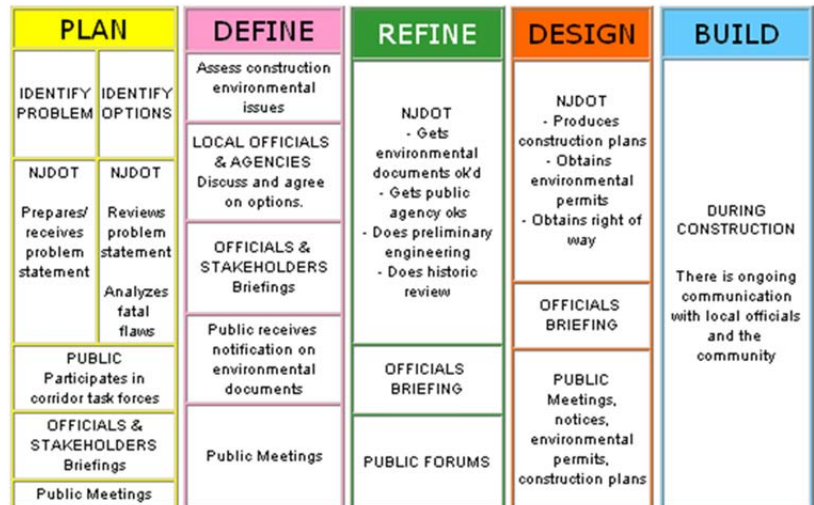


Figure 41: New Jersey Department of Transportation CSD Process

References:

- *Dondi, G., Simone, A., Lantieri, C., and Vignali, V. (2011) Bike Lane Design: The Context Sensitive Approach. Proceedings of the 2011 International Conference on Green Buildings and Sustainable Cities.
- *<http://www.state.nj.us/transportation/eng/CSD/chart.shtm>

CONTEXT SENSITIVE DESIGN EXAMPLE (ADAPTED FROM ITE CASE STUDY)

Overview: After the relocation and reconstruction of the I-30/35 interchange and a section of I-30 along Lancaster Avenue, the city of Fort Worth, Texas decided to pursue the redesign of Lancaster Avenue to encourage and accommodate the historic preservation of specific buildings and the avenue's redevelopment.

Design team: A steering committee was established consisting of agency and private stakeholders for the Lancaster Avenue Corridor. The steering committee was responsible for developing a common vision and project objectives for the project. For the TxDOT, the primary objective was to improve mobility. However, other stakeholders wanted to make Lancaster Avenue a walkable, pedestrian-friendly area to attract perspective investors. Thus, the steering committee held a three-day workshop to discuss needs, issues, and concerns. The workshop resulted in a strong consensus for the project's vision and objectives:

- (1) Create a great pedestrian street,
- (2) Promote mixed-use development,
- (3) Create a link between the medical district and the south side of the downtown, and
- (4) Create a showcase area for existing historical buildings.

Design Alternatives A separate design team generated various alternatives, balancing the needs of the

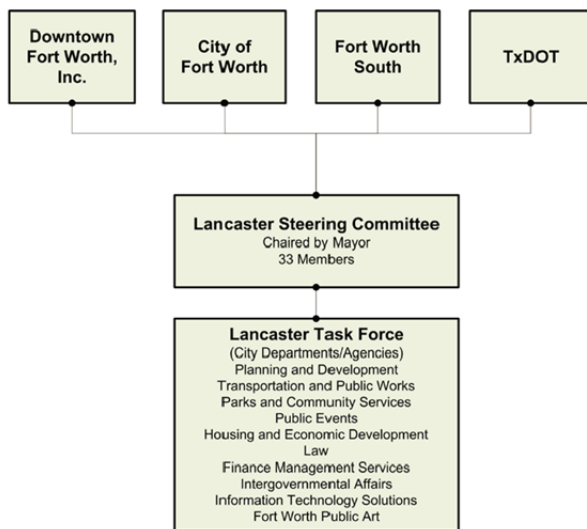


Figure 6. Lancaster Avenue Redevelopment Stakeholder Groups.

stakeholders (e.g. the desire to maintain historic preservations) with the projected traffic volumes for the area. The design alternatives were discussing with the steering committee and a preferred design was selected.



Figure 7. Initial design concept alternative with U.S. Post Office on left, T&P Warehouse in left background, and new buildings on abandoned right of way on the right. Source: City of Fort Worth.

CSD Principles used on the project:

- Extensive and real stakeholder collaboration
- Collaborative effort to establish broad range of objectives and vision, issues and needs
- A broad range of alternatives were considered and comprehensively evaluated
- Design flexibility and innovation aimed at meeting project objectives
- Design of a people-oriented environment
- Consideration of redevelopment of historic buildings and environmental impact of project

REFERENCES: Case Study: Reconstruction and the Redevelopment of the Lancaster Avenue Corridor in Fort Worth Texas. Institute of Transportation Engineers. (2012) www.ite.org/css

E.5.2 Human-Centered Design

Core Concept: A human-centered design approach brings the concerns of the stakeholder to the forefront and emphasizes interactions between stakeholders and designers throughout the design process.

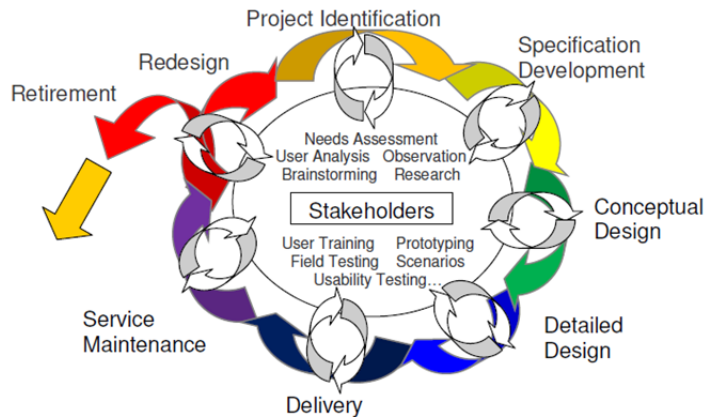


Figure 1. Human-Centered Design Process

The design approach included in Figure 1 was developed by the EPICS Service Learning Program at Purdue University. It is defined by its developers as a design heuristic which can be used to guide students and design engineers through the process. Each cycle the design process involves the stakeholders in the development of the solution.

Example design activities in the different phases include:

Project Identification: Conduct needs assessment, Identify stakeholders, Develop basic stakeholder requirements

Specification Development: Describe context of design, Create stakeholder profiles, Create simple prototypes, Develop customer specifications

Conceptual Design: Conduct functional decomposition, Brainstorm solutions, Create prototypes, Evaluate feasibility of potential solutions

Human-centered design processes incorporate methods for understanding the consumer's experiences and rapid prototyping, while also taking into account the operational environment of a design. These methods are used within product development and the human-computer interaction community.

REFERENCES:

- Zoltowski, C., Oakes, W., and Chenoweth, S., (2010). Teaching Human-Centered Design with Service Learning. Proceedings of the American Society for Engineering Education 2010 Annual Conference and Exposition. Louisville, KY.

HUMAN-CENTERED DESIGN EXAMPLE (ADAPTED FROM ZOLTOWSKI, ET AL. 2010)

Problem Statement: An example of human-centered design is the design and development of a Soap-box Derby car that can be used to provide children with disabilities the opportunity to participate in a derby-like experience of “racing” down a hill. Local Soap-box Derby representatives approached EPICS with the need to develop a two-seat car where children with disabilities could ride along with a driver. Currently, dual seat cars exist in two models: (1) Permits the children with a disability to steer the car, while the other driver also can affect the steering and (2) Does not have a working steering system for the children with disabilities. Instead, this model has a steering wheel the children can turn but isn’t connected to the car’s wheels. The design team will also need to take into account cost, as the representatives from the Soap-Box Derby want to be able to replicate the design across the country.

Problem Identification: To gain insight into the car’s design, the team volunteered to be part of a day-long race for children with disabilities on a track in Indianapolis. This race used cars that were adapted from smaller racing cars. They had two seats with the drivers in the rear and a steering system that had a 1:1 gear ratio between the drivers and the children in the front. This experience allowed students to gain insight about how the cars were towed up the hill as well as how they were released from the starting block. The students also saw the potential dangers of current steering systems when an older student overpowered the driver and rammed the car adjacent to him.



Figure 2 Current Soap-box Derby Cars

design also allowed for easier access in and out of the cars. When their prototype was taken to the race in Indianapolis, a few families who could not get their children into the standard race car designs came over to the EPICS car and let their children sit in it. The team found that the larger children (e.g. tall teenagers) could not fit into the modified smaller race cars. Also, for children with severe disabilities that limited their mobility, the smaller cars did not allow parents and volunteers to help them in and out. However, the modified design was more open and allowed more children to participate than previously.

Conceptual Design: As a result of the problem identification and specification development, the student design team developed a steering design that allowed the children to steer from either seat, but also incorporated a slip clutch to insure that the back driver could overpower the front driver if needed. The team looked at the experience of the children and wanted to simulate more of a Soap-box Derby car rather than a motorized race car. The more open



Figure 3 Testing of New Design

Reflection: This design team gave the students a greater understanding of their design constraints and a broader view of the impact their design could have.

