

The Impact of Simulation-Based Learning in Aircraft Design on Aerospace Student  
Preparedness for Engineering Practice: A Mixed Methods Approach

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## ABSTRACT

It has been said that engineers create that which never was. The university experience is a key component in preparing engineers who support the creation of products and systems that improve the world we live in. The way in which engineers have been trained in universities has changed throughout history in America, moving from an apprentice-like approach to the still-used engineer scientist. Some in industry and academia feel that this model of engineer preparation needs to change in order to better address the complexities of engineering in the 21<sup>st</sup> century, and help fill a perceived gap between academic preparation and 21<sup>st</sup> century industrial necessity. A new model for student preparation centering on engineering design called the Live Simulation Based Learning (LSBL) approach is proposed based upon the theories of situated learning, game-based learning, epistemic frames, and accidental competencies. This dissertation discusses the results of a study of the application of LSBL in a two term capstone design class in aerospace engineering aircraft design at Virginia Tech. It includes LSBL's impact on student professional and technical skills in relation to aerospace engineering design practice. Results indicate that the participants found the LSBL experience to be more engaging than the traditional lecture approach and does help students respond and think more like aerospace engineering practicing professionals and thus begin to address the "gap" between academia and industry.

**Dedication**

To my family.

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## Definition of Terms

The following terms and definitions are used in various sections of this dissertation and are provided for clarification:

*5 Minute Answer* is a refers to desire for a quick answer to a technical problem commensurate with using quick first order principles.

*AIAA* is the American Institute of Aeronautics and Astronautics.

*ASEE* is the American Society for Engineering Education.

*Aspect Ratio* is  $(\text{Wing span})^2 / \text{Wing Theoretical Area}$ .

*BAA* stands for Broad Agency Announcement.

*Back of the Envelope* is an expression for a quick technical calculation using first order principles.

*CAD* is Computer Aided Design.

*Conception* is the sum of a person's ideas and beliefs concerning something.

*Configurator* refers to aircraft designers in Conceptual Design who generate the initial aircraft concept with all major systems and structure using inputs from all subject matter experts.

*Constrictive Simulation* is a simulation that involves simulated people operating in simulated systems.

*DARPA* stands for Defense Advanced Research Projects Agency.

*Deductive Teaching* is a traditional approach to teaching science and engineering. Instruction begins with the presentation of basic principles in lectures and proceeds to the repetition and application of the lecture content by the students.

*Dogfighting* is Air-to-Air Combat.

*Dyspnea* is a shortness of breath.

*Empennage* is the tail assembly of an aircraft, including the horizontal and vertical stabilizers, elevators, and rudder.

*Epistemic Frame* hypothesis posits that skills, knowledge, values, identity, and epistemology are critical factors in the development of a professional way of viewing the world.

*FLOPS* stands for Flight Optimization System.

*HPS* means Human Patient Simulator.

*Inductive Teaching* is a form of instruction which begins with observations to be interpreted, questions to be answered, problems to be solved, or case studies to be analyzed. The content knowledge, methods, and skills that the course is designed to teach are acquired by the students, with varying degrees of instructor guidance, in the context of those exercises.

*Industry* in this proposal this term is a unifying term referring to both industry and government entities.

*Kendall's Tau* is a non-parametric rank correlation statistic.

*Kill-Ratio* is a comparator in aerial combat. For example, a kill-ratio of 12-1 for the American forces means for every twelve aircraft shot down by an American aircraft, one American plane was shot down by an enemy fighter.

*Kolmogorov-Smirnov* is a statistical test that can be used to determine if a set of data is normally distributed.

*Kremer Prize* is a monetary award, established by the industrialist Henry Kremer, given to pioneers of human-powered flight.

*Kruskal-Wallis* is non-parametric independent samples test statistic used to evaluate differences

between three or more treatment conditions or populations.

*L/D* means lift to drag ratio.

*LISA* stands for Laboratory for Interdisciplinary Statistical Analysis.

*Live Simulation* is a simulation which involves real people operating real systems.

*LSBL* means Live Simulation Based Learning.

*M* is the mean difference when used in discussions of statistical results for repeated measures statistical tests.

*Mann-Whitney U* is non-parametric independent samples test statistic used to evaluate the Difference between two treatments or populations.

*Member Checking* is a process in research where a final transcription, descriptions and themes are taken back to a participant for review to check accuracy.

*Multiversity* refers to a description of the modern university as an enterprise that serves many public and private constituents and balances the desires of many internal and external communities. Term originally coined by former University of California President Clark Kerr.

*PBL* means Problem Based Learning.

*Pembridge Mentoring Model* is a holistic, research-based view of the role that faculty assume when mentoring capstone design students.

*P<sub>j</sub>BL* means Project Based Learning.

*Professional Skills* are skills dealing with items such as the ability to work on multi-disciplinary teams, ethics, communication, lifelong learning, knowledge of contemporary issue, understanding the context (global, economic, environmental) within which engineering solutions must work. These skills are intertwined with technical skills.

*Shapiro-Wilk* is a statistical test used to determine if a set of data is normally distributed.

*Simulation* is a realistic representation (model) of the dynamics or processes with which the participant interacts with the environment, applies previously learned knowledge into the decision making process, and responds with definitive decisions and actions to deal with a problem or situation.

*Simulation Based Learning* includes live action simulation along with computer based simulation.

*SBME* means Simulation Based Medical Education.

*Sweep* refers to wing leading edge sweep in this document.

*TIDEE* refers to the Transferable Integrated Design Engineering Education consortium

*Trade Study* is an examination of various aspects of an engineering design performed to explore and define the design space of a concept. In aircraft design, three types of trade studies that are typically performed include design trades (W/S, aspect ratio, sweep, T/W, etc.), mission trades (range, payload, speed, etc.) and technology trades (TSFC, L/D, empty weight, etc.).

*TSFC* means Thrust Specific Fuel Consumption. It is a measure of propulsion efficiency.

*T/W* means thrust to weight ratio.

*Virtual Simulation* means simulations involving real people operating simulated systems.

*W/S* means wing loading (weight/theoretical wing area).

## Chapter 1: Introduction

What differentiates the expert practicing engineer from the novice? There are a number of factors that can contribute to this difference but many of these can be tied to a single item: experience. The experience of going through multiple iterations of a technical solution to a problem, making compromises, working with customers and colleagues, and a host of other events lead to the advances and setbacks that help shape the effectiveness of a practicing professional engineer. As C.S. Lewis once noted, “experience is a brutal teacher, but you learn. My God, do you learn.” Employers of engineering graduates, both in industry and the government, have made claims that though the engineers being produced in the present engineering education system are strong in technical skill, they are still lacking in certain professional skills that make them not fully ready to practice engineering in the current fast paced , interconnected world. Addressing this disconnect in student preparation is of near term concern as the baby boom generation of engineers retires, leaving a void in experience and knowledge that must be filled in part by new engineering graduates. How did this come about and what is the gap between those that produce engineering graduates (the university system) and those that hire the great majority of engineers (industry and the government)? The following discussion explores this disconnect.

### 1.1 Background

Engineering, as with many professions, is a profession that is in a constant state of flux as it responds to the constantly changing and evolving demands of the society in which it functions. This constant evolution is in part manifested in the way engineers are trained. In the United States, this change has led to substantial shifts in the focus areas of the engineering curricula over the decades.

Seely (1999) provides an excellent synopsis of the changes in American engineering education from the late 1800s to 1965. We see how in the late 1800s, the emphasis of engineering training was on apprenticeship and shop experience while tempering this hands-on experience with some study of theory. The result was engineering graduates that had enough practical knowledge to step right into the jobs that were available during the years following the Industrial Revolution in America. This emphasis began to change in the 1920s as a number of the people who would later become major names in the field of engineering, such as Stephen Timoshenko and Theodore Von Karman immigrated to America from Europe, bringing with them an emphasis on the science and theoretical bases that support engineering practice (Seely, 1999). These individuals assumed positions of power in academia (and trained a new generation of followers of this approach) and subsequently engineering research began to be practiced and emphasized more in engineering programs. The approach spread to programs across the country and gradually the “shop-based” emphasis was phased out and world events such as the Second World War forced the nation to come up with new technologies to help the United States and its allies win the war.

By the mid 1950s the *Report on Evaluation of Engineering Education*, more commonly known as the Grinter Report, recommended that engineering curricula strengthen “work in the basic sciences, including mathematics, chemistry, and physics” (Grinter, 1956, p.25). This report combined with launch of Sputnik in 1957, led to a U.S. government shift to heavily fund efforts in science in order to compete with the Soviet threat. Universities geared their programs to attract these research dollars and thus the strong emphasis in science in engineering began as universities began to depend upon research dollars from the federal government.



This trend in engineering education continued into the 1990s and some began to feel that the pendulum of engineering education had swung too far over to the science side of engineering. This led some to claim that universities were “grinding out legions of research scientists... [and] producing entire generations of engineering faculty who have never practiced engineering” (Curry, 1991, p.50). McMasters and Matsch (1996), representing an aerospace industry perspective, provide another example of the industry dissatisfaction with the type of engineering graduates being produced at the time and noted that:

Engineering is about designing and, in turn, manufacturing things people need and want, for sale. In industrial practice design and manufacturing are inextricably bound together. Thus any engineering education program that inadequately deals with either process, or artificially separates the two, is not responsive to industry needs. Further, while *engineering* and *engineering science* are related, they are not one and the same thing (p. 3).

Industry requested changes to the engineering curriculum in order to handle the mismatch between their needs and the skill sets of engineering graduates (Prados, Peterson, & Aberle, 2001). This call for change combined with some calls for change within academia contributed to the ABET Board of Directors in 1996 to adopt new standards for accreditation, called Engineering Criteria 2000 or EC2000 which shifted the basis for accreditation from what was actually being taught in the classroom to what was being learned by the students (Lattuca, Strauss, & Volkwein, 2006). Under Criterion 3, 11 learning outcomes were specified and programs were required to assess and demonstrate their students' achievement in each of those areas. Among these specified areas was the requirement that students demonstrate “an ability to design a system, component or process” (ABET, 2007, p.2). Universities have adopted capstone

design courses to address this requirement. Among the modern teaching approaches adopted by some programs is project based learning (PjBL) which is a student centered approach that emphasizes “the development of cognitive and practical skills” (Heywood, 2005, p.229) as students typically produce a product design or process as part of the course. The new accreditation approach allowed the old standards which emphasized the sciences, to be combined with a new emphasis on professional skills such as solving unstructured problems and working in teams. These standards became mandatory for accreditation by 2001.

How did this fundamental change in engineering program accreditation criteria impact the mismatch claimed by industry in the years just following the standards shift? The answer to this question depended upon who one asked. Lattuca et al. (2006) discuss the results of a study they conducted on the impact of EC2000 and found that the great majority of the employers surveyed in the study rated new hires as adequately competent in the foundational and technical skills needed in industry. That is to say that they were “adequately prepared or well prepared to use math, science and technical skills” (Lattuca et al., 2006, p.467). Even Jamieson and Lohmann (2009) noted in the report *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* that some perceive that engineering education in a post EC2000 world generates engineering graduates that “design and deliver innovative world-class products and processes” (p.2) and thus U.S. engineering education is doing well and the only changes required at this time are a matter of fine tuning the system.

This view that engineering education was in a near ideal state, however, was not uniformly held. In the same Lattuca et al. (2006) study, it was also found that the same employers, who applauded the advances in the curricula in the right direction from their standpoint, also thought that more attention needed to be paid to building skills, such as communication, teamwork and

use of modern engineering tools. The countering view expressed in that study was not the only one and the criticisms continue to today. In 2005, the National Academy of Sciences report, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, stated that the practice of engineering needed to change to meet the new demands for technologies and products that “exceed the existing knowledge bases” and lead to a change in the professional environment in which engineers need to operate (National Academy of Engineering, 2005, p.13). They expressed a concern for an acceleration of the “disconnect between the system of engineering education and the practice of engineering” (National Academy of Engineering, 2005, p.13). This acceleration of the disconnect was due to the extremely rapid increase in knowledge (readily accessible data through the world wide web), a growing complexity and interdependence of societal problems, the worldwide reach of these problems, and the need to operate in a global economy (National Academy of Engineering, 2005, p.13). As had been the case throughout the history of engineering education, the changing world continued to push engineering to react and change how it conducted business and trains its practitioners.

The call for change in 2005 was reiterated three years later. Redish and Smith (2008) discussed what engineers needed to learn in order to function in the engineering world of 2008 as part of their examination of skill development in engineers. They acknowledged the National Academy of Sciences 2005 study and subsequent studies in 2006 (the National Engineering Education Research Colloquies and the commissioned papers for the National Center on Education and Economy) that held the view that engineering education needed to not only require students to grasp and understand “traditional engineering fundamentals such as mechanics, dynamics, mathematics and technology, but also to develop the skills associated with learning to imbed this knowledge in real-world situations” (Redish & Smith, 2008, p.295). There

was a call to address the skills of creativity, teamwork, design, global collaboration, communication, management, economics and ethics.

In 2011, the call for change in engineering education to address a gap in what academia is producing and what industry desires, continued. In the January 2011 edition of the *Journal of Engineering Education (JEE)*, one finds that no less than four of the six formal papers in that centennial issue (Adams et al., 2011; Borrego & Bernhard, 2011; Johri & Olds, 2011; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011) discuss the existence of a gap between what industry desires in an engineering graduate and what academia is producing as part of their journal paper arguments. Borrego and Bernhard (2011) discuss how industry feels graduates lack important skills such as communication, decision making, problem solving, leadership, emotional intelligence, social ethics, and an ability to work with people from different backgrounds (p.18). Adams et al. (2011) state that engineering education is “holding onto approaches to problem solving and knowledge acquisition that are out of alignment with professional practice” and that “the education undergraduates’ experience overemphasizes a focus on acquiring technical knowledge over preparing for professional practice” (p. 49). Technical problem solving is at the core of this model of engineering education while professional competency is not given as much attention. Both Johri and Olds (2011) and Litzinger et al. (2011) express the need to enhance engineering education to address the workplace and challenges of the 21<sup>st</sup> century.

In the April 2011 issue of *Journal of Engineering Education (JEE)*, the gap between industry and academia continued to be addressed in two papers. In the paper by Yadav, Subedi, Lundeberg and Bunting, they discuss an experience in problem-based learning that was conducted in an electrical engineering class. In their discussion, they continued to re-iterate the previous beliefs that the engineering profession requires engineers to deal with uncertainty and

solve the complex problems of the field while serving as members of a team with communication and problem-solving skills being essential to accomplishing these tasks. They again note previous papers (Mills & Treagust, 2003; National Academy of Engineering, 2005; Nguyen, 1998; Vergara et al., 2009) showing that “today’s engineering graduates lack these skills [communication and problem solving] and have difficulty applying their fundamental knowledge to problems of practice” (Yadav et al., 2011, pp. 253-254).

In the same issue of JEE, Dunsmore, Turns, and Yellin (2011) note that the calls by various councils, national research agendas, and the revisions of accreditation standards set forth by ABET are in pursuit of an integrated conception of engineering where engineering fundamentals are only part of the picture. The recommendations of these various entities indicate “a desire for students to emerge from their degree programs thinking more like working engineers” ( p. 331).

Thus we can see that even though there was action taken by ABET in the 1990s to address the needs of industry and better match industry and academia goals, there still remains a gap between the two entities on how to best prepare students as society continues to evolve. Both entities attempt to address the issue of engineering graduate preparedness by pursuing paths that best favor their survival in the near term. The present academic system continues to conform to a “scientific research enterprise” (Dym, 2004, p.308) and industry favors ready-to-work engineers since the markets in which they function and are funded require it. They demand engineers that have not only technical and problem solving skills but also the global perspective and good communication skills to meet today’s needs. The urgency to address this disconnect is elevated by the pending retirement of the baby boom generation in the next few years. “Trends in the American science and engineering (S&E) workforce ... have troubling implications for the economic and national security of our nation...The basic problem that we face lies in

understanding the trends and their implications for the future. It is important to gain the understanding soon because of the long delays involved in building a workforce with the required skills to replace scientists and engineers of the baby-boom generation, who are retiring just as the needs of national defense and homeland security are increasing” (Marshall, 2004).

## **1.2 Statement of the Problem**

The present engineering education system, by in large, emphasizes training in the science of engineering more than the practice of engineering. This produces technically capable engineers that do not have the professional skills such as teamwork, communication and system level problem solving that are required to meet the needs of the global economy. With the pending retirement of a large portion of the existing engineering workforce, the importance of preparing “ready to work” engineering graduates in the near term is heightened in order to allow for the outgoing generation of engineers to introduce the incoming generation of engineers to the ways and experiences of the previous generations of engineering practitioners. The outcomes based approach to engineering school accreditation and in particular capstone design courses (some using modern inductive teaching approaches) have been the response by academia to address the concerns expressed by industry and others, and yet the calls for improved engineering graduates continue. Why is the present outcomes-based accreditation system not yielding the quality of engineer needed in the United States and what modifications or alternatives exist that can be utilized to help create the ready to work engineer desired and soon to be needed by the nation?

## **1.3 Purpose of the Study**

The intent of this concurrent mixed methods study is to better understand the impact of simulation based learning environments that emphasize “realism through simulation” on capstone design students’ conception and view of engineering design (and indirectly engineering

as whole). A model for live simulation based learning (LSBL) based in educational theories such as situated learning theory is proposed and tested. In the study, the quantitative analysis utilizes a combination of design reports, design presentations, and a design conception questionnaire (with emphasis on professional skills) to measure the relationship between LSBL approach in a capstone design course and student conceptions of engineering design. At the same time, the qualitative analysis explores the effect of LSBL using one-on-one semi-structured interviews with aerospace engineering capstone design students at Virginia Tech. The reason for combining both the quantitative and qualitative data was to better understand this research problem by converging both quantitative data (broad numeric trends) and qualitative data (detailed views).

#### 1.4 Significance of the Study

The LSBL model was developed for use in engineering capstone design to provide students real world experience to aid in the transition to the professional community of practice by broadening professional and technical skills, engineering professional identity, professional values, and epistemology (similar to the goals of the epistemic frame of Shaffer (2007)). This is accomplished following Gee's (2008) five elements of useful learning experiences found in game based learning which include specific goals, interpreting the experience, feedback, applying previous experience, and experience interpretation with others. In essence LSBL aims to accelerate the transition of the student from novice engineer to expert engineer through engaging real world simulation by providing the experiences that build the *conditionalized knowledge* that is characteristic of the expert (Bransford, Brown, & Cocking, 2000). The model is geared for use in capstone design courses involving large complex systems such as aircraft and naval vessels where students typically only complete the conceptual design stage of the design

process. As part of this model, an aircraft design synthesis model tool utilizing a combination of the industry programs Microsoft Excel, ModelCenter, CATIA, and Flight Optimization System (FLOPS) was developed with appropriate scaffolding, allowing the student to gain rapid tool proficiency. Though the presented approach is geared towards engineering design courses, it may also be used in classes involving subjects that are separate subject matter expert disciplines in the professional world (e.g. a structures course may be simulated to follow the point of view of a structures engineer working in airframe on a design team in industry).

The study provides a direct comparison of the engineering design conceptions of the same discipline/task capstone design students at a large university with real world active air vehicle design practitioners. In addition, reflections on and demonstration of the professional traits are examined in order to provide insight into how the current capstone design educational approach impacts the students' engineering design conception and how the LSBL model changes that impact.

In addition to the LSBL model, a synthesized and detailed explanatory account of the disconnect between academia and industry in engineering education is presented. Combined, the explanatory account and LSBL model provide a narrative and a possible solution to this challenge in engineering education. Addressing this critical need will be necessary in order maintain the preeminence that the United States has held in engineering, especially with countries such as the Republic of Singapore declaring a desire to be a world leader in innovation and a willingness by the government of that country to invest in efforts to make this goal a reality (Kao, 2007).



## 1.5 Research Overview

Figure 1 provides an overview of the research discussed in detail in Chapter 3. In an attempt to address the disconnect between industry and academia on the preparation of students for work in industry, especially relative to professional skills, LSBL model has been developed. Situated learning theory, Walther and Radcliffe's (2007) Accidental Competencies frame, James Gee's traits of good game-based learning experiences (2008) and Shaffer's Epistemic frames (2007) form the core of the theoretical framework for the model. A class of aerospace engineering senior design students is broken into two groups for the experiment testing two extremes of instruction for design, the classic deductive lecture style and the inductive LSBL approach. Data is collected in the form of semi-structured interviews, a design conception survey (used in the Academic Pathways Study), and senior aircraft design deliverables (report and presentation) to measure the impact of the two approaches on student views of professional practice and skills in aerospace engineering design. This data is then analyzed and with both quantitative and qualitative methods. From these results, conclusions are drawn about the effectiveness of the LSBL approach to address the issue of engineering professional skills and transition.