E.5.3 Participatory Design

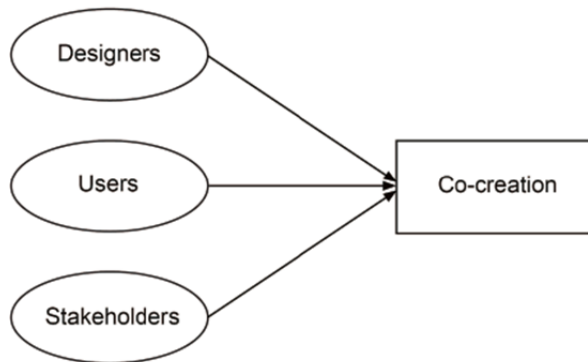
Core Concept: “People who are affected by a decision or an event should have the opportunity to influence it” (Hussain, et al. 2012, p. 1)

This approach to design focuses on the collaboration among users, other stakeholders, and designers during the design process. Participatory design is used in a variety of fields, from product design to organizational development to information technology. Participatory design practitioners have distinct views about design and the design process, specifically

- A system is defined as a network of people, practices, and technology and is situated in a particular organizational context,
- Participants (users and other stakeholders) are seen as experts in “how they live their lives” (Hussain, et al. 2012, p.1), and
- A design emerges from the collaboration among a diverse group of designers and participants.

Origins. “Participatory design was pioneered in Scandinavia. It evolved as a design approach from work beginning in the early 1970s in Norway when computer professionals and union leaders strove to enable workers to have more influence on computer systems in the workplace. Several projects in Scandinavia were aimed at finding effective ways for computer system designers to collaborate with labor organizations to develop systems that most effectively promoted the quality of work life.” (Hussain, et al. 2012, p. 1)

Model for Participatory Design.



The three groups team up to create the design. These groups can be brought together in workshops or design meetings, where problem definition and user needs are discussed.

Figure 1. Traditional model for participatory design.
This figure is based on a general understanding of participatory design often reflected in literature [derived from Figure 3 in (Sanders & Stappers, 2008, p. 11)].

REFERENCES:

- <http://cpsr.org/issues/pd/introInfo/>
- Hussain, S., Sanders, E. B.-N., & Steinert, M. (2012). Participatory design with marginalized people in developing countries: Challenges and opportunities experienced in a field study in Cambodia. *International Journal of Design*, 6(2), 91-109.

PARTICIPATORY DESIGN EXAMPLE (ADAPTED FROM HUSSAIN, ET AL. 2012)

Need: As part of a larger longitudinal project in Cambodia conducted for the International Committee of the Red Cross from 2008 to 2011, this study focused on an identified need for developing devices that enable children with prosthesis to walk in the mud. Cultivation of rice is an essential part of economic life in the area and the fields where rice is cultivated are irrigated. It is not uncommon for children to work in these fields, and as such, for the cases of children with prosthesis, it becomes more difficult to work the fields during the rainy season. This can have a negative impact on the self-esteem of the child and also on the well-being of the family who requires everyone's contribution in the fields.

Design Team: The design team was comprised of a designer, prosthetists (individuals trained by nongovernmental organizations who fit patients with prostheses and other assistive devices), mechanical engineering students, and children who use prosthetic legs. The users and other stakeholders all resided in Cambodia.

Methods: Two workshops comprised of the prosthetists and two mechanical engineering students were organized in Cambodia. The first workshop focused on idea generation through a series of activities, while the second workshop was organized so small groups of the design team members could prototype and then communicate their ideas from the first workshop to the rest of the group. Following this workshop, the designer developed three prototypes based on the other design team members' ideas. The prosthetists and children were asked to then critique the design prototypes and provide additional feedback. With this information the designer was able to draw conclusions about a final conceptual design.

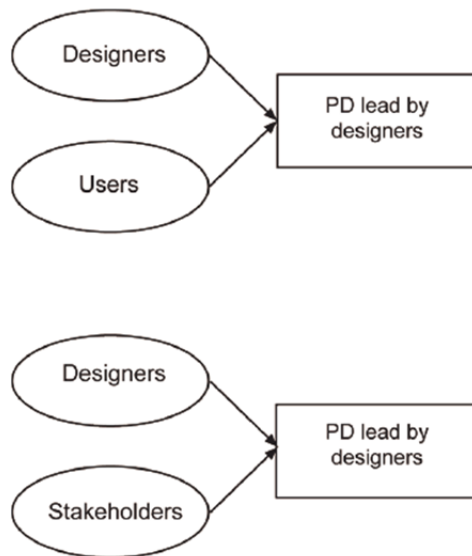


Figure 2. A description of participatory design (PD) based on the experience gained in the field study on marginalized people/children in a developing country.

Design Requirements: Based on the results of the idea generation and follow-up prototyping, the final product design should: (1) be durable, (2) provide friction in slippery mud, (3) not be heavy, (4) not add much to the length of the prosthetic leg, (5) be aesthetically acceptable for the users, and (6) have toes that look natural if the designed solution resumes a foot.



Figure 15. Prototype 1 was inspired by a snowshoe.

E.5.4 Value-Driven Design Approaches

Core Concept: Value driven design uses requirements flexibility, qualitative methods, formal optimization, and/or quantitative mathematical models to balance performance, cost, schedule, and other measures important to the stakeholders to produce the best possible design solution.

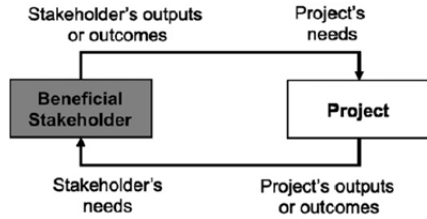


Fig. 3. Exchange of benefit in a simple two stakeholder transaction – the needs of the beneficiary are met by the project, and vice versa.

the delivery of value is represented as an exchange between two actors: (a) a design project and (b) a stakeholder. Benefit is provided to one actor at a cost to the other. If there is a break in an exchange, the value delivery will be disrupted. Thus, it becomes necessary to determine the strength of the various value loops (aka value flows).

2 - Value-Centric Approach: A value-centric approach extends the traditional cost-centric approach by incorporating additional information about the system’s environment and value potential into the down-selection process. The two key metrics for making design decisions with this framework is (1) expected value of the design and (2) value uncertainty. There are three pillars to this approach:

- (1) “An engineering system in general (a spacecraft being one example of such a system) is a value driven artifact. And the **value of the system derives from the flow of service the system delivers over its lifetime to one or multiple stakeholders.**” [emphasis added]
- (2) “...The imperative to create shareholder value entails that any investment in a technical system be guided by its value creation potential or **ability to contribute to shareholder value (not only cost considerations).**” [emphasis added]
- (3) “Unlike cost or performance based metrics, which include only endogenous information about the system, **value includes the most complete information about the system in its environment.**...as such, value allows for better, more transparent, and more relevant trade-offs for the decision-makers in system design and acquisition”. [emphasis added]

References:

- Brathwaite, J. and Saleh, J.H. (2009) Value-centric framework and pareto optimality for design and acquisition of communication satellites. *International Journal of Satellite Communications*.
- Cameron, B.G., Seher, T., and Crawley, E.F. (2010) Goals for space exploration based on stakeholder value network considerations. *Acta Astronautica*.

1 - Stakeholder Network Analysis:

This analysis method works to (1) establish and prioritize the needs based on the importance to a given stakeholder, and (2) establish and prioritize the stakeholders based on the importance of the stakeholder to a larger organization (e.g. a design firm/manufacturer). Through this method, the

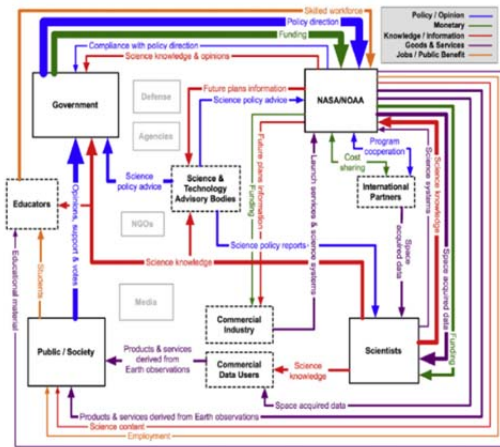


Fig. 5. Simplified stakeholder map showing relative importance of each value flow.

VALUE-CENTRIC APPROACH EXAMPLE (ADAPTED FROM BRATHWAITE & SALEH 2009)

Overview: In this example, the design of commercial communication satellites are assessed using a value-centric framework. Value assessment is a multidisciplinary effort and requires assistance from design configuration groups, along with marketing, finance, and other engineering groups. The value-centric framework for the satellite is displayed in Figure 1. The Design Module generates the set of feasible combinations of technical parameters for the system design, such as payload size. The Cost Module estimates the lifecycle cost and cash outflows of the system. The

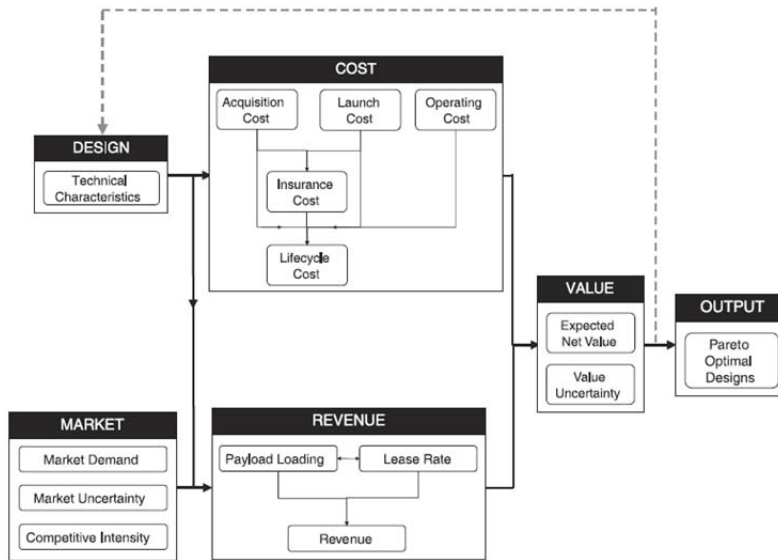


Figure 1. Value-centric framework for commercial communication satellites.