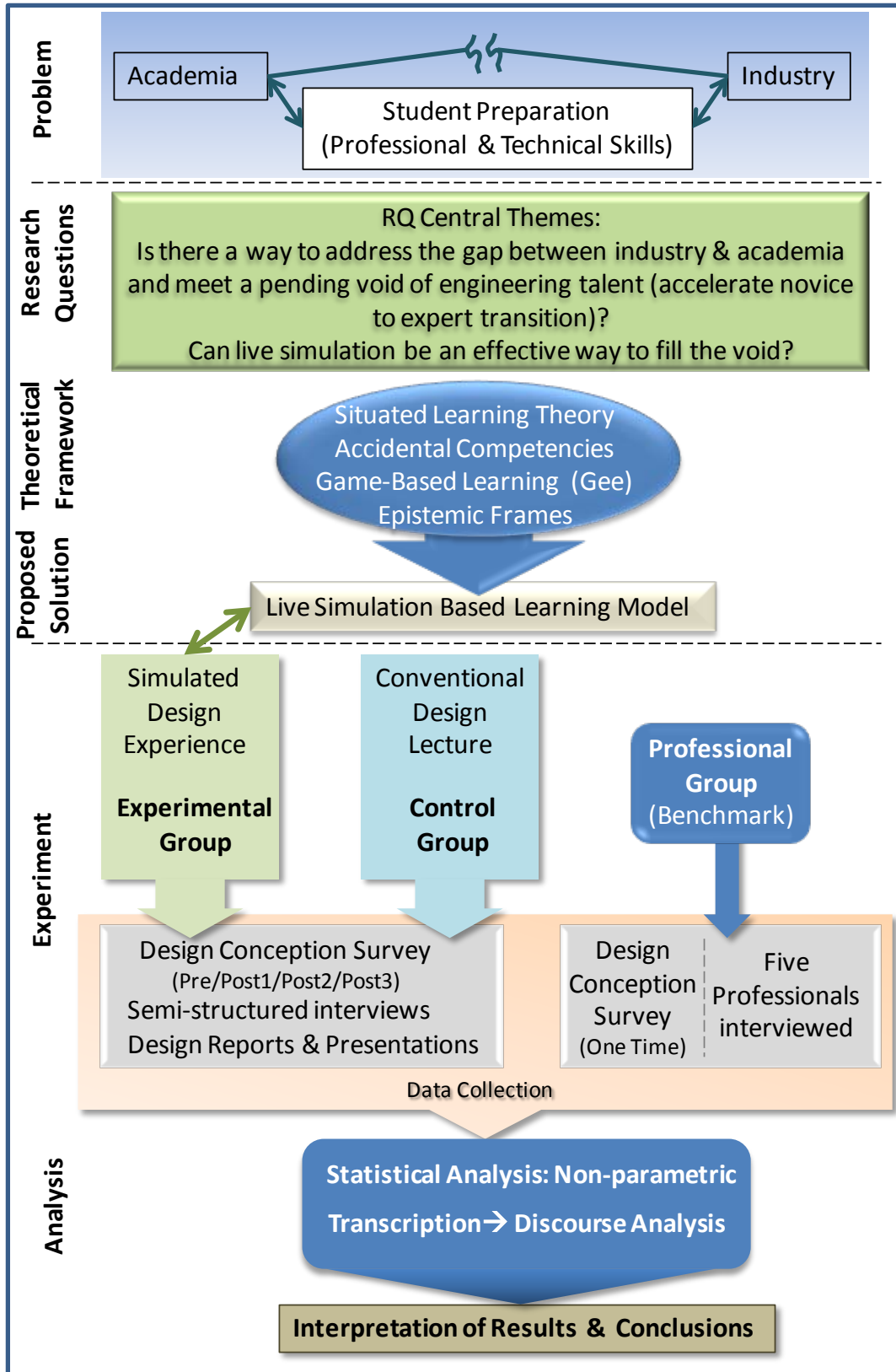


Figure 1. Dissertation Research Overview.

## **Chapter 2: Review of the Literature**

A review of the literature indicates a cultural difference between industry and academia with students/graduates caught in the middle having to negotiate both ends of the spectrum. The following sections discuss in detail the specifics of the gap, what the predominate response has been by academia to minimize or eliminate the gap, why the gap still remains after these efforts, and what other educational alternatives exist that may succeed in closing the gap in ways where others have failed.

### **2.1 Specifics of the industry and academia gap in student preparation needs**

In order to best understand why industry feels engineers being produced today are not fully meeting their needs, a discussion of the traits desired by industry is in order. Various entities in academia, industry, the government and other organizations have developed and published “desired traits/attributes of a graduating engineer” lists. In this discussion, lists from primarily non-academic entities will be examined in order to best represent the desires of government and industry for their new hires. Tables 1 and 2 are engineer desired traits/skills lists from the National Association of Colleges and Employers (NACE), the Boeing Corporation, the International Engineering Alliance, former Boeing CEO Phil Condit, National Academy of Engineering and Leland Nicolai and Eric Schrock of Lockheed Martin Aeronautics Company. Though most of these entities have dealings with aerospace engineering, all but the necessary skills suggested by Nicolai and Schrock are generic traits that could be applied in any field of engineering. Early versions of the Boeing Corporation traits influenced the ABET Criterion 3 Program Outcomes mentioned in the Introduction and discussed further in the next section. The Nicolai and Schrock skills in Table 2 are particular to design and represent the types of skills and

design tasks that new engineers need to design on an industry level and should be familiar with before leaving university.

An examination of each of these desired traits and attributes lists reveals that there are number of common entities among them. These include communication, teamwork and collaboration, understanding and applying knowledge, continuous learning, ethics, understanding the context of engineering practice, flexibility, and critical and creative thinking. Though a number of the traits could be considered technical skills such as computer and analytical skills, a large number of the traits and attributes fall under the heading of professional skills that when combined with the technical skills make for an effective practicing engineer in today's world (Shuman, Besterfield-Sacre, & McGourty, 2005).

Table 1 *Desired Engineer Traits / Skills*<sup>1</sup>

<i>Qualities/Skills (In order)</i>	<i>Attributes</i>	<i>Attributes</i>	<i>Attributes</i>	<i>Competency</i>	<i>Attributes</i>
National Association of Colleges and Employers	Boeing	Phil Condit (Boeing)	International Engineering Alliance	National Academy of Engineering	
• Communication skills	• A good understanding of engineering science fundamentals.	• Collaboration	• Comprehend & apply universal knowledge	• Strong Analytical Skills	
• Honesty/integrity	• A good understanding of design and manufacturing processes.	• Communication	• Comprehend & apply local knowledge	• Practical Ingenuity	
• Interpersonal skills	• A multi-disciplinary, systems perspective.	• Cost Awareness	• Problem Analysis	• Creativity	
• Motivation/initiative	• A basic understanding of the context in which engineering is practiced.	• Continuous Learning	• Design & development of solutions	• Communication	
• Strong work ethic	• Good communication skills.		• Evaluation	• Business and Management Skills	
• Teamwork skills	• High ethical standards.		• Protection of Society	• Leadership	
• Analytical skills	• An ability to think both critically and creatively - independently and cooperatively.		• Legal and regulatory	• High Ethical Standards	
• Flexibility/adaptability	• Flexibility. The ability and self-confidence to adapt to rapid or major change.		• Ethics	• Professionalism	
• Computer skills	• Curiosity and a desire to learn for life.		• Manage engineering activities	• Dynamism, Agility, Resilience, Flexibility	
• Detail oriented	• A profound understanding of the importance of teamwork.		• Communication	• Lifelong Learner	
• Leadership skills			• Lifelong learning		
• Organizational skills			• Judgment		
• Self-confidence			• Responsibility for decisions		
• Friendly/outgoing personality					
• Tactfulness					
• Well mannered/polite					
• Creativity					
• GPA					
• Entrepreneurial skills/risk-taker					
• Sense of humor					

Table 2

*Desired Skills of an Aerospace Aircraft Design Engineer*

- Analyzing requirements
- Developing a strategy to address the requirements
- Executing initial sizing and developing preliminary sketches
- Making tough decisions among different configuration choices
- Substantiating the choices with engineering analysis
- Developing configuration drawings
- Executing vehicle sizing to constraints
- Performing trade studies
- Making design decisions and executing them
- Documenting and finalizing the design concept

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*Note.* Adapted from *What would industry like to see covered in the senior capstone design course?*, by L. Nicolai, and E. Schrock, 2010, Paper presented at the 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference. Copyright 2010 by AIAA.

A review of the literature also reveals a number of papers where employers specifically state areas where engineering graduates could have improved preparation for real world practice and these are shown in Tables 3a through 3d. The table contains the article name and journal or proceedings title, the publication year of the article, the phrasing used to indicate an improvement is needed in the engineering graduate and the exact skill or attribute mentioned by the employer as needing improvement. The articles come from a review of engineering education literature examining specifically papers that discuss the desired traits for practicing engineers and papers mentioning shortcomings in engineering graduates. Most articles come from major journals in engineering education such as the *Journal of Engineering Education*, the *International Journal of Engineering Education* and the *Australasian Journal of Engineering Education*. The articles chosen for this table were limited to those published after 2001 in order to account for the changes enacted as a result of ABET EC2000.

Table 3a

*Industry/Academia disconnect specifics found in the literature*

Year	2011	2011	2011
Author	Charyton, Jagacinski, Merrill, Clifton, DeDios	Korte	Tryggvason, Apelian
Article Title	Assessing Creative Engineering Design	How Newcomers Learn the Social Norms of an Organization: A Case Study of the Socialization of Newly Hired Engineers	Meeting New Challenges: Transforming Engineering Education
Source Title	Journal of Engineering Education	Human Resources Development Quarterly	<i>Shaping Our World: Engineering Education for the 21st Century</i>
Phrase Indicating Disconnect	"today's engineers need to be more ..."	"Preliminary investigation of the experiences of engineers starting a new job that the most troublesome experience was learning how to work within the social systems of the organization."	"...as skill becomes a commodity and routine engineering services are available from low cost providers that can be located anywhere in the world, engineering education has to add value beyond just teaching skills. It seems reasonably safe to expect that the added value will include an extensive exposure to..."
Listed Area of Disconnect	creativity, innovation	organizational socialization	innovation, entrepreneurship, communication

Table 3b

*Industry/Academia disconnect specifics found in the literature*

Year	2011	2011	2011
Author	Yadav, Subedi, Lundberg, Bunting	Niewoehner	Dunsmore, Turns, Yellin
Article Title	Problem-based Learning in Electrical Engineering	CDIO Syllabus Survey: Systems Engineering and Engineering Education for Government	Looking Toward the Real World: Student Conceptions of Engineering
Source Title	Journal of Engineering Education	Proceedings of the 7th International CDIO Conference	Journal of Engineering Education
Phrase Indicating Disconnect	"...today's engineers lack these skills and have difficulty applying their fundamental knowledge to problems of practice"	"...accreditors charged U.S. engineering schools with re-orienting their programs to ensure student competency in traditional engineering science subjects...intended reforms largely stalled short of the original goal due in part to a lack of clear stakeholder direction and engagement..."	"Among the specific concerns voiced has been the need to prepare engineering students for the changing working world of engineering. Among the dimensions of preparation often mentioned are enhancing..."
Listed Area of Disconnect	dealing with uncertainty, teams, communication, problem solving	communications, teamwork	communications skills, dealing with the globalizing economy



Table 3c  
*Industry/Academia disconnect specifics found in the literature*

Year	2011	2010	2010
Author	Borrego, Bernhard	Van Treuren	Dees
Article Title	Emergence of Engineering Education Research	Never too Old to Learn: A Report on the Experiences in Boeing's Welliver Faculty Fellowship Program	An Industry Perspective on Future Needs for Aircraft Design Education
Source Title	Journal of Engineering Education	ASEE 2010 Annual Conference and Exposition	10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference
Phrase Indicating Disconnect	"...survey of relevant literature on student learning outcomes shows that graduates from university courses lack important skills..." "...students do not have the requisite ability to..." "...workplace performances of engineering graduates have been a constant subject of criticism"	"Most engineering programs do not talk about topics such as..."	"Some of these attributes are covered in typical aerospace engineering undergraduate curricula, but many are not... several could be better emphasized in coursework"
Listed Area of Disconnect	communication, decision making, problem solving, leadership, emotional intelligence, social ethics, work with people from different backgrounds	global market, lean engineering	project management, aircraft design & integration, practical design knowledge, communication, presentation and teaming skills, systems integration, business basics

Table 3d

*Industry/Academia disconnect specifics found in the literature*

Year	2007	2007	2006	2001
Author	Boyette	Walther, Radcliffe	Lattuca, Strauss, Volkwein	Gorman et al
Article Title	Viewpoint- The Problems of Teaching Practical Design To Today's Engineering Students-the Agricultural Engineering Experience	The competence dilemma in engineering education:Moving beyond simple graduate attribute mapping	Getting in Sync: Faculty and Employer Perceptions from the EC200	Transforming the Engineering Curriculum: Lessons Learned from a Summer at Boeing
Source Title	International Journal of Engineering Education	Australasian Journal of Engineering Education	International Journal of Engineering Education	Journal of Engineering Education
Phrase Indicating Disconnect	"Employers complain bitterly that recent graduates ... " are not able to...	" ..engineering graduates have deficiencies with respect to crucial job skills such as..."	" ... are assessed as least adequate by 3 out of 4 employers	"Each Welliver Fellow developed individual ideas about what improvements could be made based on their experience at Boeing ."
Listed Area of Disconnect	ability to apply engineering education to real world problems	problem-solving, communication, entrepreneurship, dealing with complex interactions	teamwork, communication skills, understanding of the organizational, cultural, and environmental contexts and constraints of one's work	engineering fundamentals, communication, design & manufacturing, continuous learning

As with the traits/attributes tables, there are again certain skills or traits that reoccur across the literature from the 2001 timeframe forward. We find a fair amount of overlap with the employer desired traits and attributes. The skills needing improvement include communication, working in teams, lifelong learning, applying engineering knowledge to solve problems, decision making, organizational socialization, creativity and innovation, entrepreneurship, working in the global economy, understanding of design and manufacturing, ethics, leadership and emotional intelligence. The three most mentioned items are communication, working in teams, and applying engineering knowledge to solve problems. As will be seen in the next section, many of these traits or attributes are cultivated and demonstrated in engineering capstone design courses. Most of these traits are also specifically mentioned in the ABET Criterion 3 Program Outcomes.

## **2.2 Today's predominant approach to addressing the gap**

The change in the accreditation process by ABET from the quantitative measure of inputs and resources to the outcomes based approach provides a way for the public to gain insight into how the learning gained in various programs of an institution translate into the marketplace of employment and into their lives (Council for Higher Education Accreditation, 2003). Each engineering program must:

define program objectives to meet their constituents' needs and implement a structured, documented system for continuous improvement that actively and formally engages all of its constituents in the development, assessment, and improvement of academic offerings.

Programs must also publish specific goals for student learning and measure their achievement to demonstrate how well these objectives are being met (Volkwein, 2006).

As a result, the importance of assessment of the learning has become a major focus for an engineering degree program. As mentioned in the Introduction, this shift was due in part to

employer's concerns that there was a mismatch between the needs of industry and the skill sets of the graduates being produced by engineering programs. In addition, engineering faculty and administrators felt that ABET's prescriptive accreditation criteria approach were hindrances to curricular and pedagogical innovation (Prados et al., 2001). The program outcomes presented in Table 4, that are found in Criterion 3 of EC2000, are representative of the compromises that were achieved between ABET, employers of engineers and others to create an accreditation process that would help compliant institutions train and graduate engineers that would better meet the needs of all constituents.

Table 4

*ABET EC2000 Program Outcomes*

- 
- (a) Ability to Apply Knowledge of Mathematics, Science, and Engineering
  - (b) Ability to Design and Conduct Experiments, as well as to Analyze and Interpret Data
  - (c) Ability to Design a System, Component, or Process to Meet Desired Needs
  - (d) Ability to Function on Multi-Disciplinary Teams
  - (e) Ability to Identify, Formulate, and Solve Engineering Problems
  - (f) Understanding of Professional and Ethical Responsibility
  - (g) Ability to Communicate Effectively
  - (h) Broad Education Necessary to Understand the Impact of Engineering Solutions in a Global/Societal Context
  - (i) Recognition of the Need For, and an Ability to Engage in Life-Long Learning
  - (j) Knowledge of Contemporary Issues
  - (k) Ability to Use the Techniques, Skills, and Modern Engineering Tools Necessary for Engineering Practice
- 

Adapted from *Criteria for accrediting engineering programs: Effective for evaluations during the 2008-2009 accreditation cycle*. Copyright 2007 by ABET, Inc.

An examination of the list reveals that the engineering program which meets these program outcomes aims to produce a technically sound, well rounded engineer. As mentioned in the previous section, a number of these outcomes overlap as areas needing improvement in the recent engineering graduate.

The program curriculum must prepare a student for engineering practice. This curriculum must culminate into a major design experience (often called capstone design) that

builds upon the knowledge and skills that students have acquired in earlier coursework and incorporating appropriate engineering standards and multiple realistic constraints (ABET, 2007, p. 3). Capstone design is the course where undergraduates have the opportunity to apply lessons learned from the various engineering courses they have previously taken to “generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” (Dym, Agogino, Eris, Frey, & Leifer, 2005, p.104). As described by Pembridge and Paretto (2010a):

capstone design experiences represent a critical transition between the academic classroom and the contemporary workplace, and as such have become both important sites for industry partnerships and essential components of programmatic assessment and accreditation<sup>1</sup>. Capstone projects typically require students to move beyond rote knowledge and apply life-long learning, engineering judgment, analytical decision-making, and critical thinking to address complex problems in light of a broad spectrum of social, environmental, economic, and global constraints (p.1).

In addition, Litzinger et al. (2011) note that capstone design is where students develop “the additional skills necessary such as the ability to identify the nature and relevant context of the problem, what knowledge is needed to address it, and what methods are best suited to solve the problem” (p.134). The course has become the standard response from academia across the country to the perception that the engineering graduates being produced are “unable to practice in industry because of the change of focus from the practical...to the theoretical” (Dym et al., 2005, p. 103). Both the program outcomes and the capstone design requirement are very broad statements and it is left up to the individual institutions and programs to define what is entailed to meet each of the a-k program outcomes and what the composition of the capstone course must

be. As a result, how these requirements are met in different programs varies widely in the United States.

In 2005, a survey of engineering capstone design courses nationwide was conducted to capture the educational and logistical practices in capstone design courses at the time (Howe, 2010). The study was a follow-up to a 1994 study by Todd, Magleby, Sorenson, Swan, and Anthony. The 57 question survey was answered by 444 programs from 232 institutions, yielding response rates of 26% among programs and 66% among the institutions that were invited to participate. Department types included chemical, civil, electrical, mechanical, industrial, and aerospace engineering along with a number of new fields. Respondents to the survey were asked to identify topics taught in their capstone courses. The list of topics that 50% or more of the respondents covered contains: communication, ethics, project planning and scheduling, decision-making, teambuilding, team dynamics, engineering ergonomics, developing/writing functional specs, safety in product design, and leadership (there are an additional 14 other topics that at least 13% of the respondents included in their programs not included in this list) (Howe, 2010). As one can see, a number of these topics overlap with the list of items that industry felt were lacking in the previous section including communication, teamwork, and decision making.

Another nationwide capstone design survey was conducted in 2009 by Pembridge and Paretto. This study sought to systematically explore the teaching and learning of engineering design and help identify areas of faculty development to support both current and future design educators. It utilized a 45 item survey that explored faculty background, teacher beliefs, teacher practices, course management, and institutional demographics. The survey received a total of 491 responses (39% response rate) from 204 institutions (53% response rate) that had ABET accredited engineering programs. The engineering departments participating in the survey

coincide with those in the 2005 study by Howe (chemical, civil, electrical, mechanical, industrial, aerospace etc.).

In this survey, the top five topics that the respondents covered in their capstone design courses were engineering ethics, project planning, communication, and concept generation. Each of these topics had 49.7% or more of the respondents indicate that the topic was covered in their capstone course. These topics coincide with the topics mentioned from the 2005 Howe survey with the exception of concept generation. In this same survey, most of the respondents felt that the purpose of the capstone course was to provide opportunities for students to synthesize and apply prior coursework in an environment that simulates real world experiences through open ended projects. This belief helps to guide how they teach the capstone class and what they expect the students to learn in the class (Pembridge & Paretti, 2010a, p. 8).

Most of the respondents viewed their role in the capstone class as being a “guide” instead of an “instructor.” In particular, the top three roles that they perceived themselves to have in the capstone course was to guide: (1) the development of project scope, (2) students in finding relevant technical information on their own and (3) the development of detailed deliverables (Pembridge & Paretti, 2010a). Such a view is consistent with the project-based learning approach where according to Prince and Felder (2007) there are:

assignments that call for students to produce something, such as a process or product design, a computer code or simulation, or the design of an experiment and the analysis and interpretation of the data. The culmination of the project is normally a written or oral report summarizing what was done and what the outcome was (p.16).

Instructors in this method vary in their role as “managers of learning” (Heywood, 2005, p. 238) depending upon the type of project undertaken. In the *task project* approach, student teams work

on projects that have been defined by the instructor and largely use instructor prescribed methods. In the *discipline project* approach, the instructor defines the subject area of the projects and specifies in general terms the approaches to be used (which normally involve methods common in the discipline of the subject area), but the students identify the specific project and decide and design the particular approach they will take to complete it. Finally in the *problem project* approach, the students have nearly complete autonomy to choose their project and their approach to it (Prince & Felder, 2006, p. 130). Often the instructor in this approach needs to point out how previous material used on other projects or in previous courses tie into the project at hand and the instructor may employ the help of students who readily see this link to help bring the rest of a class or group up to a comparable level of understanding. According to Dym et al. (2005), project-based learning it is inherently multidisciplinary in nature, promotes collaboration and addresses the issue of transfer (the ability to extend what has been learned in one context to other, new contexts), which are all key aspects of design as it is practiced in the real world.

As one can see, capstone design is an integral part of the preparation of the students for the real world engineering practice. It is an essential element to receiving ABET accreditation and many of the capstone design instructors feel that it is the course where many of the professional skills outlined in the Criterion 3 Program Outcomes are cultivated and demonstrated. Unfortunately, we also see that many of these same professional skills or attributes are also the ones that employers are indicating need improvement in the engineering graduate. Why are some of the very skills and attributes that the ABET program outcomes and capstone design are meant to address still not satisfying the needs of employers even after a shift to the program outcomes approach of EC2000?



The literature provides some insight into the causes. Relative to industry's part on this matter, Niewoehner (2011) states that there was an "incomplete/unclear demand signal" where industry and government have not actively ensured that the nation's engineering schools clearly know and understand industry and government's requirements of an engineering graduate (Niewoehner, 2011, p. 1). Adams et al. (2011) state that engineering education is holding on to approaches to problem solving and acquiring knowledge that are out of line with professional practice, stress technical problem solving and give superficial attention to the professional competencies (pp. 49-50). Borrego and Bernhard (2011) note that relative to professional skills "the way in which we educate them needs to change" and that the passive, lecture-style teaching approaches often used in engineering education are "not likely to develop the professional skills now required in industry, government, and academic employment" (p.19). It is suggested that inductive learning approaches, such as project-based learning, may be better ways to develop the professional skills. As has been noted, many of the capstone design courses today use project-based learning but there still are deficiencies in these areas. Why is this so? The literature indicates that the answer to this lies partially in the history and resulting university culture introduced earlier and in the way the two stakeholders, industry, government and academia, view the meaning of the ABET program outcomes.

### **2.3 Contributors to the present situation**

Industry and academia operate in different cultures. These cultures and their appropriate folkways and mores impact how they approach problems and how they operate and function. For industry, the culture is seated in the free market system. Every aspect of a company is generally geared to support making a profit for the company. This is accomplished by designing, manufacturing, and selling a product in the marketplace. This product has to beat the

competition to the marketplace and preferably do it with better quality. Timing and quality are considered to be essential and both of these are dependent upon the design of the product (Nicolai, 1998, p.7). Engineers help to make all of this happen and are considered one of the company's key resources.

As discussed in the Introduction, the present day model of engineering education tends to emphasize engineering science where engineering classes and design are taught only after a solid basis in science and mathematics has been established. These courses are often taught using a deductive lecture style of teaching (Yadav et al., 2011, p.254). Dym et al. (2005) note that the first two years of an engineering curriculum are devoted primarily to the basic sciences, which serve as the foundation for two years of "engineering sciences" or "analysis" where students apply scientific principles to technological problems and this still has changed little since the time of the Grinter report. Dym (2004) illustrates this split of engineering to science courses for civil engineering at both Cooper Union and Harvey Mudd by comparing curricula from 1962 to 2002 (p. 306). The strong emphasis on science and engineering science courses is evident at both schools. Focusing in on engineering design, if one were to look at a typical aerospace engineering curriculum through the years, we would see that design only occupies a small percentage of the overall curriculum. Dees (2010) compares his curriculum from the University of Illinois in 1979 to the one used at the same institution in 2009. We see in 1979 that only three credit hours of the 134 credit hours required to graduate were given to the senior aerospace design course. By 2009, we see improvement in the number of design course hours with there being six credit hours out of a 128 credit hour curriculum dedicated to senior aircraft design. This is an improvement from roughly 2% of the curriculum dedicated to design in 1979 to roughly 4.6% of the curriculum dedicated to design in 2009. Examining the 2009 curriculum

further, the 4.6% of dedicated design course hours is roughly half of the credit hours dedicated to explicit science courses such as chemistry and physics (totaling ~9% of the curriculum). This does not even count engineering science courses such as statics and dynamics. A look at the 2010 Virginia Tech aerospace engineering curriculum yields a similar finding with only 4.4% of the curriculum explicitly dedicated to capstone design (if we include the cornerstone design class of the freshman year, the design exposure increases to roughly 6%) (Virginia Tech Department of Aerospace and Ocean Engineering, 2011). The Virginia Tech and University of Illinois aerospace programs are fairly typical of the aerospace engineering programs in the U.S.

This emphasis on engineering science and the resulting research associated with this science is integral to the present research university system that Richard DeMillo in *Abelard to Apple: Fate of American Colleges and Universities* refers to as the *multiversity* which is “an enterprise that serves many public and private constituents and balances the desires of many internal and external communities” (DeMillo, 2011, pp.4-5). In this system, the creation of knowledge is highly prized and entities such as the National Science Foundation, National Institutes of Health, Defense Advanced Research Projects Agency, and the Department of Energy fund research in the sciences, engineering, and mathematics. The amount of money expended by these federal government agencies to such research is not insignificant. Today, of the approximately \$120 billion spent on research and development by the U.S. government, \$43 billion is directed towards nonmilitary research. In the time between 1953 and 2004, basic funding for scientific research grew at an annual rate of 6.3% which is nearly double the average annual rate of growth of the economy as whole (DeMillo, 2011, pp.7-8).

Research universities have altered their missions and priorities to accommodate meeting the needs of this tremendous source of funding. As a result, the role of the university professors

has changed as they became the maintainers of the “research operation” with responsibilities to raise money; staff, equip and manage complex facilities; and mount marketing campaigns to help justify the large expenditures of public funds. All of these responsibilities come in addition to teaching requirements that professors usually have. Professors must juggle all of these responsibilities in a way that will also help them to achieve the secure position of tenure. This pursuit often takes around six years to achieve and the criteria to achieve it vary from university to university (DeMillo, 2011). Much as in the sports industry where there is competition for a gifted athlete, there is competition among universities and with industry for top notch research talent. As a result of this lucrative research enterprise, classroom teaching, in many cases, tends to occupy “only a small fraction of a professor’s workday” (DeMillo, 2011, p. 10).

Nicolai (1998) sums up the state of affairs for engineering design in the “multiversity” by stating that universities do not, in general, value engineering design as an “intellectual activity” either in research or in teaching whereas American industries, do place the highest value on engineering design in their product development (Nicolai, 1998, p. 7). Dym et al. (2005) note that design is one of the top controversial curriculum matters in the university system and it only seems to be addressed when programs are about to be reviewed for accreditation by ABET (p.103). As McNair, Newswander, Boden, and Borrego (2011) note with regards to the ability to do interdisciplinary teamwork (i.e. cross-functional teaming) which is a trait of real world design and a skill desired in new graduates:

traditional disciplinary structures of higher education institutions stand as barriers to interdisciplinary teaming at both student and faculty levels. Alignment of departments, budgets, and promotion and tenure with traditional disciplines stands as significant

obstacle to faculty members' pursuit of interdisciplinary teaching and research, which has direct implications for undergraduate student learning (p. 375).

Though this quote is specifically aimed at interdisciplinary teaching and learning, the same could be said and holds true for engineering design. Dym et al. (2005) note that 'design' faculty (as opposed to the 'analysis' faculty) have trouble articulating the art and complexity that is engineering design which also contributes to the situation that the "leaders of engineering departments and schools are unable or unwilling to recognize the intellectual complexities and resources demanded to support good design education" (p. 103). Chudoba and Striz (2005) also note that in academia, generally the design activity is held in low regard when compared to scholarly research and that this has implications for the design faculty member in the university system. Departments, as is, are more likely to support subjects and research that are tied to the classical sciences due in part to the fact that such areas are typically well funded by outside sources such as the federal government, as has been shown. This claim is evidenced by the fact that at the end of the Dym et al. (2005) article, a major recommendation made by the authors is that faculty and administration need to raise the priority of design pedagogy in future resource allocations.

A further example of the lack of prioritization of design relative to other areas of engineering education can be seen by the way some engineering departments select the design instructor. Instead of an extensive look for an individual with practical experience in design, some departments pressure a faculty member into coordinating the capstone design course simply because the faculty member is available or willing to teach the course (Dutson, Todd, Magleby, & Sorensen, 1997). Design is a course that requires skill and a significant number of

manhours to coordinate and execute especially when using an approach such as project-based learning.

The Pembridge and Paretti (2010b) study indicated that among the respondents, around 77% of the instructors had greater than eight years of teaching experience overall and that around 50% had greater than eight years teaching capstone design courses. In the same study, while nearly 43% of those instructors had professional work outside of academia (e.g. industry, government) in the field associated with the capstone design course they teach, 49% had five years or less of such experiences and 20% had less than one year of non-academic experience (Pembridge & Paretti, 2010b). Such figures indicate a large amount of academic experience and in some cases a notable amount of non-academic experience in the same field that the instructor teaches capstone design. On the other hand, a large portion of the this sample has limited experience practicing engineering in a non-academic setting with about a fifth of them barely having any experience in that arena. This indicates that in some cases, a co-op student may have more experience in the field than the instructor. The survey does not indicate when the respondents had their non-academic experience or if it was even in design.

Selecting instructors for such a critical course as design strictly because of their availability is not fair to the potential instructor, who may not want to do the course, or to the students, who now unfortunately gain a capstone design experience taught by someone who may not have a great interest or experience with the subject. Such ways of operating by some engineering departments are good examples of a lack of design prioritization in the curriculum. What role, if any, do these traits of the multiversity have on engineering student preparation and do they contribute to the gap? The next section explores a theory on how all of these elements may combine to explain the gap.

## 2.4 The Competency Dilemma

Sheppard, Macatangay, Colby, and Sullivan (2009) studied schools of engineering in the United States and accreditation self-reports to determine the state of engineering education as part of a Carnegie Foundation series of reports on professional education. In their book *Educating Engineers: Designing for the Future of the Field*, they conclude that the current engineering curricula are heavily weighted toward analysis and this comes at the expense of developing design, experimentation and professional skills and as a result, enhancements to engineering education are needed to help graduates meet the challenges of the twenty-first century. They suggest that U.S. undergraduate engineering education be remade and that more emphasis be given to provide students more experiences that mirror professional practice and problem solving in order to better transition them from thinking like students to thinking like professionals. Academia, industry and the government must come together in order to make this happen.

Walther and Radcliffe (2007) examined the gap between academia and industry and proposed a reason behind it. They name the gap the *competency dilemma*. They believe that the reason behind the difference between what industry views as meeting the ABET program outcomes and what academia views a meeting the ABET program outcomes is not simply an issue of the “quality of the instructional design and teaching delivery” but is at a more fundamental level dealing with what is considered competence in both arenas, hence the term competency dilemma (p.42). The gap between industry and academia is characterized as difference in the approach to competency. Industry looks for certain traits in an employee, uses behavior-based competency tests and uses critical incident methods in evaluation. It values that an employee has a certain set of competencies and skills and has little concern as to how these

competencies were achieved, just as long as they are present. Academia, on the other hand, educates for technical skills, uses academic aptitude tests for assessment and expert panels to determine desired attributes in the graduate. It aims to achieve a difference in a students' competence and skills via learning (Walther & Radcliffe, 2007). Industry historically places emphasis on practical job skills and being able to apply skills in various situations. This is viewed as being at the heart of engineering. Academia historically emphasizes gaining scientifically rigorous knowledge and having a wide technical breadth (Walther & Radcliffe, 2007). These two different views of competency are consistent with the earlier discussions of the characteristics of the multiversity and industry. These differences in culture clash in the implementation of the outcomes-based form of accreditation.

In academia, in order for the instructor to deem the student competent relative to the desired outcome, the student must exhibit the desired behavior or trait after instruction. To this end, teaching is selecting and administering learning activities in order to achieve specific outcomes in a targeted way which Walther and Radcliffe term as *Targeted Instruction*. Thus a clear definition of an outcome allows for focused teaching. Both the teacher and the student have a clear goal and understanding of how to achieve it (Walther, Kellam, Sochacka, & Radcliffe, 2011, p.726).

Walther and Radcliffe, however, note that behavioral psychology suggests that this is a limited view of the complex process of student learning which assumes a relatively simple mapping between explicit teaching activities and the achievement of learning outcomes. It assumes that the overall competence of an individual is made up by adding up individual competencies or attributes. If one breaks the intended outcomes down into a series of learning objectives and then prescribes specific learning activities to achieve those objectives, the



successful completion of individual learning objectives leads to successful attainment of the desired outcome. Walther and Radcliffe note, however, that in “context of curriculum design...not all aspects of this rich experience can be designed and controlled in a deterministic sense” (Walther et al., 2011, p. 727). A students’ overall competence is formed in a complex, socially situated learning environment through intricate learning processes where there are a wide range of varied influences at play. They propose a competency formation model where students form competence by a combination of learning activities, learning environment, the student disposition, extra-curricular elements, and meta-influences (Walther et al., 2011, p.717). These impact social learning and the combined interaction of these entities leads to the formation of the student’s overall competence. These interactions lead to the development of intentional learning outcomes, accidental competencies, and accidental in-competencies. Accidental in-competencies would be unintended consequences of the curricular environments which engineers are educated and accidental competencies which are “abilities important to performance in professional practices that are not linked to targeted instruction of the stated learning outcomes of the course.” Accidental Competency conceptualizes “student learning as the diverse, contextual outcomes of the complex interaction of teaching activities and a range of other influences from the students’ educational and personal context” (Walther et al., 2011, p.731). Accidental competency also provides a lens upon which to view student’s professional formation.

Accidental in-competencies can have an impact on how the student achieves an outcome and once the student graduates, can manifest itself in the work situation as a perceived deficiency by the employer. An example of a critical incident involving accidental in-competency is discussed in the Walther & Radcliffe (2007) paper where a graduate, when in school, got into the

habit of not asking questions because the instructors did not encourage questions and gave the student the impression that “engineers don’t ask questions.” While the graduate was able to move through the degree program this way, the graduate ran into problems in the work environment when working on multi-disciplinary teams. The graduate found himself in meetings where the members from other disciplines frequently used subject specific acronyms that he was unfamiliar with and instead of requesting clarification up front, he tended to keep quiet and the conversations would advance to the point where the graduate was too lost to catch up (Walther & Radcliffe, 2007, p. 46). Thus here a cultural survival skill encouraged in one setting created an attitude that was detrimental to survival in the other. The problem here was that the academic setting was the entity primarily responsible for preparing the individual to be able to function in the work setting.

Another example of accidental competency is found in Downey and Lucena (2003) where an ethnographic study was conducted which explored how engineering students in a traditional senior design course interpreted design assignments in terms of the engineering sciences. The authors show how the students, who had been taught to value the distinction between *science* and *design*, tended to resist design education. The engineering science training they received in school which focuses attention entirely on developing knowledge in the individual student helped to lead them to think about design as the disciplined application of mathematical engineering problem solving to real-world problems. They contend that when students enter as freshmen, they typically see no distinction in design and science often view “design” as the main output of engineering education, where design means they can use technology and mold it to create whatever concept they come up with. By the time students become seniors in a design class, they acquire the science over design predisposition which as

the ethnographic study results showed made it difficult for the faculty to convince students that design introduces entirely new learning issues. The authors go on to note “that reform in engineering education may have to move beyond expanding and enhancing design education to address the very distinction between science and design, as this distinction has been taught and lived” (Downey & Lucena, 2003, p. 174).

Thus the culture of academia can have unintended consequences on student preparation for the workplace. Though institutions provide the graduate with the necessary skills to get an engineering job and deem the individual as meeting all of the program outcomes such as functioning on multi-disciplinary teams, the graduate is still not functioning at the necessary level in this area from the employer’s standpoint. Some view this shortcoming of the system which contributes to the gap as one that can only be addressed by redoing the engineering educational system. Two important commentaries on the state of engineering education that promote a major change are *The Engineer of 2020* effort by the National Academy of Engineering (2005) and the *Engineering for a Changing World* by Duderstadt (2008). Both explore the present state of engineering and engineering education and make attempts to predict engineering’s future. They provide a roadmap where both industry and academia work together to reinvent engineering education in order to allow the U.S. to maintain its leadership in engineering (National Academy of Engineering, 2004, 2005; Duderstadt, 2008). Though the radical change called by these two commentaries has not occurred, some major efforts have arisen to address the disconnect between industry and academia and attempt to produce an engineer better prepared for the current world of the practicing engineer.

## 2.5 Alternative approaches to address the gap

Change of engineering education as a whole to address the aforementioned problems has been slow but there have been a number of efforts which have attempted to change the field on the institution level. These efforts include the *Learning Factory*, the *Conceive, Design, Implement, Operate* (CDIO) Initiative, and the new engineering university to be started in Singapore called the Singapore University of Technology and Design (SUTD).

The Learning Factory originated in 1994 with funding from the Advanced Research Projects Agency (ARPA) and the National Science Foundation (NSF) (Lamancusa, Zayas, Soyster, Morell, & Jorgensen, 2008). It was a partnership of Penn State University, the University of Puerto Rico-Mayagüez (UPRM), the University of Washington (UW), Sandia National Laboratories and 24 corporate partners. It formally ran with government funding for three years but continues on today funded by university and participating industry sources. The effort was a direct response to the perceived overemphasis on engineering science in engineering education programs. The effort took inputs from the major stakeholders in engineering education (academia, industry and students) and came up with an approach to engineering education where the mission was to integrate design, manufacturing, and business realities into the engineering curriculum.

The innovations claimed by the effort include: (a) active learning facilities, called *Learning Factories*, that provide experiential reinforcement of engineering science, and a realization of its limitations, (b) strong collaborations with industry through advisory boards, engineers in the classroom, and industry-sponsored capstone design projects, (c) practice-based engineering courses integrating analytical and theoretical knowledge with manufacturing, design, business concepts, and professional skills, and (d) dissemination of findings to other academic

institutions (domestic and international), government and industry (Lamancusa et al., 2008, p. 5). Lamancusa et al. cite that the partnership/active learning approach has led to a view by industry partners that 95% of Learning Factory students would be more useful to their companies (Lamancusa, 2006, p. 7)

Starting in 2000, the CDIO initiative was begun with the founding member institutions of the MIT, Chalmers University of Technology, Linkoping University, and the Royal Institute of Technology in an effort to reengineer engineering education in response to the concerns previously discussed (Bankel et al., 2005). The three main goals of the initiative are to: (a) master a deeper knowledge of technical fundamentals, (b) lead in the creation and operation of new products, processes, and systems, and (c) understand the importance and strategic impact of research and technological development on society (Crawley, Malmqvist, Ostlund, & Brodeur, 2007, p.2). To accomplish this they have created their own curriculum based upon survey inputs from stakeholders impacted by engineering education (member institutions, alumni and industry). The curriculum is designed to correlate with the ABET program outcomes as the institutions involved maintain ABET accreditation. The curriculum is key part of the open architecture that all of the founding universities have adopted. The number of members in the initiative has expanded beyond founding institutions with the majority of institutions being located outside of the U.S. Stateside institutions include the University of Colorado in Boulder, the United States Naval Academy and recently Penn State University with its *Learning Factory* (Worldwide CDIO Initiative, 2011).