Environment/Market Analysis Module assess the environmental and market conditions for the services of the proposed system. The Revenue Module estimates the revenues per unit time that the system can generate in its proposed environment. The Value Analysis Module integrates inputs from the Cost and Revenue modules and calculates the next present value and value uncertainty of the system. Finally, the Output Module identifies and presents to the decision-maker a set of Pareto optimal designs for a final down-selection.

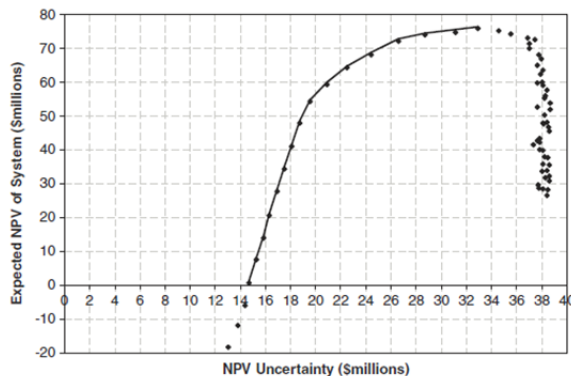


Figure 8. Pareto front of designs.

The results of the example are displayed in Figure 8. In this case, the designer calculated values for lease prices of specific technical components and market demand for on-orbit capacity for input into the framework. The model also takes into account different values for payload size for the satellite. These different values are displayed as design alternatives in the Pareto Frontier in figure. The selection of the final decision can now be made given the particular preferences and constraints of the decision-maker. The design choice also can now be said to be value-based or at least value-informed.

APPENDIX F - Stakeholders in Design Rubrics

F.1 Prototype I: Human-Centered Design Rubric

Requirements & Problem Definition

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	<p>__ Students don't include all of the requirements from the project description.</p> <p>__ There is limited, if any, discussion of stakeholders, even considering those explicitly mentioned in the project description.</p> <p>__ Discussion of related regulations is limited or not existent.</p>
1	View the focus of the design as a technical solution to the project description. Lack an understanding of the users and an appreciation of their perspective.	<p>__ Students include only the requirements from the project description.</p> <p>__ There is no discussion of stakeholders beyond the project description and the professors.</p> <p>__ Regulations discussed are limited to those included in the project description or told to students by faculty.</p>
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	<p>__ Students identified a series of stakeholders who impact or are impacted by the design. (Includes the client, the design firm, the end user and operator, but not necessarily other stakeholders)</p> <p>__ Regulations discussed may include a few operational-focused regulations, but not many.</p> <p>__ Students included additional requirements regarding stakeholders above those in the project description. (Mostly quantitative in nature)</p> <p>__ The additional requirements came directly from regulations or "hand-waving" discussions.</p>
3	Attempt to keep the stakeholders' needs and how the design will be used in mind while designing. Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.	<p>__ Students identified a comprehensive series of stakeholders who impact or are impacted by the design (Includes maintainers, manufacturers, governmental bodies/ regulatory agencies, non- users, etc.).</p> <p>__ Students gathered information about stakeholders from research or discussions with experts.</p> <p>__ Students included limited discussion about stakeholder impact on (and how they are impacted by) the design.</p> <p>__ Students researched and incorporated operational regulations into their requirements.</p> <p>__ Students included additional requirements regarding stakeholders above those in the project description (Qualitative and quantitative).</p> <p>__ Students included quantitative stakeholder requirements which were grounded in research or trade study results or were validated by the stakeholders.</p> <p>__ Students discussed both stakeholder wants and needs and may have resolved some of the potentially conflicting requirements and objectives.</p>

Requirements & Problem Definition (cont.)

Score	Students...	Evidence
4	Demonstrate an understanding of design as taking place within a particular context. Incorporate information not only about the stakeholders but about the context of the design.	<p>__ Students identified a comprehensive series of stakeholders who impact or are impacted by the design and discussed their particular needs within (and how they are impacted by) the design.</p> <p>__ Students researched and incorporated operational regulations into their requirements.</p> <p>__ Students examined the social, political, and/or environmental context of their design and its impact on the design requirements.</p> <p>__ Students gathered information about stakeholders from research or discussions with experts.</p> <p>__ Students included additional requirements regarding stakeholders above those in the project description that were grounded in research or trade study results or were validated by the stakeholders.</p>
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	<p>__ Students identified a comprehensive series of stakeholders who impact or are impacted by the design and discussed their impact on (and how they are impacted by) the design.</p> <p>__ Students examined a broad range of appropriate contextual information and regulations.</p> <p>__ Students gathered information about stakeholders from research, discussions with experts, and stakeholders directly.</p> <p>__ Students included quantitative and qualitative requirements regarding stakeholders and context considerations, which were grounded in research or trade studies or were validated by the stakeholders.</p> <p>__ Students attempted to quantify qualitative requirements to be used in trade studies and/or the later parts of the design process.</p> <p>__ Students exhibited an awareness of the multiple stakeholder perspectives and attempted to resolve these potentially conflicting requirements.</p>
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	<p>__ Students demonstrated broad understanding of the stakeholders and the context, “beyond the scope of the project”.</p> <p>__ Students included quantitative and qualitative requirements regarding stakeholders and the context of the design, based on an understanding of the stakeholders and the context from discussions with the stakeholders directly, researchers, and discussions with experts.</p> <p>__ Students quantify qualitative requirements or determine a way to use qualitative requirements in trade studies and/or the later parts of the design process.</p> <p>__ Students resolved conflicting requirements and different stakeholder perspectives within their design.</p>

Concept Generation & Concept Selection

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	<ul style="list-style-type: none"> — Concept Generation and Selection are narrowly focused and do not incorporate the metrics included in the project description.
1	View the focus of the design as a technical solution to the project description. Lack an understanding of the users and an appreciation of their perspective.	<ul style="list-style-type: none"> — Criteria for concept selection and concept options focus only on project description requirements with no explicit inclusion of environmental and stakeholder-related concerns.
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	<ul style="list-style-type: none"> — Quantitative criteria for concept selection related to stakeholders or context come directly from the project description and aircraft regulations. — Any qualitative discussion of stakeholders is not grounded in research or discussions with experts.
3	Attempt to keep the stakeholders' needs and how the design will be used in mind while designing. Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.	<ul style="list-style-type: none"> — Students include quantitative stakeholder-related criteria for selection which is grounded in research or trade study results, while qualitative discussions are not grounded in research or discussions with experts. — Students gather and use information about stakeholder-related criteria from research or discussions with experts in design-related fields. — Students claim to prioritize stakeholder concerns within criteria, but in actuality they prioritize other requirements.
4	Demonstrate an understanding of design as taking place within a particular context. Incorporate information not only about the stakeholders but about the context of the design.	<ul style="list-style-type: none"> — Students include quantitative & qualitative stakeholder and context-related criteria which are grounded in research or trade study results. — Students gather and use information about stakeholder-related criteria from research or discussions with experts in design-related fields. — Students demonstrate an understanding about how their selected concept could impact stakeholders and/or the context of the design.
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	<ul style="list-style-type: none"> — Students include a comprehensive set of criteria which include stakeholder and context-related concerns and are grounded in research or trade study results. — Students gather information about stakeholders from research, discussions with experts in design-related fields, and stakeholders directly. — Students explain concept selection as an attempt to balance multiple considerations and find a solution which will benefit all the stakeholders involved in the design.
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	<ul style="list-style-type: none"> — Students include a comprehensive set of criteria which include stakeholder and context-related concerns and are based on research and discussions with the stakeholders directly, researchers, and/or experts. — Students' discussions of concept selection demonstrate a broad understanding of the stakeholders and their relationship to the design.

Technology Integration: Technology Research and Selection

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	<p>___ Technology selection was not grounded in the requirements from the project description.</p>
1	<p>View the focus of the design as a technical solution to the project description.</p> <p>Lack an understanding of the users and an appreciation of their perspective.</p>	<p>___ Technology options and selection focuses only on project description requirements with no explicit discussion of environmental and stakeholder-related concerns.</p>
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	<p>___ Students include technology options which consider the environmental and stakeholder-related concerns from the project description and related regulations.</p> <p>___ Benefits and consequences of the technologies do not include impacts on stakeholder-related concerns.</p> <p>___ Technology selection relies solely on performance related metrics.</p>
3	<p>Attempt to keep the stakeholders' needs and how the design will be used in mind while designing.</p> <p>Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.</p>	<p>___ Students include technology options which consider environmental and stakeholder-related concerns beyond those from the project description and related regulations.</p> <p>___ Benefits and consequences of the technologies may include the impact on stakeholder and environmental-related concerns.</p> <p>___ Technology selection relies solely on performance related metrics.</p>
4	<p>Demonstrate an understanding of design as taking place within a particular context.</p> <p>Incorporate information not only about the stakeholders but about the context of the design.</p>	<p>___ Students include several technology options which consider environmental and stakeholder-related concerns beyond those from the project description and related regulations.</p> <p>___ Benefits and consequences consider the impact on stakeholder and environmental-related concerns (including manufacturers, maintainers, etc.).</p> <p>___ Technology selection may consider cost or other metrics beyond performance related metrics. No clearly defined stakeholder/environmental metrics are used.</p>
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	<p>___ Students include a wide variety of technology options which consider environmental, contextual and stakeholder-related concerns.</p> <p>___ Benefits and consequences integrate the impact of the technologies on stakeholder, environmental-related and other context-related concerns.</p> <p>___ Technology selection considers the entire context of design from multiple perspectives, including the performance related metrics, cost related metrics, environmental/stakeholder-related metrics.</p>
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	<p>___ The discussion of the technology research and selection demonstrates a clear understanding of the stakeholder and the content of the design and how the different perspectives impact technology integration.</p> <p>___ Students include a wide variety of technology options and consider how the benefits and consequences of those technologies impact environmental, contextual and stakeholder-related concerns.</p> <p>___ Technology selection considers the entire context of design from multiple perspectives (i.e. performance, cost, environmental).</p>

Concept Development: Configuration Layout & Subsystem Design

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	__ Critical aspects of the concept and its subsystems are technically infeasible or do not follow specifications from the project description.
1	View the focus of the design as a technical solution to the project description. Lack an understanding of the users and an appreciation of their perspective.	__ The design of the final concept and subsystems considers only what is provided in the course text, the project description, or the course notes.
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	__ The design of the final concept and the subsystems which directly impact stakeholders incorporates stakeholder-related considerations in the form of assumptions by the design team about what stakeholders need or want.
3	Attempt to keep the stakeholders' needs and how the design will be used in mind while designing. Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.	__ The design of the final concept and a few of the subsystems beyond those directly impacting stakeholders incorporates stakeholder-related considerations grounded in research , trade study results or discussions with experts in design-related fields.
4	Demonstrate an understanding of design as taking place within a particular context. Incorporate information not only about the stakeholders but about the context of the design.	__ The design of the final concept and a few of the subsystems beyond those directly impacting stakeholders incorporates stakeholder-related and context-related considerations grounded in research, trade study results or discussions with experts in design-related fields.
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	__ The design of the final concept and many of the subsystems incorporates stakeholder and context-related considerations grounded in research, trade study results, discussions with experts in design-related fields, and/or discussions with stakeholders directly . __ Students discuss how they integrate multiple perspectives in the design of many of the different subsystems to achieve the final design.
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	__ Students' discussions demonstrate a broad understanding of the stakeholders and how to integrate their considerations into many different aspects of the design.

Trade Studies & Balancing Trade-Offs

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	<p>— Limited or no trade studies are completed. Those completed trade studies may not consider important metrics included in the project description.</p>
1	<p>View the focus of the design as a technical solution to the project description.</p> <p>Lack an understanding of the users and an appreciation of their perspective.</p>	<p>— Students perform trade studies focused only on the design drivers included in the project description.</p> <p>— Relationship between trades and stakeholder-considerations are not discussed.</p>
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	<p>— The students perform trade studies focused on the design drivers from the project description, but also may include some parameters which impact or are impacted by the stakeholders.</p> <p>— Relationship between trades and stakeholder-considerations may be discussed.</p>
3	<p>Attempt to keep the stakeholders' needs and how the design will be used in mind while designing.</p> <p>Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.</p>	<p>— Trade studies include stakeholder-related design parameters and the quantification of qualitative considerations related to stakeholder requirements.</p> <p>— Results demonstrate how stakeholder information can be integrated with other aspects of design.</p>
4	<p>Demonstrate an understanding of design as taking place within a particular context.</p> <p>Incorporate information not only about the stakeholders but about the context of the design.</p>	<p>— Trade studies examine both stakeholder and context-related considerations. Students quantify qualitative considerations as needed.</p> <p>— Students connect performance parameters with stakeholder considerations to help make various design decisions based on the trade study results.</p>
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	<p>— Students clearly considered the question “What are the design tradeoffs, if any, necessitated by human factors [stakeholder/ context] considerations?”</p> <p>— Trade studies examine both stakeholder and context-related considerations. Students quantify qualitative considerations as needed and connect performance parameters with stakeholder considerations.</p>
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	<p>— The report includes a broad understanding about how stakeholders and context concerns can be integrated into the various trade studies and design decisions.</p>

Final and Overall Design

Score	Students...	Evidence
0	Lack a basic understanding of the project description and the requirements it specifies for the design.	__The final design does not meet all of the requirements included in the project description.
1	View the focus of the design as a technical solution to the project description. Lack an understanding of the users and an appreciation of their perspective.	__Students discuss the final design but don't revisit whether the design meets the requirements from the project solicitation.
2	Incorporate stakeholders to the extent that it does not make the design too messy or difficult and the process involves little or no feedback or iteration.	__Stakeholder considerations are not revisited in the report, aside from those explicitly stated in project description. __The report may include a discussion about how the design meets the requirements from the project solicitation.
3	Attempt to keep the stakeholders' needs and how the design will be used in mind while designing. Focus on the integration of stakeholder information with aspects of the design's feasibility and viability.	__The report revisits the design solutions from the stakeholder perspective to assess how the design is impacted by and impacts the stakeholder .
4	Demonstrate an understanding of design as taking place within a particular context. Incorporate information not only about the stakeholders but about the context of the design.	__The report revisits the design solutions to assess how the design is impacted by and impacts the stakeholder and the social, political, and/or environmental context .
5	Exhibit a commitment to incorporating stakeholder and context-related considerations into the design process.	__The report revisits the design solutions to assess how the design is impacted by and impacts the stakeholder and the social, political, and/or environmental context. __The report demonstrates how the students considered multiple perspectives in the design and may include some reflection about further ways to evaluate the design solution and/or potential limitations of the design as it relates to stakeholders.
6	Demonstrate a very broad understanding of stakeholders and how they impact and are impacted by the design.	__The report demonstrates how the students considered stakeholders throughout the design process and how that has impacted the final design . __The report may include some reflection about further ways to evaluate the design solution and/or potential limitations of the design as it relates to stakeholders.

F.2 Prototype II: Informed Designer Rubric

See subsequent page for the rubric.

	WHAT BEGINNING DESIGNERS DO	Score & Description of Evidence from the Report				WHAT INFORMED DESIGNERS DO
Requirements/Problem Definition	Understand the Challenge <i>Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.</i> <ul style="list-style-type: none"> Do not include requirements beyond the technical aspects of what the project description includes. Do not define stakeholders or the context prior to introducing possible solutions. 	Pattern A: Problem Solving v. Problem Framing				<i>Delay making design decisions in order to explore, comprehend and frame the problem better.</i> <ul style="list-style-type: none"> Include a description of the problem they are trying to solve. Define the stakeholders and the operational context for the design upfront. Define requirements beyond those included in the project description. Relate the requirements to the different stakeholders and incorporate additional stakeholder requirements from regulations/standards as necessary.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Requirements/Problem Definition	Build Knowledge <i>Skip doing research and instead pose or build solutions immediately.</i> <ul style="list-style-type: none"> May or may not include stakeholder considerations as they jump to developing solutions. Make assumptions about stakeholder-related information based on personal knowledge. 	Pattern B: Skipping vs. Doing Research				<i>Do investigations and research to learn about the problem, how the system works, relevant cases, and prior solutions.</i> <ul style="list-style-type: none"> Articulate a need to inquire more about stakeholder- and context-related considerations. Perform research to help them better understand the system and its operational context as well as to see the problem from different perspectives. Use multiple resources to gather information by asking appropriate experts or stakeholders themselves and seeking out prior solutions and relevant literature.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Concept Generation/Represent Ideas	Generate Ideas <i>Work with few or just one idea, which they can get fixated or stuck on, and may not want to change or discard.</i> <ul style="list-style-type: none"> Fixate on one idea or one selection criteria, disregarding potential impacts on stakeholders or associated constraints/requirements. 	Pattern C: Idea Scarcity vs. Idea Fluency				<i>Practice idea fluency in order to work with lots of ideas by doing divergent thinking, brainstorming, etc.</i> <ul style="list-style-type: none"> Utilize brainstorming sessions and results of research and other investigations to develop a wide variety of different concepts.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Concept Generation/Represent Ideas	Represent Ideas <i>Propose superficial ideas that do not support deep inquiry of a system, and that would not work if built.</i> <ul style="list-style-type: none"> Consider only a few critical constraints in the conceptual and preliminary design phases. Do not assess the feasibility of a design until late in the design process. 	Pattern D: Surface vs. Deep Drawing & Modeling				<i>Use multiple representations to explore and investigate design ideas and support deeper inquiry into how system works.</i> <ul style="list-style-type: none"> Develop their own tool for modeling or utilize multiple tools to investigate the design ideas and the overall feasibility of the final concept. Use multiple perspectives to better understand how the design concept could impact or be impacted by the stakeholders and the environment.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Concept Development/Trade Studies/Final Design	Weigh Options & Make Decisions <i>Make design decisions without weighing all options, or attend only to pros of favored ideas, and cons of lesser approaches.</i> <ul style="list-style-type: none"> Consider only the benefits of given design parameters and concepts or only those trade-offs explicitly defined in the project description. Do not provide explanations for their design decisions. 	Pattern E: Ignore vs. Balance Benefits & Trade-offs				<i>Use words and graphics to display and weigh both benefits and trade-offs of all ideas before picking a design.</i> <ul style="list-style-type: none"> Clearly understand the difficulties of achieving consensus among the design objectives, the stakeholders, and/or members of the design team. Perform many trade studies to understand the benefits and trade-offs of each design decision. Demonstrate an understanding of the effects of their design decisions on the different subsystems within the design and the various stakeholders.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Concept Development/Trade Studies/Final Design	Revise/Iterate <i>Design in haphazard ways where little learning gets done, or do design steps once in linear order.</i> <ul style="list-style-type: none"> Do not elicit feedback on the design or may not alter the design after receiving feedback. Illustrate the design process as a linear process without many or any iterations. 	Pattern H: Haphazard or Linear vs. Managed & Iterative Designing				<i>Do design in a managed way, where ideas are improved iteratively via feedback, and strategies are used multiple times as needed, in any order.</i> <ul style="list-style-type: none"> Utilize many resources and inquire for feedback from experts and stakeholders. Demonstrate how their final design concept is the product of multiple iterations.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	
Concept Development/Trade Studies/Final Design	Reflect on the Process <i>Do tacit designing with little self-monitoring while working or reflecting on the process and product when done.</i> <ul style="list-style-type: none"> Do not clearly illustrate how the final design concept meets or exceeds the design requirements. Do not discuss how their design will be used in its operational environment. Do not indicate how stakeholders and context affect the design process and the resulting final design. 	Pattern I: Tacit vs. Reflective Design Thinking				<i>Practice reflective thinking by keeping tabs on design strategies and thinking while working and after finished.</i> <ul style="list-style-type: none"> Note any limitations in their design process or modeling tools and the effect of those limitations on the final design concept. Indicate how stakeholders and context affect the design process and the final design. Illustrate how their final design concept meets or exceeds the design requirements and how it will be used in its operational environment.
		1 = Beginner	2 = Intermediate	3 = Advanced	4 = Informed	

F.3 Prototypes: Evaluation of Validity, Reliability and Usability

Validity

Literature on rubric development specifies three types of validity that should be examined. The first, content validity, defines “the extent to which a student’s responses to a given assessment instrument reflects that student’s knowledge of the content area that is of interest” (Moskal & Leydens, 2000) (p. 2). Content validity is most commonly explored using subject-matter experts (Jonsson & Svingby, 2007; Plumb & Sobek, 2008; Watson et al., 2013). Construct validity considers the relationship between what is being evaluated by the rubric and the criteria being used to evaluate it (Plumb & Sobek, 2008): Does the rubric measure what it is supposed to measure? Finally, criterion validity defines the predictability of the measurements with current or future performance (Moskal & Leydens, 2000; Plumb & Sobek, 2008). For instance, can performance on this report, as defined by the rubric, be generalized to future performance in industry or future design projects?