Problem and project based learning approaches are integral in the undergraduate courses and are used from the freshman level up to senior capstone design in the CDIO Initiative. The initiative has 12 standards that are considered essential for any institution adopting the CDIO

model. These standards address philosophy, curriculum development, design-implement experiences and workspaces, new methods of teaching and learning, faculty development, and assessment and evaluation (Crawley et al., 2007).

Starting in the spring of 2009, the CDIO approach expanded and became an integral part of a NASA and industry sponsored program called the *North America Aerospace Project* (NAAP) (Crawley, Niewoehner, Gray, & Koster, 2011). This effort, which runs until 2013, is a response to the pending “significant shortfall in technically competent engineers and other technical specialists necessary to keep this sector [aerospace] healthy, and preserve the nation’s aeronautics core competencies” (Crawley et al., 2011, p. 1). The team includes a number of universities such as MIT, the U.S. Naval Academy and the University of Colorado, Boulder. Major US aerospace contractors involved include Boeing, Lockheed Martin, and Northrop-Grumman. Keeping with the CDIO tradition, the core of the NAAP technical effort is the development of design-implement-operate laboratories and project-based experiences. They are developing a set of at least six learning experiences for the first and second year of aeronautical instruction, and about six for the third/fourth year learning experiences. These are being created with the guidance of an industry-university steering group. The project-based learning material developed as part of the effort will be disseminated to other institutions which adopt the approach. The effort also conducts workshops on the approaches at American Institute of Aeronautics and Astronautics (AIAA) and ASEE.

The literature discussing the success of the CDIO Initiative is predominantly limited to internal evaluation of the effort and this indicates positive gains. One such evaluation of the CDIO effort 10 years after it was initiated is presented by Malmqvist, Bankel, Enelund, Gustafsson, and Wedel (2010) for Chalmers University of Technology’s in the Mechanical

Engineering program. Among the successes of this implementation of the CDIO approach, authors count industry contact with the program for cooperation and the hiring of program students, increased student application to the program, low drop-out rates, high rate of degree completion, recognition by employer's organizations, and interest by other educators (Malmqvist et al., 2010, p. 14).

The Learning Factory, CDIO Initiative, and NAAP are all attempts and responses to a belief that the present conventional way many in engineering education approach engineering student preparation is lacking. These are attempts at reinvention on a large scale to established engineering programs in an attempt to make them better and more responsive to needs of engineering employers. All involve close collaboration with industry and an attempt to provide more of a context to engineering training. In this way they start to address the accidental competency and accidental in-competency issues that can arise in the university environment by making the ways of engineering practice more integral to all levels of the collegiate education from the freshmen year on. They believe this should be an improvement over the present system and that employers appear to be happy with the types of graduates being produced in these efforts since in part employers have a direct hand in their training by these approaches.

Long term impacts of such efforts remain to be seen. Though the CDIO Initiative has expanded in the United States, its member institutions are still in the minority when compared the number of engineering programs in the U.S. It is believed that this is due in part to the requirement for member institutions and programs to move from their existing curriculum to the CDIO curriculum and the 12 CDIO standards. This is a difficult change to make in the "multiversity" system as discussed earlier. Stakeholders in that system that have established ways of working that may benefit their mixture of teaching and research and don't have a lot of

incentive to change the status quo. Beyond this, though the effort tries to change the culture of the engineering environment on a campus, the rest of the university culture (and in most cases the research university culture) remains the same. In addition, some of those influences could still lead to some accidental competencies and in-competencies in the students. The next possibility beyond the CDIO type approach is to actually change the entire culture of the university. This will be attempted in Singapore at the SUTD.

The government of Singapore has made it a goal to become a world leader in technology and innovation and is actively investing in ventures to help make this happen (Kao, 2007). As part of this effort, the Singapore government is launching a new university, the Singapore University of Technology and Design (SUTD), which just admitted its first freshman class in April, 2012 (Magee, Leong, Jin, Luo, & Frey, 2011 ). The SUTD, in collaboration with MIT and Zhejiang University, is trying to establish a totally new approach to engineering education with an institution which recognizes a synergy between innovation and design. They aim “to create a new type of technically-grounded leader and inventor, one fully equipped to address the challenges and issues of today and tomorrow” (Magee et al., 2011, p. 3). It is felt that the location of the school in Asia positions it well to capitalize on the growing markets in the area. The university recognizes the impact of culture on the students and sees the holistic approach they are taking as best way to achieve the desired technically-grounded leader and inventor. The university is to emphasize multi-disciplinary approaches as it emphasizes design research and has no departments or schools, thus changing part of the academia culture that influences students. Projects undertaken by the university are geared to meet the real needs of the region such as sustainable cities. Engineering practice is an integral part of the culture and the university aims to produce real products to be utilized by consumers in the region.



The SUTD provides an example of the extreme engineering education remake where all of the fundamental structures of the present system and culture are placed on the table for review. The effort recognizes that it is not just the actual coursework itself that shapes the engineer but the entire experience. It remains to be seen if the effort will generate the 21<sup>st</sup> century engineer that they envision. If successful, it could be a model for other efforts though it is believed that such a radical change would most likely not be adopted by the established universities in the U.S. given the reluctance to even change an engineering program as the CDIO Initiative attempts to do. Whereas the previously discussed efforts have looked at overt major changes in engineering programs, there have been other efforts that have attempted to change the academic culture or bridge the gap between academia and industry at a smaller scale. The Boeing Faculty Summer Fellowship program is an example of this.

Gorman et al. (2001) and Van Treuren (2010) describe their experiences as experienced university instructors participating in the Boeing A.D. Welliver Faculty Summer Fellowship program. The program is designed to expose a small number of competitively selected professors from U.S. and international universities to key elements and the business realities of industry. It accomplishes this by enabling the participants to observe and interact with working professionals at several levels of the technical, business, and management career paths. The aim is for the participants to leave the program with an understanding of Boeing's business including its research needs, with an improved understanding of the practical application of technical and business skills and with a network of contacts within the Boeing company and among their fellow faculty peers participating in the program (Van Treuren, 2010, p.3). The participants are exposed to different elements of the corporation and exposed to the culture of industry. In both papers, the authors come away from the experience with a better appreciation of the world that in

which the graduates will have to function. In all instances, the authors see a need for academia and industry to work together more and the participants look at ways they can improve their courses in order to better address areas such as the professional skills. The authors note that the experience also helps to give those in industry exposure to some aspects of academia from the instructor perspective.

All of the reviewed efforts have recognized a need to better bridge the connection between academia and industry in order to better prepare the engineering graduate. The type of change ranges from giving industry exposure to professors to redefining an engineering program to developing a brand new university. In some cases the full impact of the change remains to be seen but in others, attitudinal changes in participants appear to indicate that the approaches are a step in the right direction of fixing miscommunication between industry and academia and being in agreement when it comes to what traits the 21<sup>st</sup> century engineer needs and ways to help them attain them.

On the other hand, however, these efforts, save the Boeing Fellowship Program, require universities to make certain cultural changes that would require universities in the multiversity model to modify their priorities and raise the level of priority given to the education and teaching of the engineers in training. As mentioned previously, it is viewed that the momentum of the present multi-billion dollar research enterprise may continue to prevent such radical changes from being enacted in the near term. Is there a way to take elements from the approaches that could be deployed now and make a change in graduate preparedness? It is suggested that this answer may be found in other professional fields such as medicine and the military where there is a need to train an individual on methods, tools and procedures so that the individual may deal with real world issues and problems. The individual becomes a member of a distinct community

of practice. In these fields, live simulation has been found to very effective and the next section discusses this approach to education and its use in engineering education.

## 2.6 Simulation-Based Learning Approach

Simulation may be defined as “a realistic representation (model) of the dynamics or processes with which the participant interacts with the environment, applies previously learned knowledge into the decision making process, and responds with definitive decisions and actions to deal with a problem or situation” (Johnson, Flagg, & Dremsa, 2010, p. 10). It provides a simulated real world experience for the participants in the safety of an environment where the participants can make mistakes and learn from them without the potential financial or safety concerns that can arise in a real situation. Simulation allows the instructor/facilitator to control the conditions for the participant and thus the level of realism of the simulation. The Department of Defense (DOD) classifies the different simulation types as virtual, constructive, and live (Page & Smith, 1998, p.54). Virtual simulation refers to simulations involving real people operating simulated systems. An example of this type of simulation is Purdue University’s *AeroQuest* simulation which simulates a corporate aerospace design firm in a virtual environment (Velankar, Brophy, Okutsu, & Delaurentis, 2009). Constructive simulations refer to a simulation that involves simulated people operating in simulated systems. Live simulations involve real people operating real systems. This review will solely examine live simulation due to the similarity to reality that live simulation can provide using real systems and interactions with real people which is the most authentic way to develop professional skills. The literature on simulations that can be classified as live can be broken into three categories: military applications, medical applications, and engineering applications.

The military has been developing simulations for years as an instructional technique for service men and women. The DOD provides training and education for the 2.1 million members of its active and reserve armed forces, and 700,000 civilian employees. Since the 1960s, the DOD has made an investment of \$150 to 250 million each year on research and development in education, training, training devices, and training simulators. As Fletcher (2009) notes “military organizations rely on education and training to prepare individuals and groups of individuals to perform extremely difficult tasks at high levels of proficiency under stressful conditions” ( p.72).

Shortening the required duration of the training process, while maintaining its effectiveness, has been a continuous goal for the military. *Accelerated Proficiency and Facilitated Retention: Recommendations Based on An Integration of Research and Findings from a Working Meeting* by Hoffman and Feltovich (2010) explores recent work that has been done in quickening the training process and proposes a roadmap for future work. The aim is to shorten the period of time from novice to expert which, depending upon the desired skill can be around 10 years (Ahmed, 2007). Among the methods highlighted for accelerated training is simulation, which is considered a critical and necessary training method which still possesses some untapped potential. The authors feel that the “modes and means of training should engage realistic work practice, including the challenges, contexts, and duties of the job (pp. 161-162). It is felt that simulation aids in the transfer of knowledge by providing a context for the learner where one can more easily see the value of what one is trying to learn because its value is apparent in the work that one is actually doing. A classic example of live simulation is the Navy’s *Top Gun* program which originated because the kill ratio for US pilots had lowered to an unacceptable level and this needed to be remedied quickly. The Navy established a training program involving intensive practice at "dog-fighting" with pilots trained to fly like the enemy

pilots over Vietnam. Trainees from the program subsequently engaged the enemy at a 12-to-1 ratio following the Top Gun experience (Hoffman & Feltovich, 2010, p.106). Success such as this is viewed as encouraging by the authors and serve to support continued efforts to develop simulations for military training.

Live simulation has also played a role in the training of medical personnel in the military. Johnson, Flagg, and Dremsa (2010) discuss a study exploring the effects of two approaches to training (one using a Human Patient Simulator or HPS and the other a CD-ROM) on the management of patients exposed to chemical agents. A pretest-post test experiment design was utilized with a total of 92 active duty and reserve military nurses that were split into an HPS group, a CD-ROM group and a control group. The nurses were trained on how to care for patients exposed to chemical warfare via the use of the HPS or the use of a CD-ROM with specially developed software on the same subject. There was also a control group that received no training. The participants were assessed using a new instrument they created called the Management of Chemical Warfare Patients Performance (MCWPP) instrument which contained 105 criteria.

Results of the experiment showed that the HPS group scored statistically significantly higher on the instrument when compared to the other groups and had larger score improvements in the pretest-posttest comparison. The authors felt the HPS let the participants “use the cognitive skills of assessment, treatment, and evaluation in a realistic simulated environment” (Johnson et al., 2010, p.14). The results also supported previous studies with simulation which show that simulation does not make a difference in increasing lower-level cognition, specifically knowledge and comprehension but does make a difference in higher-level cognition and critical thinking cognition which they consider as pre-requisites for effective performance in the study.

They also feel that the results support situated cognition theory as the participants were learning what and how to do something in a real world environment. The researchers note that limitations to their study include the use of a convenience sample and that a disadvantage was the expense to purchase and maintain the HPS. The researchers present very complete work for a quantitative study providing details on all of the statistical results. The article does not present any qualitative information such as participant interviews.

The literature on the use of simulation in the medical profession is not just limited to the military. A number of papers have been written which discuss the use of live simulation in the training of personnel involved in acute care assessment or management of medical emergencies. Ziv, Wolpe, Small, and Glick (2003) present a commentary on the benefits of simulation-based medical education (SBME). They note how SBME can be used as a tool to reduce the risk of medical error by those in the medical profession and how it eliminates the issues of using live patients as a teaching tool for clinicians (p. 783). They note a resistance in the profession in previous years to use simulations and point to cost and uncertainty about the effectiveness of prior simulations as some of the reasons for the lack of simulation use. They point out that simulation in some form has existed in medicine since the 16<sup>th</sup> century when mannequins were utilized.

The article goes on to provide an ethical analysis of SBME under the themes of best standards of care and training, error management and patient safety, patient autonomy, and social justice and resource allocation (Ziv et al., 2003, p. 784). It is within this discussion that one sees within the medical community a parallel issue to the engineering education community where within medicine there has been a traditional focus on the assessment of cognitive skills which has come at the expense the skills of communication, management, cooperation, and

interviewing. It is thought that deficiencies in these skills have been “causal factors in adverse outcomes” (Ziv et al., 2003, p. 785). Simulation-based assessment as a way to evaluate history taking, physical examination, and communication skills was starting to become commonplace at the time of the article. The authors go on to discuss other benefits of simulation such as enhancing humanistic training in medicine. The authors conclude the article by stating that the proper and careful development of simulations is an ethical imperative.

Weller (2004) provides the results of an experiment in simulation to teach management of medical emergencies. In the study, small groups of Year 4 medical students attended a simulation workshop on management of medical emergencies and evaluated the experience using a self-assessment post-course questionnaire. The simulation involved the use of a medium fidelity simulator called *SimMan* which is a full-body manikin. Results indicated that the participants highly valued the simulation-based learning experience. It gave them an opportunity to apply their theoretical knowledge in a safe and realistic setting and allowed them to develop teamwork skills and a systematic approach to a problem solving (Weller, 2004).

Steadman et al. (2006) discusses an experiment comparing full-scale simulation to interactive problem-based learning (PBL) when teaching medical students acute care assessment and management skills in a pre-test/post-test experiment. The study involved 31 Year 4 medical students in a weeklong acute care course. Students were randomly split into two groups, simulation (SIM) or PBL. As with the previous studies, the simulation involved the use of a computer controlled patient simulator mannequin. All subjects were initially given a simulator-based initial assessment designed to evaluate their critical care skills. Outside technically qualified investigators assessed each student using a standardized checklist.

The PBL group then learned about dyspnea (a shortness of breath) in a standard PBL format while the SIM group learned about dyspnea using the simulator. To equalize the simulator education time, the PBL group then learned about acute abdominal pain on the simulator and the SIM group learned about the same topic using the PBL format. Following this, each student was finally tested on a unique dyspnea scenario. A statistical analysis was performed on the checklist scores ( $p < 0.05$  for significance). Whereas the participants had similar scores in the pre-test, the SIM group scored better than the PBL group on the post-test and demonstrated improved skill acquisition. The researchers note that teaching the clinical problem solving skills of interviewing and physical examination can be challenging in the medical school curriculum but their results show that simulation can be an effective tool in teaching such skills. The researchers conclude that the simulation-based learning was superior to problem-based learning for the acquisition of critical assessment and management skills (Steadman et al., 2006). This paper is a good example of a well defined experiment on the impact of simulation-based learning.

The literature on the use of live simulation in engineering education is sparse. Papers by Russell, Brestovansky, and McCullough (1982) and Debelak and Roth (1982) detail experiments in simulation in chemical engineering courses in the early 1980s many years prior to the EC2000 ABET changes. In one case the students use a live simulation to combine basic engineering skills with “economic considerations and risk-taking judgments in order to effectively design and operate a chemical processing unit in a competitive environment” (Russell et al., 1982, p. 76). In the other case the instructors combined the design and laboratory courses to relate “the design project to real facts, real chemicals, real alternatives, and involving industrial practitioners” as the students designed a wastewater treatment facility for coal conversion processes (Debelak &



Roth, 1982, pp. 72-73). Both efforts could be classified as project-based learning where the instructors played the role of facilitators in the efforts and the students drove their own learning. In both cases a product (a design final report) was the main deliverable that was used for evaluation and the use of student's prior knowledge was essential to success. In both cases the researchers desired to create a realistic environment and scenario for the students to learn design and its many facets and found that the participants had a positive response to the experience.

In 2007, McManus, Rebentisch, Murman, and Stanke explored the effects of live simulation on teaching Lean Enterprise Thinking at CDIO Initiative participant MIT. Lean Enterprise Thinking pertains to the lean principles approach to manufacturing and production utilized by Toyota. The authors note that applying lean principles in an aerospace context requires that students understand the complex subject of aerospace enterprises and their transformation at a deep learning level. Without such a deep and basic understanding, the researchers claim lessons in the Lean Advancement Initiative (LAI) Lean Academy Course® would make little sense. In the simulation the students fabricated parts, processed engineering design jobs, assembled, and supported a fleet of Lego® aircraft, to satisfy customer and corporate demands. The aim was to transform the simulated enterprise from an inefficient legacy state to a high performance future state (McManus et al., 2007). It is claimed that the simulation taught participants “advanced lessons in applying lean thinking at the enterprise level, quantifying the value of lean improvements, and managing change in a complex, interdependent enterprise” (McManus et al., 2007, p. 2). The exercise used a project-based learning approach with their transformed enterprise being the deliverable.

One hundred ninety-four students evaluated the experience using daily feedback sheets that contained both quantitative and qualitative elements. Comments on the experience indicated

that the students found the experience met study goals of increasing comprehension, learning through hands-on experience, and increased enthusiasm and personal involvement. However, the students did not indicate a “better understanding of the context and holistic, system-spanning nature of the material” which the researchers attribute to the timing of the simulation relative to other activities that the students participated in as part of the course (McManus et al., 2007, p.12). Consistent with results from the use of simulation in the medical field, the researchers noted that acquiring the material for the simulation was expensive and that the students thought the time given to do the simulation was not long enough (roughly one class period).

The literature indicates that simulation can be an effective tool to replicate real life experiences and provide the student with opportunities to develop complex skills. This can range from dog-fighting skill as a pilot, to emergency care skill as a medical care-giver, to learning the complexities of engineering practice including professional skills. Whereas there are multiple sources discussing the impact of live simulation-based learning in the medical field (including efforts which address professional skills), there are very few research papers discussing the impact of this approach in engineering education. Of the sources available, the approaches have not taken a rigorous research approach in the study thus creating a gap in the literature. Can live simulation be used as a teaching approach to introduce students to the ways of engineering practice and positively impact their conception or the sum of their ideas and beliefs concerning the field which include their professional and technical skills? Can this approach help the students to be more engineering practice ready? The research that was conducted as part of this dissertation effort attempts to address this issue by examining the impact of LSBL on aerospace engineering students in a capstone design class.

## Chapter 3: Methodology

### 3.1 Research Questions

This study explores the impact of the use of LSBL in engineering design on students' conception of design. In particular the study attempts to answer the following research questions:

1. Can the use of live simulation-based learning (LSBL) in aerospace capstone design alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design?
2.
  - a. How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?
  - b. How do (aerospace) engineering students describe their experiences with realism through simulation in relation to their previous academic experiences?
3. What, if any, is the relationship between LSBL students, lecture-based students and aerospace industry professionals with regards to their conception and viewpoints of aerospace engineering design?

In particular:

- a. How do LSBL students, lecture based students, and aerospace industry professionals compare on the professional skills of communication and teamwork?
- b. How do predominantly LSBL student design groups and predominantly lecture-based student design groups compare on the professional skill of problem solving as exhibited in an aircraft design project?

### 3.2 Theoretical Perspective

In the completed research, both the pragmatist worldview and the situative learning perspective were assumed. The pragmatist worldview, as described by Creswell and Plano Clark (2011), places emphasis on the consequences of the research, the primary importance of the question, and on the use of multiple methods or mixed methods of collecting data to inform the problems under study (p. 41). It is felt that this view best captures the complexity of one's views on engineering practice and design.