Clarity and Reliability

During the rubric development process, it is necessary to consider how to promote consistency among raters with scoring criteria descriptions and overall rubric instructions (Moskal & Leydens, 2000; Plumb & Sobek, 2008). This consistency is examined using measures for interrater reliability, intrarater reliability, and clarity (Moskal & Leydens, 2000). Inter-rater reliability measures the variability among the raters, while intrarater reliability measures variability among a single rater (Moskal & Leydens, 2000). There are many statistical measurements that can be used to examine interrater reliability, from consensus agreements to consistency estimates (Jonsson & Svingby, 2007). The decision of which measurement to use is dependent on the number of raters and ratings as well as whether each rater rated all of the sample or only a partial sample. Threats to intrarater reliability include rater fatigue or rater bias (e.g. if the rater is knowledgeable that they are rating someone who may fail a class if they do poorly on this assessment) (Moskal & Leydens, 2000). Statistical measures exist for intrarater reliability, but again, are dependent on the research design (Jonsson & Svingby, 2007).

Beyond statistical measures for examining reliability, the clarity of a rubric can also be evaluated to understand the reliability of the scoring criteria. This evaluation includes asking questions to raters, such as “are these scoring categories well defined?”, and “are the differences between the score categories clear?” (Moskal & Leydens, 2000). Finally, when considering the implementation of the rubric, researchers have defined methods for improving consistency among the raters, including

- The use of anchor papers, which provide an example how the rubric is used (Moskal & Leydens, 2000);
- The use of a sample set of responses for raters to evaluate, which provides information about discrepancies among the raters (Moskal & Leydens, 2000); and
- The use of sample responses that represent the top level of performance (Watson et al., 2013).

Methods

During the rubric development process, specific measures were taken to improve the validity of the rubric itself. Specifically, the process incorporated the use of specific objectives to guide the selection of the scoring criteria, scale and the descriptions for construct validity. Each level of the scoring criteria was created to align with relevant literature which considered how stakeholders can be integrated into a design both in a higher education setting and in an industrial setting to support construct and criterion validity.

To further examine the validity, clarity, and reliability of the rubric, a group of four subject-matter experts (SMEs) were recruited to evaluate the rubric from an instructor perspective by attempting to assess a small sample of student projects using the rubric. The group represents researchers and engineering educators in varying sub-disciplines of aerospace engineering, including conceptual aircraft design and cognitive engineering.

Each of the SMEs was provided a rubric packet with an explanation of the rubric objectives, the scales, and the scoring method. In addition, the packet included a rubric design questionnaire (adapted from the work of Moskal and Leyden, 2000, and Stevens and Levi, 2005). The questionnaire examines the clarity of the scoring criteria, the descriptions, the scale, and the overall rubric, along with content validity, construct validity, and criterion validity (Moskal & Leydens, 2000; Stevens & Levi, 2005) (see the sample questions in Table 86 and the complete questionnaire in the Appendix F.4).

Table 86: Sample Questions from the Rubric Development Questionnaire

	Rubric Evaluation Questions
Evaluation Criteria	Are the evaluation criteria distinctly different from each other?
Overall Rubric	Does it balance the necessary level of detail with the time required for the assessment of a single project?
Content-Related Validity	Does this rubric evaluate how students consider stakeholders in the design process?
Construct-Related Validity	Are all the important components of the integration of stakeholders into the design process evaluated in the rubric?

Prior to utilizing the rubric, each SME was required to receive one-on-one training on the rubric. This training was provided to support consistency and overall understanding of the rubric among the SMEs (Plumb & Sobek, 2008; Watson et al., 2013). The SMEs were introduced to both the Human-Centered Design Rubric and the Informed Designer Rubric.

Following training, the SMEs were asked to read and assess a series of senior design projects from an aircraft design course, the site for this research study. Within the course, ten teams of students, ranging in size from 6 to 9 students, developed a conceptual design for an aircraft based on an RFP developed by the AIAA. Each team was required to submit a report at the end of the semester, documenting their design solution and their approach for developing that solution. The reports were used for this rubric evaluation with approval by the Institutional Review Board.

Results

The SMEs noted challenges with both the Human-Centered Design Rubric and the Informed Designer Rubric. When considering the clarity of the rubrics, the specificity in the descriptions within the Human-Centered Design Rubric was viewed as overwhelming, even though one SME referred to it as the simpler of the two rubrics. The SMEs agreed that this rubric did not adequately balance the necessary level of detail with the time required for the assessment of a single project. In addition, the SMEs noted that while the Human-Centered Design Rubric was very detailed, there were still missing items that the SMEs described as important for evaluating how students consider stakeholders. For example, one SME inquired about whether the rubric considered if students validated their requirements with stakeholders or if the students examined or resolved conflicting requirements.

With the Informed Designer Rubric, two of the SMEs struggled with the assignment of points if a team is somewhere between a Beginner Designer and an Informed Designer. The descriptions, as viewed by the SMEs, were generic, and it was unclear if this rubric would be able to adequately assess a design deliverable, as compared with observations of student design teams. While the Informed Designer Rubric was shorter, thus providing a better balance of detail and time required for assessment, the SMEs believed this rubric required more justification for a given score than the Human-Centered Design Rubric.

Finally, the one SME described how

“some criteria in the rubrics seemed to focus on general issues related to the design and design process, and not specifically to stakeholder issues. I struggled somewhat to know whether I should base my evaluations on non-stakeholder issues for these criteria or to view them through the stakeholder lens.”

An examination of the rubrics following the SMEs’ assessment of a small sample of the students’ projects demonstrated that it was clear some confounding was occurring within the rubric descriptions. The separation between students’ design understanding and students’ integration of stakeholder considerations was indistinguishable in many cases, creating challenges, for example, when a team utilized an iterative design process, but lacked appreciation for stakeholders. Overall, while portions of these prototype rubrics would support the assessment of students’ integration of stakeholder considerations, several weaknesses arose which suggest an additional iteration of the rubric development process is necessary.

F.4 Rubric Development Questionnaire

	Rubric Evaluation Questions	Yes	No	Comments
Evaluation Criteria	Are the evaluation criteria clear?	—	—	
	Are the evaluation criteria distinctly different from each other?	—	—	
	Do the evaluation criteria address any extraneous content?	—	—	
	Do the evaluation criteria address all the aspects of the intended content?	—	—	
	Is there any content addressed in the task that should be evaluated through the rubric, but is not?	—	—	
Descriptions	Do the descriptions match the evaluation criteria?	—	—	
	Are the descriptions clear and different from each other?	—	—	
	Is there a clear basis for assigning the points for each evaluation criteria?	—	—	
Scale	Do the descriptors under each level truly represent that level of performance?	—	—	
	Does the rubric have a reasonable number of levels for the age of the student and the complexity of the assignment?	—	—	
	Would two independent raters arrive at the same score for a given response based on the scoring rubric?	—	—	
Overall Rubric	Does the rubric clearly connect to the outcomes that it is designed to measure?	—	—	
	Can the rubric be understood by external audiences (avoids jargon and technical language)?	—	—	
	Is the rubric of appropriate length?	—	—	
	Does it balance the necessary level of detail with the time required for the assessment of a single project?	—	—	
	Is this a rubric you could see yourself using in your classroom?	—	—	
Content Related Validity	Does the rubric evaluate how students consider stakeholders in the design process?	—	—	
	Could this rubric be used for groups outside of AE?	—	—	
	Or for different project descriptions within AE?	—	—	
Construct Related Validity	Are the elements of the responses being evaluated appropriate indicators of students' abilities to consider the stakeholder in design?	—	—	
	Are all the important components of the integration of stakeholders into the design process evaluated in the rubric?	—	—	
	Are any of the evaluation criteria irrelevant to the construct of interest?	—	—	
Criterion Related Validity	Can the students' performance on this report be generalized to their future performance as new hires and in their careers?	—	—	
	Are all the important components of the students' future performance evaluated in the rubric?	—	—	
	Are there any components of the students' future or related performance that are not reflected in the scoring criteria?	—	—	

F.5 Stakeholder in Design Rubric

See subsequent two pages for the rubric.

Instructions: As you read through the project, please score each project by considering how stakeholders are integrated into each phase of the design process. Provide any specific evidence which served as the basis for your score.

	Stakeholder Integration by Design Phase			
	Requirements/ Problem Definition	Concept Generation/ Development	Technology Integration	Overall Design
Did the student(s) state an intention to incorporate stakeholder concerns at this phase? [Yes – 1pt, No – 0pts]				
Did the student(s) apply a design process at this stage that could include stakeholder concerns? [Yes – 1pt, No – 0pts]				
Was the student(s) successful in integrating stakeholder concerns? [Yes, in an integral manner – 2pts, Yes, but in a superficial manner – 1pt., No, the student(s) was not successful – 0pts.]				

Considering the students' work as a whole, use (1) the design understanding scale to rate how the team applied or abstracted the engineering design process and (2) the stakeholder integration scale to score how the team perceived and integrated stakeholders in the design of this complex system. The scales are defined and examples are provided on page two. Also please provide comments or evidence from the project to support the reasoning behind your score.

Design Understanding Score (0 to 4pts) _____	Stakeholder Integration Score (0 to 4pts) _____
Comments:	Comments:

Score	Design Understanding Scale	Description
0	<i>Design Process Knowledge is Absent</i>	Lacks a basic understanding of the design process, as exhibited by missed steps or an incorrect application of design process knowledge to the problem
1	<i>Application I: Design Process is Linear</i>	Reproduces the design process as presented within the course, but does not recognize when findings later in the design process warrant revision of earlier steps
2	<i>Application II: Design Process is Integrated and Iterative</i>	Applies the design process as presented within the course and demonstrates how the final design concept improved iteratively via feedback and additional analysis
3	<i>Abstraction I: Very Integrated and Iterative</i>	Exhibits deep understanding of the design process. Abstracts and augments the principles of the design process to reach an innovative solution to the problem through an iterative process. (e.g. may develop a new tool for modeling or analysis)
4	<i>Abstraction II: Reflective Designer</i>	Exhibits a deep understanding of design. Design process is very iterative and reflective. Frequently re-evaluates ideas relative to new knowledge. Notes any limitations in the design process or modeling tools and the impact of those limitations on the final design concept.

Score	Stakeholder Integration Scale	Description
0	Lacks appreciation for stakeholders	Lacks integration of contextual and stakeholder considerations.
1	Considers stakeholders implicitly	Includes stakeholder-related considerations, but does not explicitly discuss the human aspect of the consideration. (e.g. noise and people living near the airport, cost and the customer, etc.)
2	Incorporates stakeholder considerations at isolated points	Identifies stakeholder considerations at isolated points in the design process, but overall these considerations are not the basis for design decisions and are not addressed consistently through design
3	Integrates stakeholder considerations consistently throughout the design process	Exhibits a commitment to incorporating stakeholder considerations throughout the design process. Design decisions clearly account for their potential impact on stakeholders and related research or communication with experts/stakeholders.
4	Leverages the multiple perspectives of stakeholders to pursue a more innovative, competitive design	Demonstrates how multiple perspectives (and at times, competing requirements) were integrated to develop their final solution. Overall solution can be marketed as a design driven by stakeholder, context, and performance requirements.

F.6 The Stakeholder in Design Rubric: Evaluation of Validity, Reliability and Usability

The Stakeholder in Design rubric was developed to assess how students integrate stakeholder considerations into the design of a complex system. To evaluate the ability for the rubric to measure what it is intended to measure and to produce consistent results, we examined the validity, clarity, and reliability of the rubric. These concepts are introduced more formally in Appendix F.3.

Methods

During the rubric development process, specific measures were taken to improve the validity of the rubric itself. Specifically, the process incorporated the use of specific objectives to guide the selection of the scoring criteria, scale and the descriptions for construct validity. Each level of the scoring criteria was created to align with relevant literature which considered how stakeholders can be integrated into a design both in a higher education setting and in an industrial setting to support construct and criterion validity.

To further examine the validity, clarity, and reliability of the rubric, a group of seven subject-matter experts (SMEs) were recruited to assess student performance on their senior design reports using the rubric and to evaluate the rubric from an instructor perspective. The group represents researchers and engineering educators in varying sub-disciplines of aerospace engineering, including conceptual aircraft design and cognitive engineering.

Each of the SMEs was provided a rubric packet with an explanation of the rubric objectives, the scales, and the scoring method. In addition, the packet included a rubric design questionnaire (adapted from the work of Moskal and Leyden, 2000, and Stevens and Levi, 2005). The questionnaire examines the clarity of the scoring criteria, the descriptions, the scale, and the overall rubric, along with content validity, construct validity, and criterion validity (Moskal & Leydens, 2000; Stevens & Levi, 2005) (see the sample questions in Appendix F.3 and the complete questionnaire in the Appendix F.4).

Prior to utilizing the rubric, each SME was required to receive one-on-one training on the rubric. This training was provided to support consistency and overall understanding of the rubric among the SMEs (Plumb & Sobek, 2008; Watson et al., 2013). The SMEs were introduced to the rubric and the individual scales and were encouraged not to consider the rating process as a “grading” process. In other words, a well-done design project does not necessarily mean the team must receive a “4” on the *Stakeholder Integration* scale or even the *Design Understanding* scale. The same was true for a poor design project. Additionally, it is possible for a team that performs poorly in one scale to perform well in another.

Following training, the SMEs were asked to read and assess a series of senior design projects from an aircraft design course, the site for this research study. Within the course,

ten teams of students, ranging in size from 6 to 9 students, developed a conceptual design for an aircraft based on an RFP developed by the AIAA. Each team was required to submit a report at the end of the semester, documenting their design solution and their approach for developing that solution. The reports were used for this rubric evaluation with approval by the Institutional Review Board.

Due to the size of each design project (approximately 90 to 100 pages), six of the seven SMEs were assigned four of the reports, while the seventh SME read all ten reports. This approach for assigning the reports allowed for all of the reports to be rated by at least three SMEs. To examine the variability among the raters more closely, one of the reports was read by all of the SMEs. Finally, each report assignment was organized such that the SMEs did not read the same projects in the same order. The distribution of reports is illustrated in Table 55.

Table 87: Assignment of Reports to SMEs (Note: All identifying information was removed from each report prior its distribution)

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7
A	1	1			1		
B	1		1			1	
C	1			1			1
D	1	1			1		
E	1		1				1
F	1			1		1	
G	1	1	1	1	1	1	1
H	1	1					1
I	1		1		1		
J	1			1		1	

Based on the small number of reports read by each SME, traditional statistical measures for reliability (e.g. Cohen's kappa, Krippendorff's alpha, interclass correlation coefficient) are not be presented in this evaluation. A more in-depth review of the rubric's reliability using a larger sample of reports per SME will be completed in a future study. At this stage, the variability of among the SME is examined using the Rubric Development Questionnaire questions on scoring criteria, descriptive statistics, and a qualitative examination of SME's comments about each team.

Results

Validity and Clarity

Overall, six of the seven SMEs believed the evaluation criteria were clear and distinctly different from each other without addressing any extraneous content. Yet, within the Stakeholder Integration by Design Stage section, it appeared that four of the SMEs did not agree with the use of three design stages and the fourth "overall design" category. In some cases, these stages were seen as not aligned with the project requirements, which had not emphasized the problem definition stage and which had required students to perform other analyses not included explicitly in these design stages.

In regards to the descriptions, all of the SMEs indicated that the descriptions matched the evaluation criteria and were clear and different from one another. All of the SMEs felt that the rubric could be understood by external audiences and balanced the necessary level of detail with the time required for the assessment of a single project. In addition, they all commented that they could see themselves using it in their classroom. Still, some of the SMEs believed they misinterpreted the “Did the student(s) apply a design process at this stage that could include stakeholder concerns?” question, which may have impacted their scoring of the projects.

In terms of content validity, the SMEs described that the rubric successfully evaluates how students consider stakeholders in the design project and could be used for different projects within and outside of aerospace engineering. However, a couple of the SMEs raised the following question: *How can the rubric account for teams that considered one stakeholder thoroughly versus one that considered a lot of stakeholders superficially?* Finally, one SME noted that the design understanding scale could be more thorough, while another explained how it may be an unnecessary scale if instructors utilize their own rubric for evaluating students’ design understanding.

With construct-validity, the SMEs reported that all the important components of the integration of stakeholders into the design process were evaluated in the rubric. Nevertheless, as defined previously, some of those components could be divided differently or expanded upon slightly. In the discussions of criterion validity, five of the seven SMEs believed that students’ performance on this report could be generalized to their future performance. However, in general, the SMEs did not believe the generalization would necessarily be accurate at the individual level or for all of the scores. For instance, one SME explained how an excellent score would indicate students’ ability to incorporate stakeholder requirements within an iterative and integrated design process, but a poor score could be attributed to other influences besides students’ ability to incorporate stakeholders.

Finally, two SMEs discussed the impact of the project requirements (i.e. RFP) on students’ stakeholder integration scores. While some teams may have acknowledged stakeholders as important, they may not have integrated stakeholder considerations because they were adhering to the pre-defined project requirements. In addition, differing viewpoints among the SMEs emerged on what it means to consider stakeholders during the project evaluations. Even though some teams incorporated stakeholder considerations inherently in the design (e.g. cabin sizing, cost, noise, etc.), some SMEs did not view this as evidence these student teams had valued stakeholders, but instead these teams had adopted some measures suggested by the RFP or instructors that happened to relate to stakeholders.

Reliability

The resulting scores for each of the scales are presented in Table 88 and Table 89. The SME’s scores varied little for some teams and significantly across the scores given other

teams. With the both scales, only 40% of the ratings per team were within one performance level.

One possible reason behind these results could be the SME's scoring strategy and the few ratings that they could choose between. When examining the scoring criteria scale, two of the SMEs responded in the questionnaire that they would have preferred the option for half points, while one of the SMEs scored the projects using half points. A review of the SMEs' comments on the team rating sheets confirmed that allowing for half points might have improved the overall reliability. Five of the seven SMEs explicitly discussed indecision between scoring levels on their rating sheets.