Situated learning theory as described by Johri and Olds (2011) has the central aim to “understand learning as situated in a complex web of social organization rather than as a shift in mental structures of a learner” (p.160). [Barab and Duffy (2000) describe it as “knowledge is situated through experience” (p. 25). As students construct their own versions of reality integrating new knowledge with prior knowledge and experiences, it is happening within the context of some situation.] In this perspective, learning is assessed by the individual’s ability to participate in a community of practice where a “community of practice” is “any naturally emergent group of people who work together to accomplish some activity usually involving social collaboration between individuals with different roles and experience” (Jonassen, 2011, p.158).

The situative perspective is assumed in this study because the central aim is to address a problem with how recent engineering graduates are not transitioning as easily as desired from academia (and the ways of the academic community from the student perspective) to the industrial and government workplace (and the ways of the practicing engineer). A solution is explored in the form of LSBL which embraces the practicing engineer ways of thinking and performing as one way to bring the student into the “community of practice” of the practicing

engineer before graduation. The approach requires the students to interact with each other and a member of the community of practicing engineers (the instructor/facilitator) to learn approaches, methods, and ways of thinking and interacting in order to enter the community. The social interaction and context are essential to achieving the desired goal of the approach.

Choi and Hannafin (1995) identify four aspects of situated learning that serve as guidelines for the design of situated learning environments: context, content, facilitation and assessment. Crooks and Eucker (2001) have applied these guidelines in the development of a simulation for training manufacturing professionals and it is felt that these same situated learning guidelines are applicable to LSBL. Choi and Hannafin note that “context provides the framework for learning, but content determines its authenticity and veracity” (1995, p. 57). They go on to say that “facilitation provides learners with opportunities for internalizing information, thereby promoting higher-order, metacognitive skill development” (1995, p. 61). Scaffolding and collaborating are important elements of facilitation. Relative to assessment, Choi and Hannafin recommend performance assessments which involve students producing things or performing tasks that have some direct connection to the real world. It is these guidelines grounded in situated learning theory that help drive the design of the LSBL.

The experiment attempts to address the issue of professional skills which are interconnected to the technical skills under the Accidental Competency lens. Ideally to fully examine the impact of LSBL versus the classic design class combination of lectures with project based learning, which is used in aircraft design at Virginia Tech, it would be desirable to split a class into an experimental and control group and observe each group for an entire semester thus comparing the full simulation experience to a traditional method. Practical issues such as instructor flux for the AOE design class during the 2010-2012 timeframe have prevented such a

larger scale experiment from being conducted. Instead, as will be seen, a smaller duration intervention of four to five class periods in a semester has been implemented. As a result, the experiment provides a comparison of how engineering students who have had three years of predominantly lecture-style engineering training (deductive learning) compare in their design conception and engineering design views after a limited exposure to the opposite end of the pedagogical spectrum with the inductive LSBL approach.

In addition to the situated learning perspective and the Accidental Competencies lens, the LSLB model is guided by the epistemic frame as described by Shaffer (2007). The epistemic frame hypothesis posits that the skills (the things that professionals do); knowledge (the understandings that professionals share); values (the beliefs that professionals hold); identity (the way that professionals see themselves); and epistemology (the ways of knowing shared by professionals) are critical factors in the development of a professional way of viewing the world. Development of LSLB model that is guided by this frame directly addresses the professional skills that are identified as deficient by industry. Shaffer has looked at the use of computer simulations or games as manifestations of the frame. The LSLB model is the “not explored” live simulation manifestation of the epistemic frame where a live simulation based model for learning is developed with a “Top Gun” simulation approach applied to engineering education.

The LSBL approach is an inductive learning approach and could be considered a special case of problem or project based-learning depending upon how the exercise is conducted. As discussed earlier, project-based learning emphasizes the development of cognitive and practical skills and typically has a product, usually a design in a capstone design class as a deliverable. Problem-based learning is concerned with the acquisition of content and its application where students work in teams to solve ill-structured, open-ended, real-world problems. The students

lead in defining the problem, deciding upon the information they need to solve the problem and deciding upon the appropriate solution options and final solution (Heywood, 2005; Prince & Felder, 2007). As with the project-based approach, the instructor of the class serves as a facilitator. Combining of the problem and project-based learning approaches is called the *hybrid* approach and this is the approach that is to be used in this research experiment. The hybrid approach is used at the Aalborg University in Denmark where there is *design-oriented project-organized* education and *problem-oriented project-organized* education (Dym et al., 2005, p.109).

As will be discussed in the Research Design section, the LSBL exposes the students to a real world design problem, where they have to develop a solution using real world design tools, guided as necessary by the instructor as a facilitator. The exercise ran for a short period of time and thus there was not as much emphasis on the final design produced (though it was important that they produce a design) as much as on how the solution was arrived at and the reasoning behind the solution. For these reasons the effort was considered an example of the hybrid approach. It is felt that the situative perspective as described earlier is applicable to the hybrid approach given the design of LSBL where emphasis is placed on the student transition to the practicing engineer community of practice.

### **3.3 Research Design**

An overall aim of this research was to explore the effectiveness of a teaching approach that could help better prepare engineers entering the workplace. Data was obtained that provides insight into one's thoughts and views of the engineering profession, practice, and design. To best capture the complexity of such topics, a mixed methods research approach was utilized. The mixed methods approach in research can be defined as one that combines or associates both the

qualitative and quantitative forms of research. In the approach, philosophical assumptions help to determine which of the qualitative and quantitative approaches are used and how they are mixed in the study. The result is a method that is more than simply collecting and analyzing both kinds of data (Creswell, 2009, p. 4). Table 5 provides an overview linking specific research questions to a particular data collection, data analysis, and expected outcomes. In addition, desired industry traits found in Table 1 addressed by the experiment design are listed.

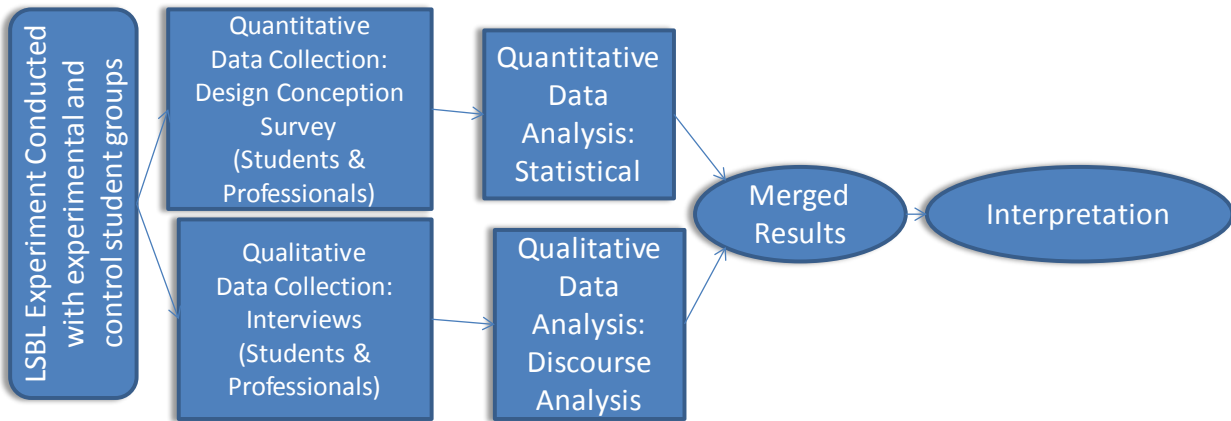
Table 5. *Summary of research questions, data collection, data analyses, projected outcomes and industry traits*

Research Question	Methods: Data Collection	Methods: Data Analysis	Findings/ Contribution to the body of knowledge & understanding	Industry Traits linked to Table 1 in Proposal (Examined the in Data Collection)
<b>1. Can the use of live simulation-based learning (LSBL) in aerospace capstone design alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design?</b>	Design Conception Survey - Existing tool previously used in assessing respondent conceptions of design	Statistical Analysis: Non-Parametric Methods	-Quantitative comparison of aerospace student and aerospace professional conceptions of engineering design -Quantitative data capturing the impact of the LSBL approach versus the Lecture style approach in a design class relative to conceptions of design	Communication, Understanding of Design, flexibility and adaptability, analytical skills, interpersonal skills, multidisciplinary perspective (The listed items are contained in the survey.)
<b>2a. How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?</b>	One-on-One Semi-Structured Interviews	Discourse Analysis	-Detailed descriptions of student and professional views of aerospace engineering design - Qualitative data capturing the impact of the LSBL approach versus the Lecture style approach in a design class relative to views of various aspects (process, teamwork, flexibility etc.) of aerospace engineering design.	Communication, Understanding of Design, flexibility, teamwork, interpersonal skills, professionalism (The listed items are addressed in the interview questions.)
<b>2b. How do (aerospace)</b>	One-on-One Semi-	Discourse Analysis	- Detailed descriptions of student views of live	Not applicable



engineering students describe their experiences with realism through simulation in relation to their previous academic experiences?	Structured Interviews for all participant groups		simulation -Student feedback on the experience as a method for teaching a subject such as design and others including a comparison to previous class experiences	
<b>3. What, if any, is the relationship between LSBL students, lecture-based students and aerospace industry professionals with regards to their conception and viewpoints of aerospace engineering design?</b>				
<b>3a. How do LSBL students, lecture based students, and aerospace industry professionals compare on the professional skills of communication and teamwork?</b>	Combination of data analysis results from questions 1, 2a, 2b	Side-by-side comparison for merged data analysis	-Comparison of LSBL, lecture based and professionals results to see if either student group holds views and opinions and exhibits language relative to teamwork and communication that are comparable to industry professionals - A measure of the impact of the experiences (LSBL and Lecture) relative to an industry benchmark created through use of the same tools applied to the students	Traits covered in questions 1 and 2a combined
<b>3b. How do predominantly LSBL student design groups and predominantly lecture-based student design groups compare on the professional skill of problem solving as exhibited in an aircraft design project?</b>	Modified TIDEE rubric results for final term presentation and reports	Side-by-side comparison for merged data analysis	-Quantitative comparison of predominantly LSBL and lecture based student group design projects using modified TIDEE rubric scored by industry professional and primary researcher -A measure of the impact of the experiences (LSBL and Lecture) on system level problem solving (aircraft design) using established rubrics	Problem solving, collaboration, cost awareness, developing solutions, responsibility for decisions, creativity, analytical skills, understanding design, teamwork

The experiment was a *Pre-Test-Post-Test Control Group Design* (Creswell, 2009) involving two student groups, experimental and control, involved in the actual intervention and a group of aerospace industry professionals who provided benchmark results for comparison with the students using the same two study instruments that were utilized with the students.



*Figure 2.* Diagram of the Dissertation Research Study.

Figure 2 illustrates the research design. The instruments used for the mixed methods approach include an engineering design conception survey (taken by all participants), semi-structured interviews (conducted with a sample from each of the three study group participant sets), and design presentation/project assessment using a rubric (for only the student study groups). The survey was administered to the professionals once and serves as a benchmark while the students were given the survey four times total during the course of the study. The four student administrations of the survey included a pre-test at the beginning of the experiment, an immediate post-test after the intervention, a progress test at the beginning of the second semester of design and a final test near the end of the design class in the second semester. This allowed observation of the participants during the course of the year after the intervention in order to see the impact of the design class itself in addition to the LSBL intervention. The LSBL intervention period of the study lasted five class periods each lasting 75 minutes and took place within a three calendar week period. Both the experimental and control groups participated in the intervention at the same time during the regularly scheduled class time. The study was conducted at the beginning of the fall semester in order to minimize the number of confounding variables that could impact the results. At the beginning of the term, the students did not have any formal aircraft design instruction/experience, other than what they would have brought with them

through internships, cooperative education experiences, or voluntary underclassmen membership in capstone projects such as the *Design, Build and Fly* effort. The research design provided an opportunity to see the impact of a controlled intervention on students (in a typical large university environment) who have had three years of training predominantly under the deductive learning model where emphasis is often not placed on the application of theory to real world problems. The intervention period was a duration negotiated with the instructor of record for the class in order to minimize disruption to the instructor's regularly scheduled lesson plans. The study was conducted under the approval of the Virginia Tech Institutional Review Board (IRB # 10-664).

### **3.3.1 Live Simulation Based Learning Model (LSBL).**

As part of this study, the live simulation based learning model has been developed. This model is designed to provide the students with a simulated experience that can be considered the most realistic form of PjBL – just short of an actual insitu industry project and is the closest one can get in a classroom environment. This approach is compared to the other end of the pedagogical spectrum, the classic lecture where there is no inductive instruction but lecture is the method used in most engineering classes. The table below compares the LSBL model to the Lecture style and the current Virginia Tech AOE aircraft design capstone experience. The AOE design experience described is fairly typical of aircraft courses found in the United States involving the design of relatively complex systems such as a manned aircraft.

Table 6. *Comparison of Lecture Based Approach, VT PjBL, and LSBL Approaches*

Lecture-Based Instruction (Deductive)	Current VT Aerospace - Aircraft Capstone Design (PjBL)	LSBL Model (Simulation)
Teacher-centered	Teacher & Learner centered (switches around the middle of the 1 <sup>st</sup> semester)	Learner-centered
Lectures given on general principles - heavy theory emphasis	Lecture portion has moderate level of theory discussion	Just-in-time minimal instruction to be able to accomplish task. Theory covered to the degree to allow understanding of the application of the theory in an analysis/design. Constant emphasis on rules of thumb and sanity checks to results obtained by the tools.
Principles used to derive mathematical models	Models are derived and presented (1 <sup>st</sup> part of semester)	Models used in actual practice.
Illustrative applications of the models are shown	Illustrative applications of the models are shown	
Students given practice in similar derivations and applications in homework	Homework on various design principles given	Homework in this case is that the design has a deadline that must be met and the student needs to schedule time appropriately to meet the deadline.
Students given tests and exams to assess their ability to do the same sorts of things	Students given a mid-term exam and entrance exam	No exams. The design is the major deliverable and a reflection of what they have learned or understand. Instructor's constant involvement with the teams much like a supervisor lets the instructor know how the teams are doing - real time assessment of success in completing the design task. Instructor develops a rapport (similar to Pembroke mentor model) to allow free communication with students.
Generally problems are not provided in a context and students are not explicitly told	Once students have selected a team and project, context of the various disciplines/topics	Context provided on day one. Students see directly why they need to know certain subjects.

of the relationships between different subjects in the discipline → The <i>why</i> any of this is being done	is made apparent	
Student motivation is that it is implied that the topic will be important later	Students are aware that the next stop after course is the “real world” and this is an important step in preparation	Students are aware that the next stop after course is the “real world” but that this experience is designed to give them an introduction to many aspects of the real world (culture, methods, tools)
Student-teacher interaction in class is often limited but varies with instructor	First part of 1 <sup>st</sup> semester interaction is limited. Second part of 1 <sup>st</sup> semester and rest of course more interactive with individual teams and team leaders	Instructor interaction is constant from the first day. Follows an apprentice-like approach. Involvement decreases as students become more proficient and confident
Generally no hands-on experiences. Student still has to transfer knowledge gained from theory to practice.	Generally hands-on after first part of 1 <sup>st</sup> semester. Real world professional tools can be used but depends upon the design team. Often readily available codes found in typical university settings used. Student transfer of skill acquired requires learning new tools on the job.	Hands-on involvement from first day. Real world professional tools used in simulation thus allowing real world marketable skills to be attained. Transfer is direct. Student uses the same tools with different problems and possibly in different ways on the job.
Generally an individual experience (no teams)	Team experience most of the course	Team experience all but first day
Little student autonomy	Large student autonomy	Large student autonomy
Depending upon the course, knowledge gained in previous courses may be necessary	Assumes students have had training and have a certain level of proficiency relative to specific disciplines prior to class	Assumes students have had training and have a certain level of proficiency relative to specific disciplines prior to class
	Problems generally come from design competitions (some have build elements such as Human Powered Flight and Design-Build-Fly). Level of detail provided/requested varies with competition RFP	Uses real world RFPs and BAAs with all of the real world complexities. Students gain experience reading and interpreting the same documents as working professionals
	Atmosphere of project tends to be of an important “project done in a school setting” – students aware it is a “paper	Students provided with a simulated corporate culture and the company needs from a financial and status standpoint.

	airplane” in the conceptual airplane design competitions- there is no real customer with an interest or means to build what has been designed. (Note not all students show this view but many do.)	Students know that a real world customer had/has an interest in the design and a means to make it happen. Students see aspects of what they will encounter on the job.
	Competition projects have more of an “institution vs. institution” flavor	Competition is among teams of the same “company” and fictitious other companies
	End design project and presentations are significant and used in determining course grade	As LSLB was implemented in the experiment, a course “grade” was not a factor. Students allowed to learn/act without a “grade threat”.

As seen in Table 6, the major differences between the LSBL approach and the lecture approach are the level of interaction between the student and the instructor along with the role of each individual. Whereas the lecture is less participatory, requiring the student to observe and learn via out of class exercises, the LSBL approach requires the student to actively participate in the experience in class with out-of-class time providing the student with the opportunity to finish tasks not completed in class. Students address real problems and solve them with real world tools and know the “why” behind actions from the start as opposed to being given the statement that working a particular exercise will be important to them later. LSBL attempts to accelerate the often long journey (typically ten years) from apprentice to expert as described by Ericsson, Krampe, and Tesch-Romer (1993). The activities of LSBL provide the student with engineering skills during this expertise pursuit that allow the student to depend less on abstract principles and more on concrete experience which is key in developing expertise as described by Dreyfus and Dreyfus (1980).

In relation to situated learning theory as described by Choi and Hannafin (1995), the learning environment of LSBL provides a context and content (real world problems and tools),

facilitation (students assume the roles of working engineers tasked with addressing a complex problem requiring them to use their engineering knowledge without formal instructor instructions for solving the problem) and assessment (students must deliver the design product). In this way the students experience the working engineer's community of practice and become part of that community which is also supported by Shaffer's epistemic frame. Whereas the P<sub>J</sub>BL approach shares a number of common features with the LSBL approach, the LSBL approach's requirement for real world tools, problems, and student/facilitator interaction similar to a boss/employee make the LSBL approach closer to the in situ work experience and should minimize the possibility of accidental in-competencies relative to the engineering work environment the students will become part of upon graduation. P<sub>J</sub>BL may have those features at the discretion of the instructor but LSBL *requires* them consistent with the principles of situated learning being the theoretical background supporting the effectiveness of the approach. Table 7 provides a summary of the links between the theoretical perspectives supporting LSBL and the design of the LSBL experience used in this research.

Table 7. *Theoretical Framework and LSBL Design Characteristic Links*

Contributing Theoretical Framework	Theory Contribution to LSBL Design
<b>Situative Learning Perspective –</b> Learning is situated in a complex web of social organization.	LSBL introduces the participant to the community of practice of the practicing engineer through the use of industrial world tools, real world problems, and facilitators with experience in or training in engineering design practice as practiced in the industrial world.
<b>Shaffer's Epistemic Frame -</b> Skills, knowledge, values, identity, and epistemology are critical factors in the development of a professional way of viewing the world.	As with the situative learning perspective, the facilitator/industrial world tools/real world problems combination provides the participant with the opportunity to attain industrial world desired skills (such as computer aided design), knowledge of engineering practice and discipline history along with ways of knowing as conveyed by the facilitator(s). These elements combine to help form the identity of the participant as a practicing engineer.

<p><b>Accidental Competencies –</b> Student learning as the diverse, contextual outcomes of the complex interaction of teaching activities and a range of other influences from the students’ educational and personal context.</p>	<p>Within the bounds of the academic environment and the physical location of the LSBL exercise, a simulated industrial world environment is created where student participants are treated as new hires to the fictitious company of the exercise with the facilitator as the boss. Industrial world engineering tools are also utilized in order to provide industrial world skill sets. Through simulation, efforts are made to suspend disbelief in the experience and demonstrate authentic industrial world attitudes and practices.</p>
<p><b>Gee’s Game Based Learning -</b> Five elements of useful learning experiences in games: specific goals, experience interpretation, feedback, applying previous experience, and experience interpretation with others.</p>	<p>The LSBL exercise contains specific goals (creation of a vehicle design with a deadline), and involves working in teams to create, analyze, and present a vehicle design (this allows team member interaction and facilitator, as the “boss,” feedback on progress and design results).</p>

The following are a set of guidelines necessary for implementation of the LSBL approach and are supported by the four elements of the epistemic frame:

- **Real Tools –** authentic marketable skills (an intrinsic incentive for student). This lets students develop strategies to approach problems based upon what’s available and to improvise when needed. For example using Computer Aided Design (CAD) does impact how designer approaches the problem (limitations of tools can be and are a factor in the real world). The types of tools necessary for the simulation depend upon the discipline and hence cost to acquire these tools varies. Often institution discounts are available. This experiment used CAD, design synthesis, and optimization software along with the standard MS Office suite of programs.
- **Real procedures for analysis and design –** (e.g. use industry expectations for drawings and illustrations).
- **Real World problems, real world complexity, real government Request For Proposals and Broad Agency Announcements** develop a real experience base in the student. They are encouraged to question requirements (what does the customer really want/need). Problems selected should consider the level of previous training the



students have and level of scaffolding instructor is willing to implement to fill-in for the lack of experience.