Table 88: Stakeholder Integration Scores by SME

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7	Range
A	0	2			1			2
B	2		2			2		0
C	3			2			3	1
D	0	2			2			2
E	0		0				0	0
F	0			2		2		2
G	1	2	2	0	1	1	2	2
H	1.5	2					2	.5
I	2		0		3			3
J	0.5			3		2		2.5

Table 89: Design Understanding Scores by SME

Team #	SME 1	SME 2	SME 3	SME 4	SME 5	SME 6	SME 7	Range
A	3	2			2			1
B	1.5		1			1		0.5
C	3			1			3	2
D	2.5	2			2			.5
E	3		2				1	2
F	1			3		1		2
G	1.5	1	1	0	3	1	1	3
H	2	2					1	1
I	2		1		3			2
J	2.5			4		2		1.5

The scores within the Stakeholder Integration by Design Stage reflected the same variability among SME scores as the two scales (see Table 90). With these results, many of the SMEs disagreed completely as to each team's intention to incorporate stakeholder considerations and overall success in incorporating those considerations. Similarly to the two scales, three SMEs requested a wider range for scoring the Stakeholder Integration by Design Stage section (for instance, 0 to 4 points). It will be necessary to examine how to improve the variability among the raters for the next iteration of the rubric.

Table 90: Example Ratings from the Stakeholder Integration by Design Stage

Team J	SME #1	SME #4	SME #6		Team D	SME #1	SME #2	SME #5
Requirements/ Problem Definition					Requirements/ Problem Definition			
<i>Intention</i>	0	1	1		<i>Intention</i>	1	1	1
<i>Application</i>	0.5	1	0		<i>Application</i>	1	1	0
<i>Success</i>	0	2	1		<i>Success</i>	1	2	1
Concept Generation/ Development					Concept Generation/ Development			
<i>Intention</i>	1	1	0		<i>Intention</i>	0	1	1
<i>Application</i>	0	1	0		<i>Application</i>	0	1	0
<i>Success</i>	0.5	2	1		<i>Success</i>	0	0	1
Technology Integration					Technology Integration			
<i>Intention</i>	0	1	0		<i>Intention</i>	0	1	1
<i>Application</i>	0	1	0		<i>Application</i>	1	1	0
<i>Success</i>	0	1	0		<i>Success</i>	0	1	1
Overall Design					Overall Design			
<i>Intention</i>	0.5	1	0		<i>Intention</i>	0	1	1
<i>Application</i>	1	1	0		<i>Application</i>	0.5	1	0
<i>Success</i>	1	2	1		<i>Success</i>	0	1	1

APPENDIX G - 2012-2013 AIAA Foundation Undergraduate Team

Aircraft Competition

The RFP begins on the subsequent pages. (7 pages)

2012-2013 AIAA Foundation Undergraduate Team Aircraft Competition

Design of a 2030 Regional Airliner Considering Hybrid Electric Propulsion

I. Rules – General

1. All undergraduate AIAA Student Members are eligible and encouraged to participate.

2. An electronic copy of the report in MS Word or Adobe PDF format must be submitted on a CD or DVD to AIAA Student Programs. Total size of the file(s) cannot exceed 20 MB.

Students may submit their final report via email to the AIAA Student Programs Coordinator (Rachel Andino, rachela@aiaa.org).

A “Signature” page must be included in the report and indicate all participants, including faculty and project advisors, along with students’ AIAA member numbers and signatures. Designs that are submitted must be the work of the students, but guidance may come from the Faculty/Project Advisor and should be accurately acknowledged.

Each proposal should be no more than 100 double-spaced pages (including graphs, drawings, photographs, and appendices) if it were to be printed on 8.5” x 11.0” paper, and the font should be no smaller than 10 pt. Times New Roman. Up to five of the 100 pages may be foldouts (11” x 17” max).

3. *Design projects that are used as part of an organized classroom requirement are eligible and encouraged for competition.*

4. The prizes shall be: First place-\$1,500; Second place-\$750; Third place-\$500 (US dollars). Certificates will be presented to the winning design teams for display at their university and a certificate will also be presented to each team member and the faculty/project advisor. One representative from the first place design team may be expected to present a summary paper at the 2013 Aviation Conference.

Reasonable airfare and lodging will be defrayed by the AIAA Foundation for the team representative.

5. More than one design may be submitted from students at any one school.

6. If a design group withdraws their project from the competition, the team leader must notify AIAA Headquarters immediately!

7. Team competitions will be groups of not more than ten AIAA Student Members per entry. Individual competitions will consist of only 1 or 2 AIAA Student Member per entry.

II. Copyright

All submissions to the competition shall be the original work of the team members.

Any submission that does not contain a copyright notice shall become the property of AIAA. A team desiring to maintain copyright ownership may so indicate on the signature page but nevertheless, by submitting a proposal, grants an irrevocable license to AIAA to copy, display, publish, and distribute the work and to use it for all of AIAA’s current and future print and

electronic uses (e.g. “Copyright © 20__ by _____. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission.).

Any submission purporting to limit or deny AIAA licensure (or copyright) will not be eligible for prizes.

III. Schedule and Activity Sequences

Significant activities, dates, and addresses for submission of proposal and related materials are as follows:

- A. Letter of Intent – 22 March 2013**
- B. Receipt of Proposal – 14 June 2013**
- C. Announcement of Winners – August 2013**

Groups intending to submit a proposal must submit a Letter of Intent (Item A), with a maximum length of one page to be received with the attached form on or before the date specified above. LOI may be emailed to Rachel Andino (rachela@aiaa.org). If you chose to mail your forms, they must be typed or clearly printed and mailed to:

AIAA Student Programs
Attn: Student Programs Coordinator
1801 Alexander Bell Drive, Suite 500
Reston, VA 20191-4344

The CD containing the finished proposal must be received at the same address on or before the date specified above for the Receipt of Proposal (Item B).

IV. Proposal Requirements

The technical proposal is the most important factor in the award of a contract. It should be specific and complete. While it is realized that all of the technical factors cannot be included in advance, the following should be included and keyed accordingly:

1. Demonstrate a thorough understanding of the Request for Proposal (RFP) requirements.
2. Describe the proposed technical approaches to comply with each of the requirements specified in the RFP, including phasing of tasks. Legibility, clarity, and completeness of the technical approach are primary factors in evaluation of the proposals.
3. Particular emphasis should be directed at identification of critical, technical problem areas. Descriptions, sketches, drawings, systems analysis, method of attack, and discussions of new techniques should be presented in sufficient detail to permit engineering evaluation of the proposal. Exceptions to proposed technical requirements should be identified and explained.
4. Provide a description of automated design tools used to develop the design.
5. The students, in writing their proposal, must justify and document the configuration selection and design processes they used to determine the most cost effective and technically feasible solution.

As a team the students are required to: Evaluate the effectiveness of at least three air vehicle configurations* at meeting the required capabilities listed in this RFP (using weighted objectives or a similar

method – see Table 1) and down select to one preferred configuration with detailed justification; Perform a comprehensive trade study analysis on the preferred configuration and be able to explain the motivations behind design choices with logical supporting rationale; Propose a final, optimized conceptual air vehicle design.

* As there are a variety of configurations that could be utilized to achieve this capability, no specific one is prescribed as a preferred solution to the students. (NOTE: Three different fixed wing configurations would be just as acceptable to evaluate as would a combination of fixed wing and rotorcraft configurations).

3. Originality (20 points)

The design proposal should avoid standard textbook information, and should show the independence of thinking or a fresh approach to the project. Does the method and treatment of the problem show imagination? Does the method show an adaptation or creation of automated design tools?

4. Practical Application and Feasibility (25 points)

The proposal should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or insolvable problems.

VI. Request for Proposal

Capabilities	Priority Weighting	Configuration A	Configuration B	Configuration C
Short Landing Area Operations Autonomous Flight Payload Carriage & Useful Load Speed & Altitude Payload & Range Affordable & Supportable Transportable		Design of a 2030 Regional Airliner Considering Hybrid Electric Propulsion		
SCORES				

Table 1: Weighted Objectives Method Example

V. Basis for Judging

1. Technical Content (35 points)

This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. are all major factors considered and a reasonably accurate evaluation of these factors presented?

2. Organization and Presentation (20 points)

The description of the design as an instrument of communication is a strong factor on judging. Organization of written design, clarity, and inclusion of pertinent information are major factors.

Fuel consumption of ground vehicles can be reduced with plug-in hybrid propulsion, where both petroleum and electricity is stored on the vehicle. This has been enabled by recent advancements in battery technology, but it hasn't reached a level where enough energy per pound can be stored for commercial airliners to get a similar benefit. However, batteries have been improving rapidly, and may reach a point where they can be useful on aircraft, especially for short missions.

Recent NASA funded research into technologies for commercial aircraft in the 2030-2035 timeframe has identified hybrid electric propulsion as a potentially "game-changing" technology. A hybrid propulsion system combines the best features of gas turbine (high thrust/weight, high energy

density Jet-A fuel) with the best features of electric propulsion (high efficiency over a wide range of operating speeds, no local emissions, potentially lower noise).

Airliners typically fly much shorter ranges than their maximum range capability. Especially at these shorter ranges, electric propulsion has a greater potential benefit. Hybrid propulsion, where some of the energy stored on the aircraft is jet fuel, and some is electricity in batteries, can allow aircraft to efficiently fly a wide range of missions, by varying the ratio of electrical energy (batteries) to chemical energy (jet fuel) loaded on the aircraft.

Future Scenario:

Assume that in the year 2030, FAA certified batteries are available for flight operations at many airports across the US. Airports will still have jet fuel that can be pumped to aircraft similar to what is done today. The batteries take two hours to charge, so a battery rental service is used to charge batteries outside the aircraft at airports. Battery packs are a standard size and can be unloaded and swapped for charged ones. The aircraft pay a rental fee for the battery and the electricity that is used to charge the battery.

Project Objective:

Considering hybrid electric propulsion and advanced modular batteries, design a regional-sized commercial airliner with the lowest operating cost per seat-mile for the economic mission of 400 NM. Determine if hybrid electric technology offers fuel burn, cost, noise, or emissions advantages over conventional propulsion.

General Requirements:

This aircraft is representative of the Q400 / ATR-72 class aircraft.

Safety & Airworthiness Regulations: FARs, but identify any exceptions needed due to the introduction of new technologies.

Crew: 2

Passengers: 70 (1 Class)

Seating: Pitch 32", Width 17.2"

Cargo Volume: 280 ft³ for passenger baggage. (4ft³ per passenger)

Cargo Weight: 2450 lbs (35 lbs per passenger)

Revenue Cargo: none

Full Payload Weight: 16,450 lbs. (200 lbs per pax plus 35lbs of baggage)

Balanced Field Length: 4000-ft Sea level standard day

Minimum Cruise Speed: Mach 0.45

Initial Cruise Altitude: >20,000 ft

Maximum Cruise Altitude: 45,000 ft

Maximum Range with full payload: 1200 NM

Economic Mission: 400 NM with full payload

Battery Module Properties:

Dimensions: EH Container with hard points on each corner for securing to the aircraft

http://www.unitedcargo.com/shipping/container_aircraft.jsp?name=EH&type=ccontainer

Battery Volume: 9 ft³

Battery Weight: 360 lbs

Useful Energy: 122,471 Wh (750 Wh/kg) (investigate +/- 33% of this value)

Battery energy cost (includes battery rental): \$0.05 per kWh

CO₂ of battery electricity and battery use: 10 g CO₂ / kWh

Battery Discharge Rate: 10 C

The battery is a sealed unit with the following environmental requirements: pressure altitude between 0 and 10,000-ft; temperature between 130 and -50 degrees F during operation. Five of the six sides of the

battery modules need 2-inches of clearance from each other or surrounding structures. Note: The Team may use other values if research substantiation is provided.

Other Electric System Properties:

Electric motor system (motors + motor controllers) power density: 3 hp/lb

Electric motor and controller combined system efficiency: 95%

Generator power density: 3 hp/lb

Generator efficiency: 96%

Note: The Team may use other values if research substantiation is provided.

Fuel and Energy Storage:

Only Jet fuel and Batteries are allowed for energy storage on the aircraft. Any amount of jet fuel and number of battery packs (including zero) can be used depending on the length of the mission and weight of the payload. For jet fuel, only conventional petroleum-based jet fuel or “drop-in” fuels, such as blended biofuel or blended synthetic fuel can be used.

Economics:

The design metric is to minimize operating cost per seat-mile for the economic mission of 400 NM. Assumptions:

Jet fuel price: \$5.00 per gallon (includes carbon tax)

Electricity price including battery rental fee: \$0.05 per kWh (includes carbon tax)

The value of passenger time can also be considered in the economic analysis.

Projected aircraft and engine technology and assumptions:

Many potential 2030 propulsion, structures, aerodynamics, subsystems, and operations technologies were identified in recent FAA and NASA studies (see References) and can be applied to this design study.

Data Requirements

The technical proposal must convincingly demonstrate that the design can satisfy the design mission performance requirements will achieving the best possible cost and environmental impact with the nominal mission. The proposal should satisfy the following tasks to show how the design would be developed:

1. Justify the final design, and describe the technologies, gas turbine engine selection, electric motor and controller selection, and technical approach used to meet the mission requirements.
2. Provide carpet plots used to finalize the final selected design
3. Provide subsystem architecture trade studies
4. Include a dimensioned 3-view general arrangement drawing
5. Include an inboard profile showing the general internal arrangement
6. Include an illustrated description of the primary load bearing airframe structure, and state rational for material selection
7. Show an estimated drag build-up and drag polar for the cruise configuration, the take-off configuration, and the landing configuration
8. Show a weight breakdown of the major components and systems and center of gravity travel
9. Provide an estimate of community noise and compare to standards

10. Provide an estimate of CO₂ emissions from the aircraft, as well as electricity generation
11. Provide an estimate of landing and takeoff NO_x and compare to standards
12. Demonstrate aircraft stability for all flight and loading conditions
13. Describe any advanced technologies or design approaches and their relative benefits as used to obtain performance improvements. For advanced batteries, describe impact if this technology achieves +33% or -33% relative to the stated values, including cost and/or performance changes. Determine level of battery performance where cost is the same for a hybrid electric and conventional aircraft.
14. Provide flyaway cost and life cycle cost estimate for a production run of 500 and 1000 units. Carbon taxes, fuel cost, and electricity cost are specified above. Estimate the sensitivity of the total costs to the assumption for electricity price (for example, what is the impact if the electricity price is \$0.10 instead of \$0.05 per kWh).

References:

- 1) FAA CLEEN – The FAA CLEEN project is looking at a variety of near term technologies that could be applied to this design study.
- 2) NASA ERA – The NASA Environmentally Responsive Aviation program has funded multiple contractor teams that have reported on technologies that could be applied to this design study.
<http://www.aiaa.org/KeySpeeches2012/> (see 50th Aerospace Sciences meeting)
- 3) NASA SFW – The NASA Subsonic Fixed Wing program has funded multiple contractor and NASA teams working on concepts and technologies that could be applied to this design study.
<http://www.aeronautics.nasa.gov/fap/subfixed.html>
http://www.nasa.gov/topics/aeronautics/features/future_airplanes.html
 Of particular relevance is the work reported by the Boeing and General Electric related to hybrid electric propulsion.
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011321_2011011863.pdf

Intent Form

AIAA
Undergraduate Team Aircraft Design Competition

Request for Proposal: **Design of a 2030 Regional Airliner Considering Hybrid Electric Propulsion**

Title of Design Proposal:

Name of School:

Designer's Name	AIAA Member #	Graduation Date	Degree
Team Leader			
Team Leader E-mail			

In order to be eligible for the 2012-2013 AIAA Undergraduate Team Aircraft Design Competition, you must complete this form and return it to AIAA Student Programs (rachela@aiaa.org) **before 22 March 2013**, at AIAA Headquarters to satisfy Section IV, "Schedule and Activity Sequences" of the competition. For any nonmember listed above, a student member application and member dues payment should also be included with this form.

Signature of Faculty Advisor	Signature of Project Advisor	Date
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Faculty Advisor – Printed	Project Advisor – Printed	Date
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APPENDIX H – Instructor Interview Protocol

01/28/2013 – Week 2 & 3 Project Check-in

1. In general, how are students fairing with their projects so far?
2. What roadblocks or challenges are students running into?
3. Can you describe the first project presentations? What did students focus their talks on?
4. Were there discussions of stakeholders? Or the planned design process?
5. What would you like to see in this week's presentations?

02/15/2013 – Week 4 & 5 Project Check-in

1. In general, how are students fairing with their projects so far?
2. What roadblocks or challenges are students running into?
3. What are students focusing their talks on each work?
4. Have students who didn't previously focus on requirements revisited the requirements in their projects so far?
5. Were there discussions of stakeholders? Or the planned design process?
6. What would you like to see in this week's presentations?

03/11/2013 – Prior to Midterm Design Reviews Project Check-in

1. Why do you think student teams have stopped @ acquisition costs or similar metrics rather than \$/psm which is explicitly stated in the RFP?
2. Thinking about stakeholder considerations requires a broad perspective about design, which groups do you feel have the broadest perspective about the design at this stage?
3. What stakeholder requirements would you like to have seen teams consider by the midterm design reviews?

03/25/2013 – Post Midterm Design Reviews Project Check-in

1. If you graded the students' projects today, could you rank or provide an acceptable, marginal, unacceptable score based on team's design approaches/skills?
2. What challenges will the teams face over the next four weeks?
3. How well did they incorporate stakeholder considerations?

04/27/2013 – Post Final Design Reviews

1. Which teams met or exceeded expectations?
2. Who are you most concerned with?
3. Who is on the high end?

05/08/2013 – Final meeting with instructors, included discussions about

- The prototype rubrics (i.e. feedback, recommendations for improvement)
- General reflections on the course and students' projects
- General reflections on the teams' integration of stakeholder considerations

02/28/14 – Follow-Up Meeting

1. What changes have been made to the course since last year?
2. What challenges are the students having on the projects? Are these challenges similar or different from last year?
3. What do you see as the overall impact of my participation in the course (includes the labs, my attendance, etc.)?
4. Do you have any recommendations for me/these interventions moving forward?

APPENDIX I – Informal Focus Group Protocol

As a future aerospace design faculty, I hope to be teaching a senior design course. So I want your perspective on the different components of the design process and what you see as feasible for students to complete over the course of a single semester. (*I will distribute these items on notecards and let students organize them and explain their reasoning as needed*).

1. Configuration Selection
2. Requirements Analysis (based on detailed RFP)
3. FOM Definition
4. Constraint Analysis
5. Cost Analysis
6. Market Analysis
7. Technology Research, Trades, & Selection
8. Sizing the Aircraft
9. Stakeholder Analysis
10. Weight/Balance
11. Historical Research about other similar aircraft
12. Component Design
13. Completed Conceptual Design
14. Aircraft Sketches and CAD Models
15. Or any other additional elements

Follow-up questions: Which areas do you feel most confident about? (in terms of your ability to complete that component of design) Thoughts about the project solicitation?

If Time Questions

1. How is senior design going so far?
2. What would you change about the course if you could? Are there particular topics that you found particularly helpful either this semester or last semester? What about any additional topics you would have found helpful during the fall semester, in preparation for this term?
3. Clarify components of presentations as necessary.

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