- Quick paced schedule. This yields a sense of urgency to pick up tools and processes similar to workplace. Extra time may be needed by student to accomplish tasks. It is the student's judgment (meta-cognition) that drives this decision to put extra time in to solve the design problem. Scaffolding is provided as needed to support the schedule.
- Simulation allows students to make mistakes without major financial, safety, time penalties. This is a benefit of simulation as a whole.
- The LSBL Experience addresses the desired industry traits of communication, complex system level problem solving, thinking critically and creatively (independent & cooperative), flexibility, teamwork and interpersonal skills, ethics, analytical skills, cost awareness, leadership, professionalism, and developing habits for life-long learning.
- Teams compete against each other. This forces the groups to consider options and what others might do as they develop their solution.

The following are suggestions on executing an LSBL exercise:

- Instructor demonstrations are straightforward but applicable (e.g. in CAD draw an airplane to demonstrate to the aerospace student not a bracket and then tell the student to adapt /transfer the approach or skill to other scenarios)
- Determine the number of students with industry experience and spread them out amongst groups (students can relate to other students who say the experience is authentic).
- Keep teams to no more than 5, preferably 4 members. This keeps every team member busy and co-dependent to accomplish the task in the short period of time of the exercise. Each member serves a different function/authentic professional role on the team. This contributes to identity formation.
- Each member must develop initial concept and sell the concept to rest of team. This addresses the professional skills of communication, teamwork, compromise, consideration of alternatives.
- Depending upon the size of the class, multiple instructors may be necessary given the student/teacher interaction of the model.

In the LSBL experience, each principal member of the experience has certain traits that are commonly seen or expected. The following is a summary of some of these traits:

#### Student Traits

- Senior Engineering Students (bulk of technical training completed)
- Some have coop/internship experience (most likely 30% for aerospace students)
- Computer savvy. They pick up Microsoft-like programs easily.
- Have little or no experience with older programming languages such as Fortran. There is a need for scaffolding to handle heritage programs written in such programming languages. This is a real world issue.

#### Instructor/Supervisor Traits

- The instructor is the living example of how the students should approach problems and conduct oneself in the community of practice of the practicing engineer. This is similar to the apprenticeship approach where one attempts to bring the novice up to expert levels.
- The instructor possesses domain knowledge of the field and the topic. Actual experience in engineering design for the capstone discipline is preferred. In the case of aircraft design, familiarity with a variety of aircraft and their histories is desired. Using the typical level of experience required to be an expert as found in the literature, 10 or more years of experience is preferred in the discipline. This is in line with the experience levels of first line supervisors/leads in large defense companies who often supervise new hires like the soon to be graduates. A “method actor” who does the research could fill the role to a point but may lack the technical depth when needed. Direct industry contact/interaction with working engineers by faculty (beyond occasional conversations) can help to bring an instructor lacking the experience up to a level necessary to be able to tell the appropriate stories and rules of thumb, and exude the industry culture to the students that helps to make the experience authentic (demonstrating to the students what is expected). Newly retired engineers in the discipline are ideal sources outside of instructors possessing the experience.
- The instructor should know applicable stories for context for various aspects of the experience. The oral history of appropriate lived experiences (passing along the professional culture) is part of the experience.

- The instructor should be familiar with useful “Rules of Thumb” for discipline and in case of design, familiar with getting the accurate “5 Minute Answer”. These should be demonstrated. The exact back of the envelope sanity checks to use vary with the field.
- The instructor should be able to demonstrate and understand processes and tools shown to students.
- Instructor should provide constant real time feedback on progress, procedures and product of the students. The instructor should observe and comment on the students’ work.
- Flexibility. The instructor should practice improvisational instruction. There is a big picture (in the case of the experiment, a design and industry professional approach is desired for the students) but the path to get there is allowed to evolve with the students and conditions of the simulated environment (e.g. as was experienced, outside interferences by other AOE instructors where the inconvenience was turned into a learning moment).
- Treat participants not like “students” but as junior colleagues.
- The instructor should provide real assessment of the final design product including its viability (technically and business case). This guidance should help the student to improve. The instructor as supervisor judges which concept from the students will move into the next phase of development for the fictitious company.

### LSBL Resource Requirements

- As mentioned previously, the types of tools necessary for the LSBL experience depend upon the discipline and the type of class using the simulation. As a result, cost to acquire these tools varies from implementation to implementation. The dissertation study experiment utilized CAD, design synthesis, and optimization software along with the standard MS Office suite of programs. In this instance, institution software discounts were available or the software was free from a U.S. federal government agency. Such discounts are usually available to institutions who agree to use and promote the software. Expenses can be comparable to hardware and software expenses associated with project-based learning approaches used in many capstone design courses. Facilitator expertise and engineering experience are key contributors in the selection of appropriate hardware and software tools for the LSBL exercise.

- The amount of time required to do research and develop support material for the LSBL experience, may be greater than that required for a typical lecture class. This is also the case with the typical project-based and problem-based learning class approaches. Research and final refinement of the combined tool set for this research effort took approximately 60-70 hours where some pre-existing experience with the tools of the experiment existed for the LSBL facilitator. Such existing experience with the industry tools would be expected of an LSBL instructor, as that experience is an integral part of the industrial world that the facilitator is representing. The preparation time also permits the facilitator to identify and be prepared for possible problems that the LSBL participants might encounter.
- The instructor to student ratio for LSBL should be kept low in order to allow for proper feedback and interaction with the students. Initially, as the students are learning the software, a 1:15 facilitator to student ratio may be necessary. Once students become familiar with the software, the number of instructors may be reduced as the students work more independently. (A teacher to student ratio of 1:25 may be more appropriate at that time.) The number of instructors required also depends upon the area being simulated and the type of hardware and software being used in the simulation.

Together these LSBL traits help to provide an authentic experience to aid in the transformation of the student from novice to expert in the field. Implementation follows what Gee (2008) considers the necessary conditions for useful learning experiences that can be found in well-designed games where: (a) there is a specific goal at hand, (b) thinking and interpreting of the experience during and after the experience, (c) feedback, in this case, between participants including the facilitator, (d) application of previous experience which is required to even be in a senior design class, and (e) experience interpretation with others where the group experience to solve problems is key and an essential part of professional engineering practice.

### Study Facilities

The experiment was conducted in two locations. The experimental group met in the Aerospace and Ocean Engineering Design Lab (AOE Design Lab) located in Virginia Tech's Randolph Hall. The control group students met in a large classroom, Randolph 331, also located

in Randolph Hall. The AOE Design Lab provided the necessary computing equipment and software to conduct the live simulation. Management of the lab also allowed straightforward updating of necessary class software as needed. The lab contains eight PC workstations with enough room to support up to five students seated around a single workstation. Randolph 331 classroom is a traditional educational space that is large enough to hold classes on the order of 60 students.

### LSBL Class Details

In the live simulation, the students experienced being an aircraft design engineer for a large fictitious defense contractor. The students used a combination of electronic tools and real world role playing in order to simulate the aircraft designer experience. These real world industry level design tools include the computer CAD tool CATIA by Dassault Systems, the synthesis tool ModelCenter® by Phoenix Integration, and the aircraft design and evaluation tool Flight Optimization System (FLOPS) developed by National Aeronautics and Space Administration (NASA). The students used a combination of personal tablet notebooks, paper and pencil and workstations with the CAD software and other aircraft design analysis tools to develop their concepts. Artifacts such as memos with company letterhead were issued to the students with invitations to group meetings and notification of the latest developments on the design effort that was occurring between the simulated company and a potential US government customer.

The students assumed the role of new hires in the engineering leadership development program of a fictional large defense contractor named *Ace Aero*. Such programs exist in companies such as General Electric and Lockheed Martin. In this capacity, the students were given the backstory explaining the engineering leadership development program and letting them

know that as participants in this program, they had been rotated between a series of engineering positions within the company in order to become more familiar with its products, processes and people. In this exercise the new hires had been rotated into the Conceptual Design group of the company that is responsible for designing the new aircraft concepts and next generation airplane products that the company will produce. The group was headed by the class instructor playing the role of a supervisor to the new hires providing assignments and direction as needed and informing the students about good industry design practices such as always being able to legitimately support all design decisions made and double checking one's work before giving it to others.

In the simulation scenario, *Ace Aero* had been producing fighter aircraft for 20 years and their Washington DC business representatives learned that a new Broad Agency Announcement (BAA) was to be coming out from the Defense Advanced Research Projects Agency (DARPA). The BAA announced a pending design study to explore the viability of a submersible aircraft. (In keeping the experience as real as possible, the BAA used was a real DARPA BAA that was issued in 2008.) The students were told that the design group of the company had been tasked to respond to this BAA and develop concepts that may be shown to DARPA ahead of any official competition in the hopes of making an impact on the requirements that the government was to issue for the new vehicle. The students were told that as new hires rotated into the group, they were invited to be a part of this study and were asked to develop concepts of their own that would be reviewed by management at the end of the exercise.

In the exercise itself, the students experienced an abbreviated aircraft conceptual design cycle. The exercise was broken into four stages: requirements development, brainstorming, conceptual level design analysis and CAD model development, and concept presentation. In

keeping with the hybrid (PBL and PjBL) learning approach, the instructor provided a brief introduction to each stage and provided the students with the necessary background information to perform tasks required of that stage. The students worked individually during the requirements and brainstorming stages of the simulation, but formed design teams of four to five people during the conceptual design and presentation stages. During requirements development, the students examined in detail the DARPA BAA in order to develop requirements and specifications for their designs. In the brainstorming exercise, students were tasked to explore the web for reliable sources that could provide information on previous vehicle concepts and efforts that have explored submersible aircraft. The students were also tasked to sketch up concepts on paper that they felt could meet the design requirements. The students then formed design teams.

Once in teams, the students assumed various roles of a typical aircraft design team which included a project manager, vehicle configurator, aerodynamicist, structural designer, stability & control engineer, mass properties engineer, and performance engineer. The role of propulsion engineer was not assumed by the students since the students hadn't had a course on aircraft propulsion at the time of the study. Students could assume multiple roles. The instructor provided the necessary background information on the roles of each of these team members and interacted with the teams to answer questions and provide inputs characteristic of a supervisor such as praise for good work and the pointing out of areas in a design or approach that may require re-evaluation on the part of the student (new hire). Appendix A contains some sample introductory slides presented to experimental group to help set the stage for the day's simulation experience.

Following this stage, the teams were tasked to select a concept that the teams would explore further using the aircraft design tools and they were to present this concept at the end of the exercise. Here the students utilized the CATIA, FLOPS and ModelCenter codes. ModelCenter was used to link the FLOPS sizing code to an actual CAD model in CATIA. Microsoft Excel was also used to provide a recognizable interface for the other programs and method to store summary information of the different iterations of the designs under investigation. Given the short duration of the intervention, scaffolding was necessary in order for the students to be able to execute the exercise within the allotted time. A parameterized generic vehicle model was created in CATIA for ease of use by the students. This combined model designed to replicate aerospace industry design practice and provide rapid student proficiency was a key tool developed as part of this LSBL implementation.

The FLOPS program was originally written in Fortran utilizing a namelist input file. The Excel spreadsheet provided a single input source for the FLOPS and CATIA models thus reducing the need for students to have prior experience with either program. The FLOPS program is available for home use and the students were provided with the program ahead of the actual classroom use in order for the students to become familiar with it. The use and linking of these programs is an industry practice and thus the students are also able to gain actual marketable skills that can be mentioned in their real world engineering employment pursuits.

Keeping with real world procedures, if the teams had comparable and valid tools to accomplish various tasks within the study, they were encouraged to propose those to the facilitator/instructor as supervisor. Here the students were given the chance to adapt skills they had gained elsewhere to the situation at hand. For example, some students had CAD skills using programs other than CATIA. Though the CATIA/FLOPS/ModelCenter combination was



necessary to size the parametric vehicle, the students used another CAD program they had skill in, to develop a higher fidelity model of their concept. The previous CAD experience also helped these students more quickly learn how to use the CATIA program.

During the team portion of the exercise, the students gained experience in teamwork in a design environment. They needed to practice communications skills as they attempted to convince their fellow team members that their concept was the one the team should pursue. They had to test out their organizational social skills as they decided on team roles and assignments. They also practiced compromise in order to accomplish the team goals. In the final stage of the exercise, the students were tasked to develop a small presentation describing their team's concept and they had to present this concept to the facilitator/supervisor and the other teams. Here again the students were given an opportunity to practice communication as they attempted to convince the other teams and the supervisor that their concept was the one that should be moved into the next phase of design. From there the facilitator/instructor provided feedback on the concepts to all teams and selected a design that *Ace Aero* would go forth with into preliminary design based upon what was presented. All of this was accomplished in the context of a simulated work environment. The short duration of the exercise exposed the participants to the demands and pressures of deadlines as experienced by a practicing engineer.

In this application of the LSBL approach the students were introduced to the culture and day-to-day existence of those in industry working advanced design. The BAA chosen, in addition to being an actual DARPA document, was also a technical challenge requiring the students to explore areas where they most likely did not have previous experience such as submarines and propulsion systems that could operate in mixed modes. The students had to tackle having competing technical requirements that alone would yield two very different design

concepts. The students had to decide what kinds of information they needed in order to do the design study work and had to consider how to sell their concepts to the potential DARPA customer. At the same time they also had to consider what concepts other teams in the class might propose which were in competition with theirs.

The instructor or facilitator for the experimental class is very important for its success. In order for the instructor/facilitator to play the role of the supervisor for the simulation and be able to demonstrate the traits of a practicing engineer, keeping with the LSBL guidelines provided earlier, it is best that the individual have recent work experience in that arena. By having those recent experiences, the instructor/facilitator is be able to consciously and unconsciously demonstrate the traits of the practicing engineer which were intended to help to minimize the chance for the students to gain undesired accidental competencies. Practical engineering design work experience also helps in the students buying into the simulation and suspending disbelief.

As this simulation was a hybrid form of inductive learning, in addition to having the technical foundation, the instructor/facilitator also needs to have some experience with conducting inductive learning instruction in order to anticipate areas where students may have problems or may resist the approach since it was far different than the lecture style that they have often experienced in their collegiate careers (Prince & Felder, 2006, p. 134). The instructor for this part of the experiment was the lead researcher for this study and had nearly 20 years industry experience in air vehicle design that was current. In order to gain experience in inductive teaching, this instructor conducted a pilot study for the proposed research and was observed by the Principal Investigator, Dr. Richard Goff, during some of this pilot study period. This pilot study is discussed in the Pilot Study section of this proposal.

### Control Class Details

Students in the control group along with the balance of the design class (who choose not to volunteer for this study) received formal instruction on the same aircraft design content that was covered in the design exercise with the experimental group. This class followed the classic lecture style that was used in most collegiate classes including design. Typically in the design class, formal traditional lecture classes run before or in parallel with the project portion of the class. Pembridge and Paretti (2010a) indicate that for their respondents nearly 80% held the lecture classes in parallel with the project (p.5).

The class lecture titles were: (1) *The Design Process, Requirements and Alternatives*, (2) *Choosing Aircraft Features*, (3) *Aircraft Sizing Overview*, (4) *Design Teams and Roles*, and (5) *Selling the Concept and a Case Study*. The *Design Process, Requirements and Alternatives* lecture covered the overall design process and how it applies to aircraft design. The lecture then covered the development of requirements and specifications followed by brainstorming. The *Choosing Aircraft Features* lecture covered an overall discussion of the different features of a design, how they work, and why they are there. *Aircraft Sizing Overview* provided a discussion of the aircraft sizing equations and how they are used. *Design Teams and Roles* introduced the students to all of the different roles on an aircraft design team, the tasks they perform and the types of products they produce. The last lecture, *Selling the Concept and a Case Study*, introduced the students to typical standards for presentations and reports expected of one working in industry. This discussion was wrapped up by a case study of the X-1 experimental aircraft that took the topics from each of the previous lectures and applied them to a real world case.

The material utilized in these lectures was very representative of the slides (many are the same) of the lecture material used at Virginia Tech for twenty years. Virginia Tech has traditionally followed the lecture, then project approach, to capstone design where the students are introduced to all of the material necessary to do aircraft design at the first part of the semester and then the students work on their senior design projects for the remainder of the term and the school year. The material was presented by the same professor that created much of the material and taught the aircraft design class for the aforementioned twenty year period. This instructor in addition to having many years teaching aircraft design also had many years in industry as an aerodynamicist doing aerodynamic design in an advanced design group in industry. The combination of these professional experiences allowed the instructor to present the class material and then provide additional context from experience to help reinforce it (as will be seen by some of the student comments in the Results Section).

In addition to the lectures, the students also saw a portion of the television mini-series *From the Earth to the Moon* that illustrated the vehicle design process as practiced in industry by recounting highlights of the design of the Lunar Excursion Module. Students also received three homework assignments designed to reinforce some of the concepts covered in class. Appendix A also contains sample slides presented to the control group class. The combination of instructor, presentation slides, video, and homework were intended to give the students in the control group a consolidated experience of the way the class was classically taught and is conducted at other institutions.

Cross-talk between groups and outside influences could not be totally eliminated since the students could not be observed 24 hours a day. However in an attempt to minimize the cross-talk, the exercise was held during the same class time for both groups in different locations. The

students were also requested not to talk about what they did in either class to each other during the study period.

### 3.4 Participants

The participants of the study were members of the senior class of the Aerospace and Ocean Engineering (AOE) Department and were enrolled in the aircraft design section of the capstone design class. The population of the design class was 59 students.

Of the class population of 59 students, the dissertation study had a sample size of 53 students who volunteered to participate in the study after being briefed about it at the beginning of the 2011 academic term in order to comply with IRB requirements. Given the relatively small population by statistical analysis standards, Rea and Parker (2005) suggest that the sample size for such a study be around 50% of the population which translated into a need of around 30 students to participate. Thus the student study participation exceeded the requirements. This sample had both convenience and purposive attributes, but it was still felt that the results would be useful in indicating a trend that could be evaluated again with a larger population.

Participants were randomly assigned to control and experimental groups for the study. The Control group contained 35 students with the remaining 18 in the Experimental group. The students stayed in these groups throughout the five class period exercise.

There were also professional members of the aerospace industry with experience who participated in the assessment portion of the study by taking the same survey and being interviewed with applicable questions from the same protocol as the students. Their responses served as the benchmark with which the student responses were compared. These industry members all are or have been directly involved in aircraft design typically at a systems level as opposed to detailed design engineers. There was a need for a minimum of at least 15 industry

participants for this study following guidelines for such studies from Rea and Parker (2005). There were 20 participants on the survey and five participants in the interviews.

### 3.5 Quantitative

The purpose of the quantitative methods section of this study was to provide insight into the participants' conceptions of engineering design. Conception can be defined as the sum of a person's ideas and beliefs concerning something. McLaughlin (2003) when describing British philosopher Alasdair MacIntyre's conception of a practice, described it as "involving a coherent, overall, holistic vision of the activity in question" (p.345). Under such a definition, it includes an entire set of beliefs, views of the world, and ways doing things. When one joins a community of practice, one starts to adopt a conception of activities done in that community and held by its members. In the case of the McLaughlin paper, the discussion centers on the conception of educational practice and how it relates to the community of educators. The same concept can be applied to engineering.

Dunsmore, Turns, and Yellin (2011) discuss engineering students' conceptions of core concepts in engineering, including their conception of engineering itself by examining student's portfolios for an introductory mechanical engineering course in manufacturing processes. Conception of engineering design also reflects upon an engineer's conception of engineering including both professional skills and technical skills. Simon (1996) notes that design is the central or distinguishing activity of engineering. An example of the examination of conception relative to engineering design has been the work by Mosberg, Adams, Kim, Atman, Turns, and Cardella (2005) which assessed the conceptions of the engineering design process with advanced practicing professionals (Mosberg et al., 2005). As part of this study, the authors created a

survey that was derived from the efforts of Newstetter and McCracken (2001) which explored novices' conceptions of design. The survey is included in Appendix B.

The Mosberg et al. Design Conception Survey contains two parts. The first part of the survey examines the respondent's ideas about design and requires the respondent to select the six most important and the six least important design activities from a list of 23 items. The second part, examines respondent's definition of design as the respondent answers 27 Likert scale items. The questions used in the survey address content validity in that they present a student's knowledge of design; construct validity in that selection of the most and least important design activities gives some insight into the student's reasoning; and criterion validity in that we also gain some insight into how the students may perform in the future by comparing their responses to the aerospace professionals (Moskal, Leydons, & Pavelich, 2002). The instrument provides insight into the student's views of the professional skills.

The instrument has been used to illustrate the differences between experts and novices and was one of the tools utilized in the Academic Pathways Study or APS (Atman et al., 2010). In preparation for use of this instrument in the APS, the researchers informally performed (unpublished) validation exercises with the instrument which included having several undergraduate engineering students respond to the questions of the survey and debrief about how they interpreted item wording. Those exercises did not indicate a need to reword the tool (K. Yasuhara, personal communication, November 9, 2011). The survey has also been used in three published engineering education research efforts (Atman, Kilgore, & McKenna, 2008; Atman et al., 2010; Yasuhara et al., 2011) with a variety of different types of engineers at different levels of experience participating. These previous implementations of the survey speak to its validity as a tool for assessing engineering design conception.

Given the desire to obtain data from both students and members of industry, a constraint on instrument selection was that the instrument had to be portable and only require a short period of time to complete. Another constraint was that the instrument has to convey the respondents' thoughts about design while not causing the respondent to divulge proprietary processes that may be used by a company in industry. By selecting a tool that meets these requirements, it was thought that there would be increased industry member participation by only creating a small interruption in the professional's schedules. This desire for larger industry participation was realized during the study. (It may be noted that these requirements also impacted how interviews were conducted in this study and this is discussed in the Qualitative section.) Such requirements precluded the use of assessment instruments such as the Transferable Integrated Design Engineering Education (TIDEE) suite of formative and summative tasks which examine the respondent's professional skills and knowledge of the design process but can require more than 20 to 30 minutes to complete (Gerlick, Davis, Trevisan, & Brown, 2011). For these reasons, the Design Conception Survey was selected for implementation in this study. The survey was also used with the students four times as part of the pre-test, multiple post-test experiment design and the industry professionals only took the survey once. The survey was administered electronically through the secure survey.vt.edu website approved for use in research by the Virginia Tech IRB. Results from the study participants were also compared to those published for the instrument and is included in the Discussion section.

The independent variables in this portion of the study were the three participant groups (experimental, control, industry). The dependent variables were the responses to the areas of the most important and least important design activities and the respondent's definition of design as measured in with the Likert scale questions of Part 2 of the survey. Limitations of the survey are



that even though the survey has been designed to measure conception, the respondent is limited and somewhat guided by the options listed on the survey. These may not fully reflect the respondent's conception of engineering design. To help address this, the survey does provide the option for the respondent to provide additional comments and add design activities.

The statistics program SPSS was used for a large portion of the statistical analysis of the survey results. The results of Part 2 of the survey were checked for normality using the Kolmogorov-Smirnov and the Shapiro-Wilk tests. Based upon the results of these tests, it was determined that the data sets did not meet the normality requirement necessary to use parametric statistical tests. As a result, the non-parametric independent samples Kruskal-Wallis statistical test was used to compare the two student groups with the aerospace industry professionals.

Data collection did not include person by person tracking of the survey results and only tracked the different study groups as a whole. As a result, when comparing the students to themselves statistically at different times during the study (pre-test to any given post-test), related samples tests such as the paired t-test or the Related Samples Wilcoxon Signed Ranks test were not applicable. Under the recommendation of personnel at Laboratory for Interdisciplinary Statistical Analysis (LISA) at Virginia Tech, the Mann-Whitney U test was used instead to do pairwise group comparison. Though this is an independent samples method and all the pre-post comparisons are dependent, the Mann-Whitney U can indicate overall increases or decreases in a study group from one time period to the next which is consistent with the aim of performing multiple post tests. This approach also allowed for flexibility in dealing with differing response quantities between tests (thus if a number of students didn't answer the survey in a subsequent post-test, the analysis could still be done looking at the entirety of both samples that did answer).

Consistent with the Atman et al. (2007) study, a significance level of 0.05 was used for the statistical tests. This significance level is commonly used in social research.

Relative to the first part of the survey involving the selection of most and least important design activities, it was desired to compare which items were selected by the various groups and the order of importance as determined by each group, as such the rank correlation statistic, Kendall's Tau, was used. This non-parametric test was applied to each of the obtained datasets. It was assumed that a correlation of 0.2 was a weak correlation between the student group and the professionals, 0.5 was moderate correlation between the student group and the professionals, and 0.7 or larger was considered to be a strong correlation between the student group and the professionals. In addition, 95% error bands for the correlations were estimated using the bootstrap re-sampling method. This bootstrap analysis with Kendall's Tau was conducted by Jonathan Stallings of LISA at Virginia Tech using code he wrote in the R programming language.

In addition to the survey and interviews (discussed in the next section), copies of the end of the first semester team design reports and presentations were obtained as evidence of the students' design learning during the semester. This gave some insight into the longer term impacts of the intervention on the participants as design reports and presentations from groups that consisted of mostly experimental group participants were compared to groups that consisted mostly of control group participants. (The regular design course schedule prohibited the creation of 100% control and 100% experimental member design teams for this study.) A modified version of rubrics geared towards capstone design courses and developed under the TIDEE Consortium (Davis, Beyerlein, Thompson, Harrison, & Trevisan, 2009) effort were used to evaluate the reports and presentations. (The modification entailed the elimination of assessment

categories not applicable to the aircraft design class as practiced at Virginia Tech.) These rubrics were utilized by a member of industry that was brought in to assess the student designs and presentations and were also used by the lead researcher to evaluate the end of the semester team design reports. These rubrics are contained in Appendix C.

### 3.6 Qualitative

The purpose of the qualitative methods section of the study was to provide additional insight into the thoughts and views of the participants that could not be obtained by the questionnaire alone. The protocol for these interviews is provided in Appendix D. The 16 item protocol can be broken into three main groupings. Group 1 contained six questions exploring the participants' view of the exercise or class, depending upon the group the participant was a part of. Group 2 also contained six questions which explored the participant's view of various aspects of aircraft design such as teamwork and the design process. Group 3 contained four questions and these overlapped portions of the design conception questionnaire where the respondent was asked to select a single most important and single least important design activity from the list that was provided in the questionnaire and provide an explanation for why that selection was made. The last three questions asked the respondent to provide interpretation of select questions from Part 2 of the questionnaire. The questions selected for reflection were based upon an initial assessment of the quantitative results in order to provide additional respondent insight. Group 3 questions helped to provide triangulation with the questionnaire results. The interviews were expected to last 30 minutes.

A minimum of eight audio recorded semi-structured interviews (four from the control group and four from the experimental group) were conducted with the student participants. These interviews were conducted in a conference room in Virginia Tech's McBryde Hall at a

time convenient to the participant interviewee outside of the regularly scheduled class. All interviews were voluntary and were conducted within two weeks of the last intervention class so that the experience would be fresh on the students' minds. It was intended to help to minimize the impact of factors beyond the experiment period influencing the results. A monetary incentive of a \$25.00 Virginia Tech gift certificate per interview (up to eight interviews total) was provided to the study participants as compensation for their extra time to provide the desired eight student interviews.

There was a single interviewer for all of the student interviews. This interviewer had an aerospace engineering background similar to the students to aid in developing a rapport with the students. This interviewer was a Virginia Tech Engineering Education PhD candidate at the time of the interviews and had previous experience conducting interviews. This approach permitted the student interviewee to use aerospace technical language without having to explain terminology. This freedom for the student to speak freely without concern for terminology was essential in capturing the student's views of aircraft design through the use of language.

As with the quantitative portion of the study, interviews were conducted with members of industry and served as a benchmark upon which the student interviews were compared in the mixed methods portion of the study. Invitations were sent out to a number of prospective interviewees. A total of five interviews were conducted with the members of industry who also completed the questionnaire described in the Quantitative section. The interview protocol was the same as that of the students minus the Group 1 questions which did not apply to the industry professionals. A combination of phone interviews and email interviews were used in order to increase the likelihood of industry participation by providing multiple options to prospective

interviewees. A phone interview was conducted by the lead researcher with one interviewee due to the unavailability of the interviewer of the students.

After the interviews were conducted, they were transcribed by the lead researcher. A discourse analysis was then used. Tajla (1999) states that discourse analysis “systematizes different ways of talking in order to make visible the perspectives and starting points on the basis of which knowledge and meanings are produced in a particular historical moment” (p.2). With the aim of capturing how a community of practice influences an individual, discourse was used as a recordable manifestation of that influence that can be analyzed with qualitative approaches such as discourse analysis. Such an approach is not new to engineering education where Dunsmore, Turns, and Yellin (2011) have used discourse analysis of the written portion of student portfolios to examine student conceptions of mechanical engineering. It was felt that the portfolios and the language in them were “social constructions of the students in the context of a specific class, in an engineering undergraduate program, in a society in which engineering is a profession the students expect to join” (Dunsmore et al., 2011, p.332). The approach was also used by Kittleson and Southerland (2004) who used discourse analysis in the study of mechanical engineering students in a capstone design course where the course had been redesigned to explicitly combine aspects of numerical simulation and experimentation in response to some industry concerns that these areas had been traditionally neglected and needed to be addressed (Case & Light, 2011; Kittleson & Southerland, 2004).

The transcripts were examined to look for trends among the different participant groups during this stage of the study. These trends were then compared between groups in the mixed methods portion of the study where the results will be merged with the quantitative results. Initial codes developed by the lead researcher during discourse analysis were cross-checked by

two other independent researchers (Engineering Education PhD. graduate students) with qualitative data analysis experience. This coding was refined to include minor modifications suggested by both researchers. Limitations to this overall interview approach were that participants' insights were limited to those areas and topics explicitly asked for in the interviews and any additional comments that arose as a result of interviewer prompting in the semi-structured interview format. As such, some insights and perspectives of the participants as expressed in language had the potential to be missed. Interviewer rapport and thoroughness were essential in minimizing the occurrence of this.

### 3.7 Mixed Methods

The purpose of the mixed methods section of the research design was to combine the results of both the qualitative and quantitative research to determine if the combination of both sets of data revealed any sort of relationship between the experimental, control and industry professionals groups. In particular, responses relating to the professional skills of communication, teamwork, and problem solving were examined.

To achieve this merging of the data, a *side-by-side comparison for merged data analysis* as described by Creswell and Plano Clark (2011) was used (p.223). In this approach the quantitative results and the qualitative findings are presented together in a discussion or summary table for comparison. Similarities between the industry benchmark and either student group could be viewed as an indication that either approach (live simulation or lecture style) helped students to think and present themselves in a manner similar to a practicing engineer. Causality could not be definitively proven by this approach but by minimizing the number of confounding variables, one could derive an indication of whether or not either approach under the setting of the study contributed to the students responding as they did. The inherent

impracticality of being able to completely shut off the participant from all other external influences save the two treatments in order to see exclusively if either treatment caused a desired response was a limitation of this approach.

Relative to validity, as described by Creswell and Plano Clark (2011), challenges to validity for the merged data could be categorized under the headings of data collection, data analysis, and interpretation (pp. 240-241). To address data collection issues, samples for the qualitative and quantitative analyses were drawn from the same population. Separate data collection procedures were utilized for the quantitative and qualitative portions of the study. There was some triangulation achieved by having some of the same questions asked in both the qualitative and quantitative parts of the study. Member checking, where the final transcription and themes were taken back to the interviewee for review, was used to ensure accuracy.

In the area of analysis, appropriate quantitative results and qualitative results were merged into a combined analysis addressing each of the research questions. In areas where the same question was asked for both the qualitative and quantitative data collection, there was a search for quotes that matched the statistical results. For the quantitative, data normality was checked and an appropriate statistical procedure was selected. Finally with regards to interpretation, when irresolvable divergent findings occurred, the data was re-analyzed and double checked to ensure mistakes had not been made. A single researcher performed all of the analysis eliminating the issue of inter-rater reliability.

Experience and personality differences between the study instructors could have impacted how the students reacted in the study. To account for these potential differences, a third party who was the Associate Director for the Center for Instructional Development and Educational Research or CIDER, Dr. C. Edward Watson, observed both classes and instructors

and rendered an opinion on the instructor impact in the study. The CIDER organization has a specialty in pedagogy. The findings of this outside observer are discussed in Chapter 5.

### **3.8 Research Permission and Ethical Issues**

The IRB must approve all research involving humans. A complete research protocol including instruments had to be submitted to the IRB in order to gain approval for the research. Utmost care was taken to protect the participants of the study. All student participants signed a consent form to participate in the study. The identity of the participants was only known by the Principal Investigator and the lead researcher. Participants were only identified by Participant IDs that were generated at the beginning of the study. Master lists that tied the participants to the Participant IDs were secured with limited access. Interview recordings were also kept for a short period of time until completion of the transcription task, after which the recordings were destroyed. All information and tools presented to both groups were available to all students in the design class following the study period in order to ensure no one group was placed at an advantage or disadvantage in the class.

### **3.9 Role of the Researcher**

The lead researcher for this effort served as both a participant and an observer. As a participant, the lead researcher was the instructor/facilitator for the experimental class. The combination of the researcher's 18+ years of industry experience and engineering education experience gained through the pursuit of the PhD in Engineering Education for three years made the researcher uniquely qualified to perform the instruction for that portion of the study. As an observer, the researcher attempted to provide an objective review of the data collected and drew conclusions based upon the data obtained. Where possible, existing proven instruments were utilized for data collection to help minimize the potential for researcher bias.



The researcher's industry ties as a result of the industry experience were utilized in the performance of this study. It is viewed that this connection is a benefit to this study by having access to a culture and personnel that does not often appear in engineering education research. Students who are learning design, and thus momentarily learning to be aircraft designers, were being directly compared to those who do aircraft design for a living and on average have been doing it for more than 20 years.

### **3.10 Pilot Study**

A pilot study of the proposed research was conducted in first term of the 2010-2011 academic year at Virginia Tech using a different combination of simulation tools and assessment instruments. A detailed summary of the pilot study is contained in Appendix G. Lessons learned from this pilot study led to the following changes in the study protocol when moving from the pilot study to the formal proposed study: (1) an extension of the study period beyond four class periods, (2) further research and discovery of the Mosberg et al. Design Conception Survey, (3) refinement of the simulation tool including more design code integration with the ModelCenter program, and (4) modified and additional interview questions including the addition of interviews with the industry professionals.

## Chapter 4: Findings

The subsections 4.1 through 4.3 present the results of the research design presented in the Chapter 3. Section 4.1 presents a review of observations and products from the LSBL class experience as viewed from the lead researcher. Sections 4.2 and 4.3, respectively, present the quantitative and qualitative results for the entire study. The sections show results for the student participants (both experimental and control groups) in comparison to the aerospace industry design professionals who took the design conception survey and answered applicable interview questions that were also posed to the student participants. Together the participant responses provide the evidential basis for the answers to the research questions posed earlier, restated below and answered in Chapter 5:

1. Can the use of live simulation-based learning (LSBL) in aerospace capstone design alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design?
2.
  - a. How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?
  - b. How do (aerospace) engineering students describe their experiences with realism through simulation in relation to their previous academic experiences?
3. What, if any, is the relationship between LSBL students, lecture-based students and aerospace industry professionals with regards to their conception and viewpoints of aerospace engineering design?

In particular:

- a. How do LSBL students, lecture based students, and aerospace industry professionals compare on the professional skills of communication and teamwork?
- b. How do predominantly LSBL student design groups and predominantly lecture-based student design groups compare on the professional skill of problem solving as exhibited in an aircraft design project?

The quantitative results provide the evidential data for the first research question while the qualitative results provide the evidential data for the second research question. A combination of both the quantitative and qualitative data provides the evidential data for the third research question.

Quantitative findings indicate that the LSBL intervention did have an impact on the student conceptions of aerospace engineering design while the qualitative findings indicate that students found the LSBL approach engaging and that they also have maturing views of aerospace engineering design that are greatly influenced by a combination of their academic experiences and their engineering work experiences such as co-op experiences and internships. The results also indicate that the basic PjBL approach of the regular aircraft design class can help the students to respond in similar fashion to the aerospace professionals over the course of the year long aircraft design course but that the LSBL approach did help students to achieve higher levels of agreement with the professionals in their answers at a quicker rate.

#### **4.1 Experiment Review**

Students were recruited for the exercise on August 23, 2011 following a presentation by the lead researcher describing the project to the AOE capstone design class. As discussed previously these volunteers were given participant IDs and randomly assigned to the

experimental and control groups. The intervention itself was executed from August 25 through September 8, 2011. As mentioned in Chapter 2, the instructor for the control group class was Dr. William Mason while the lead researcher instructed the experimental class. Full attendance was achieved for the experimental class during the study period. Control group class attendance remained in near full attendance range for the duration of the study period.

There was one unplanned event that occurred during the study period for the experimental group. On the last day of the study classes, the experimental group students and instructor were forced to move from the study classroom to another room in another building at the last minute preventing students from being able to access all of their files for the presentation portion of the exercise and forcing the students to assemble ad hoc presentations with the study material that was available to them in the remote classroom location. This is noted in some of the experimental group interview responses. One exercise team was an exception to this and had a full PowerPoint presentation ready for the last class. The teams that could not access their files during the last class were given extra time to provide a small PowerPoint presentation to the lead researcher after the actual study period. All design teams in the experimental group provided such a presentation. Samples of some of the team sketches for the submersible aircraft and final presentations are presented in Figure 3.

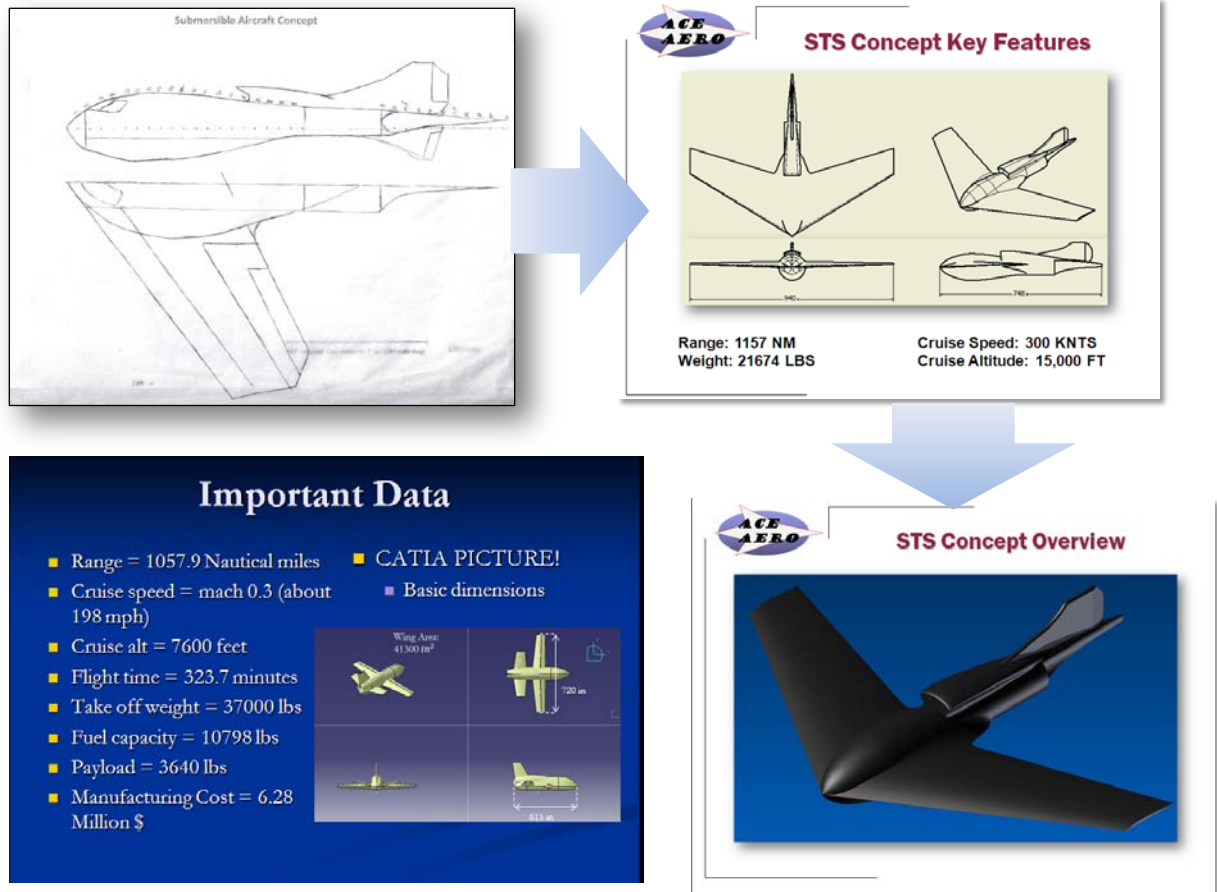


Figure 3. Experimental Group Submersible Aircraft Sketch and Final Presentation Samples.

Interviews were conducted with four students in the control group and four students in the experimental group from September 9 through September 27, 2011. As was discussed in Chapter 4, these interviews were conducted with a separate researcher having an aerospace engineering background who was not involved in the intervention. These interviews were conducted in a one-on-one format in conference rooms located in a building away from where the exercise was conducted and where the students take most of their aerospace engineering classes. There were three male interviewees and one female interviewee for both the experimental and control group interview sessions.

## 4.2 Quantitative Results

### **Demographics.**

Fifty-three of the 59 aerospace engineering design class students participated in the study. These participants were split into the experimental and control groups of the study with a split of 18 students in the experimental group and 35 students in the control group. The majority of the students (around 69%) had less than one year real world engineering experience as a co-op or intern. Twenty aerospace design professionals participated in the study. The majority of professionals (around 65%) had greater than 20 years of professional experience. Figure 4 illustrates the split of experience level of the participants per study group.

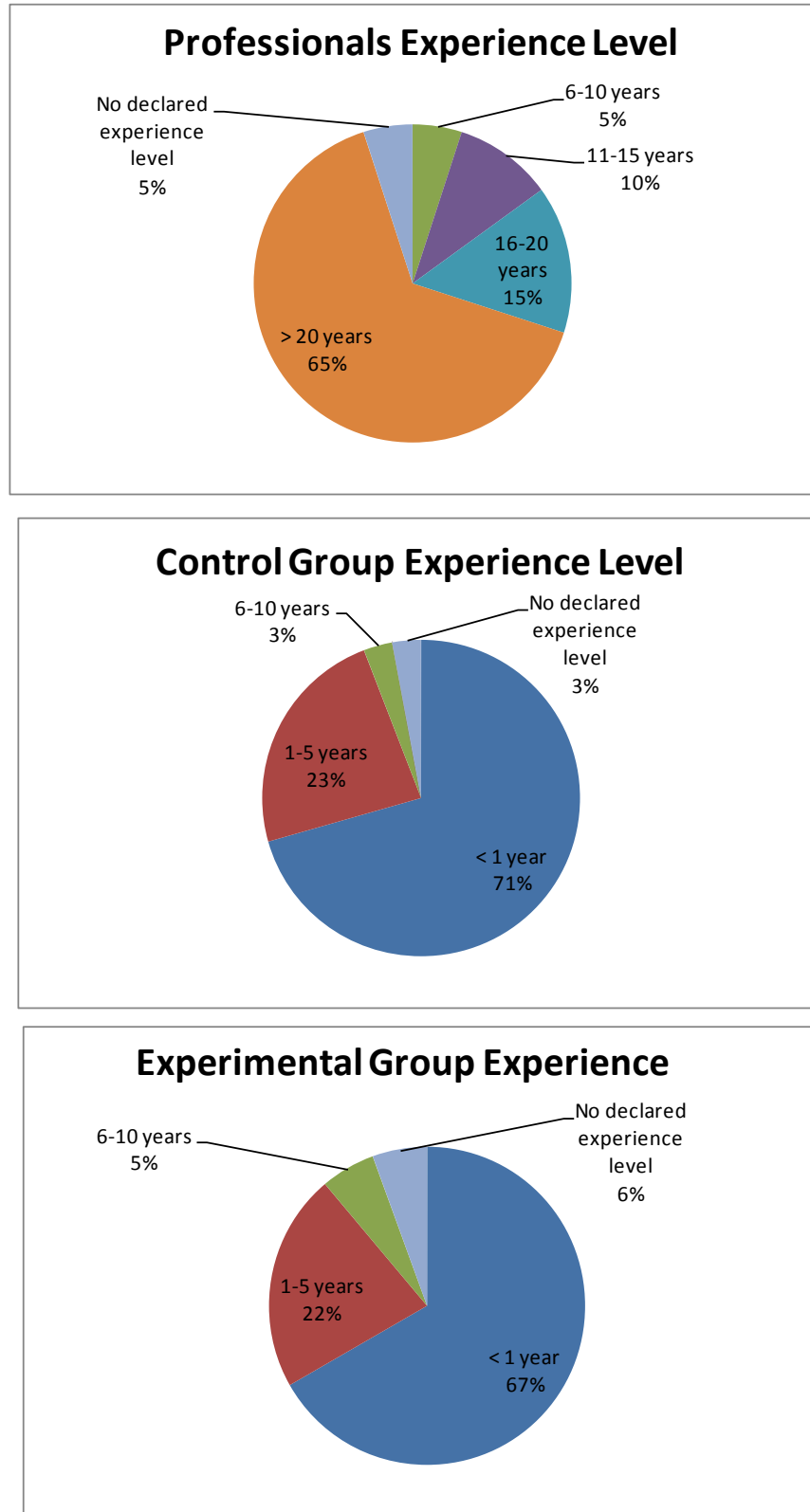


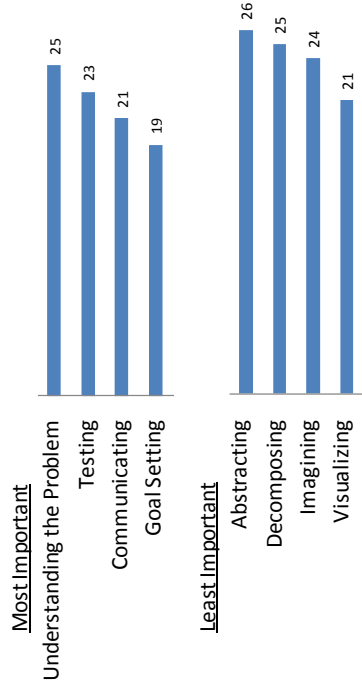
Figure 4. Engineering Experience Levels of the Study Groups

### **Survey Part 1.**

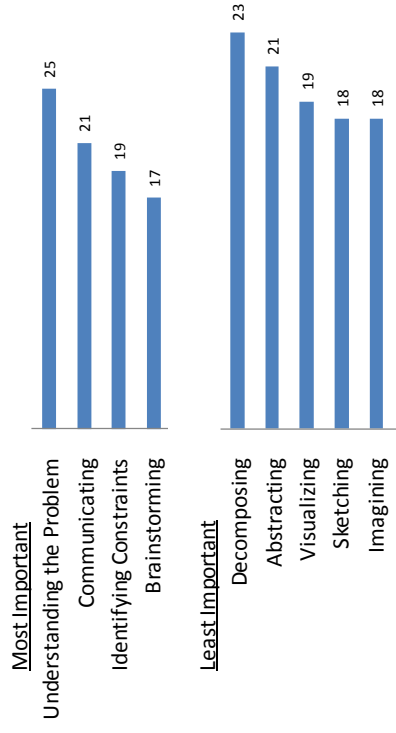
Figures 5 and 6 present the top four most important and top four least important design activities (including ties) as selected by the aerospace design professionals (sample size of 20), the experimental student group (initial sample size of 18) and the control student group (initial sample size of 35). The student selections are presented for four key milestone periods of the study, Pre-Test (just before the five class intervention), Post-Test 1(right after the LSBL intervention period), and Post-Test 3 (just before the end of the year long regular aircraft design course). Following the Pre-Test, the selections of the experimental and the control groups became closer to the professionals as time went on, as one would expect. Understanding the problem remains a top or near top selection by all groups for most important while abstracting was a common selection for the least important design activity. The numbers at the end of the bars in Tables 5 and 6 represent the number of participants in that group that selected that item for most or least important. Appendix E contains a complete listing of the most and least important design activities for all participant groups at all administrations of the survey.



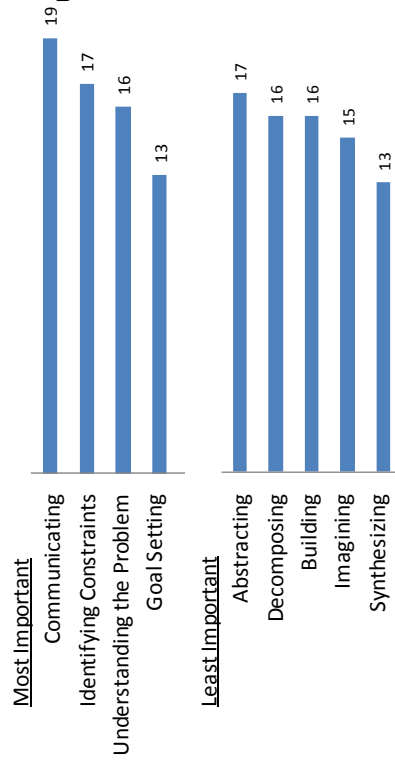
Control Pre-Test (n=35)



Control Post-Test 1 (n=35)



Control Post-Test 3 (n=25)



Professionals (n=20)

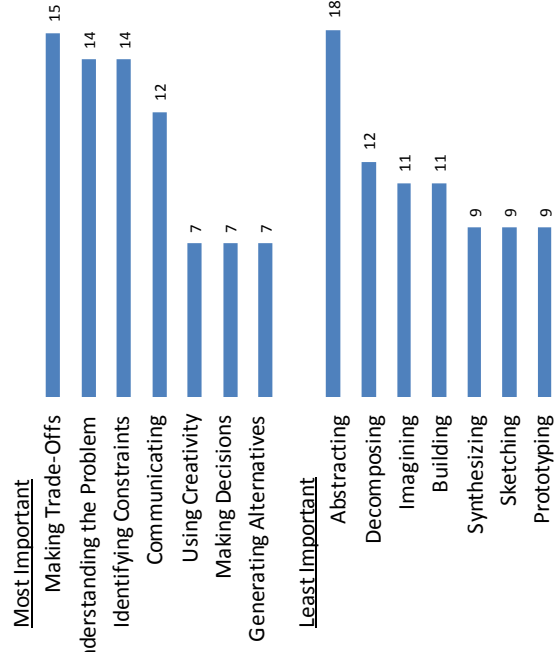


Figure 5. Control Group Design Conception Survey Results: Part 1

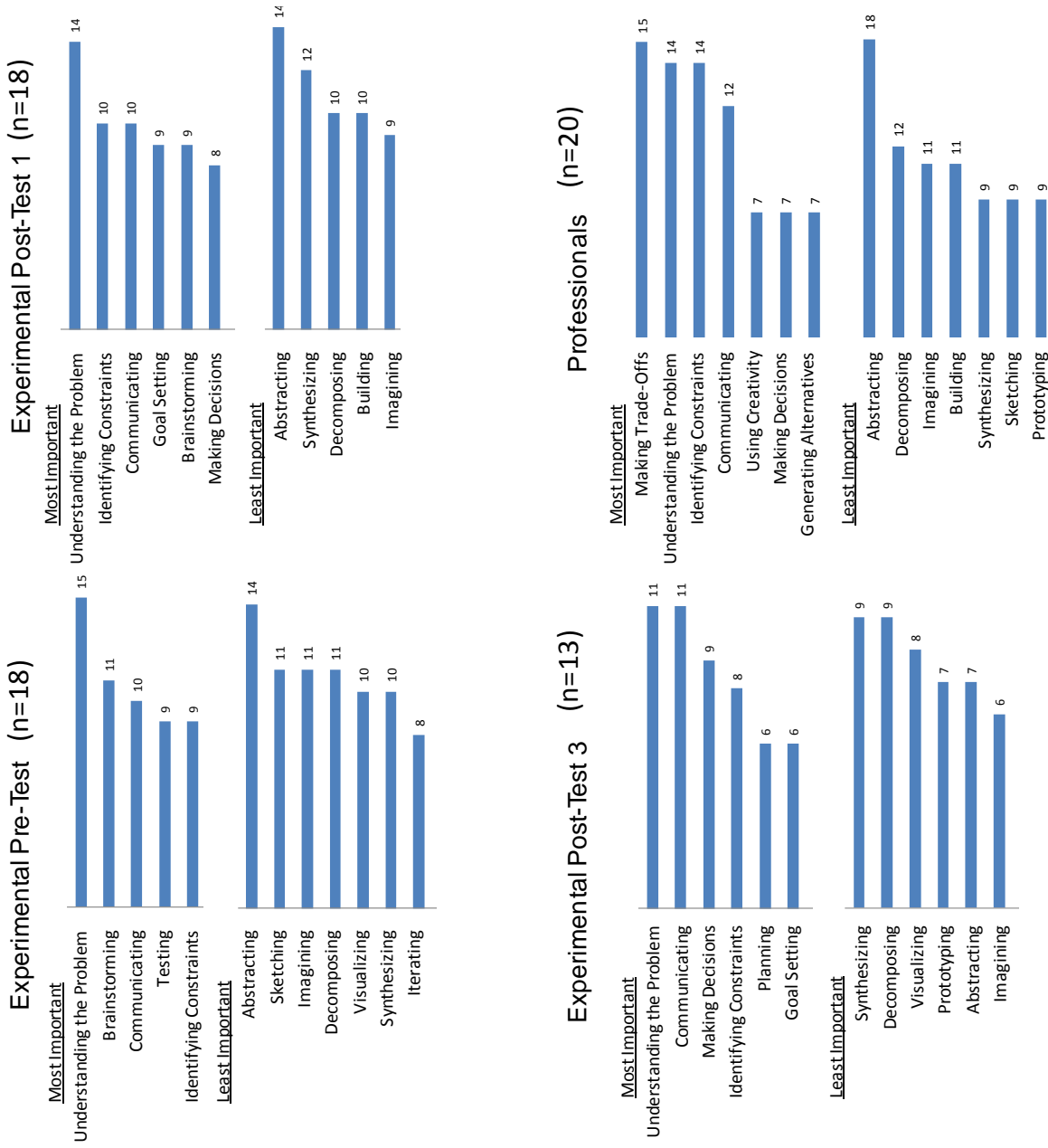


Figure 6. Experimental Group Design Conception Survey Results: Part 1

Table 8 shows the Kendall's Tau correlations between the professionals and the two student groups for the most and least important design activities at different times during the study. Figure 7 graphically illustrates the mean bootstrapped Kendall's Tau results. The bootstrap results in Figure 7 involve an ordering that combines both the least important and the most important activities selected into one dataset per group with the least important items treated as negative values and the most important items treated as positives. In this case, a zero count can occur if the option was not chosen by any of the respondents as a least important or a most important activity or when an equal number of respondents picked an item as least important as those who picked it most important. Relative to ranking, which is being analyzed in this Kendall's tau analysis, neither situation would impact the top most important and the top least important rankings.

Table 8. *Kendall's Tau Rank Comparison Values between groups*

	Survey Sampling Time	Professional/ Experimental Group	Professional / Control Group
Most Important Activities	Pre-Test	0.445	0.447
	Post-Test 1	0.611	0.603
	Post-Test 2	0.570	0.590
	Post-Test 3	0.713	0.519
Least Important Activities	Pre-Test	0.543	0.572
	Post-Test 1	0.627	0.605
	Post-Test 2	0.603	0.726
	Post-Test 3	0.649	0.719

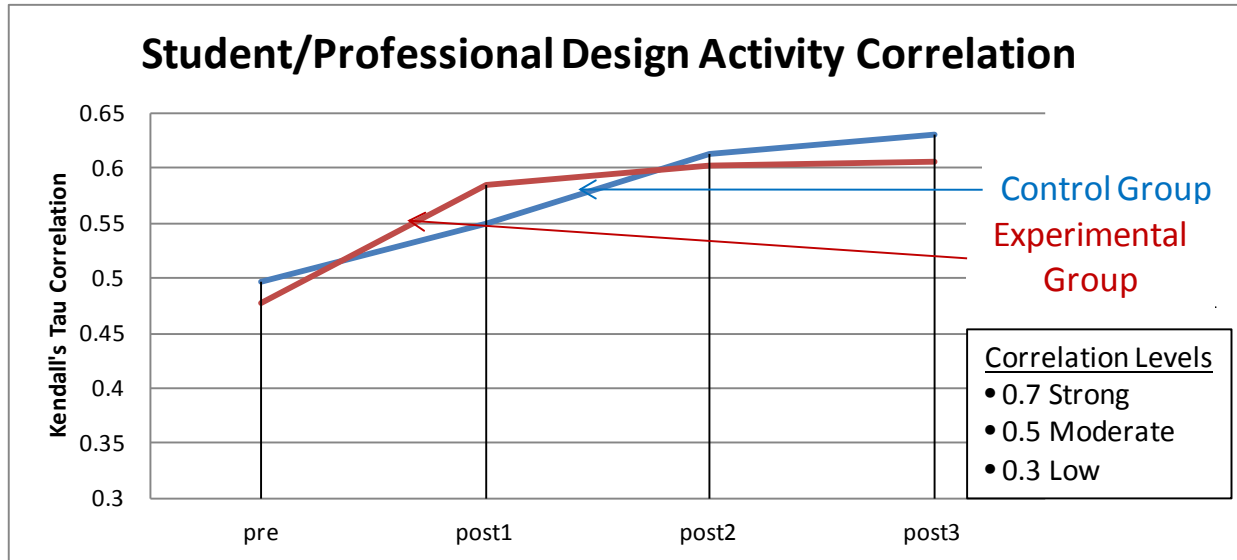
Results indicate that the students are comparable during the pre-test period, diverge somewhat after the intervention and then merge back together at Post-Test 2 (end of the first semester) and level off around the 0.6 correlation range for the rest of the design course.

As is desired, the experimental and control groups correlate highly in the Pre-Test. From Table 8, we see that overall the students stay in the moderate to strong level of correlation with the professionals. The experimental group increases in correlation to a higher level (0.611 for the experimental group versus 0.603 for the control group at Post-Test 1) than the control group for the most important activities just after the five class intervention. However, both groups decrease in correlation slightly relative to the professionals, approximately three months after the intervention and then diverge again with the experimental group increasing to the 0.7 strong correlation level and the control group staying in the 0.5 moderate correlation level with the professionals relative to the most important activities.

In relation to the least important design items, we see a similar trend with increases in correlation for both groups with the slight edge in favor of the experimental group (0.627 for the experimental group versus 0.605 for the control group at Post-Test 1). We see that by the time of Post-Test 2 (approximately three months after the intervention), the experimental group decreases in correlation to 0.603 while the control group actually increases to the strong correlation level with a value of 0.726. By the time of the last survey, the experimental group increases to the 0.649 level of correlation while the control group maintains its strong correlation at a value of 0.719. The bootstrapping results discussed in the next paragraph and illustrated in Figure 7, also show differences between the experimental/professional results and the control/professional results, when comparing the two. However, when examining the confidence intervals (in essence the error band) of the experimental/professional results and the control/professional results, the differences between the two groups are not statistically significant. This could be due in part to the fact that non-parametric statistical tests such as Kendall's Tau, though appropriate for this analysis, are not as powerful at detecting small

differences, such as those seen here. This in turn can make it difficult to reject the null hypothesis with this test and indicate a statistically significant result between items. Refinement of the design conception survey itself could also be done to draw out more differences between groups.

The combined effects of the most and least important items indicate that between the Pre-Test and Post-Test 1, the experimental group students made selections that more closely matched the professionals (a positive correlation change of 0.108) than the control group (a positive correlation change of 0.054). This was the largest separation between the experimental and control group results. By the time of Post-Test 2, we see that both the control and the experimental groups continued to make selections that more closely matched the professionals but showed a lower level of improvement than that which occurred just after the intervention (i.e. Post-Test 1). After the first semester of the design class (time of Post-Test 2), the plot shows that both groups level off or slightly decrease in correlation with the professionals. The overall changes discussed are shown graphically in Figure 7 (using the bootstrap values for Kendall's Tau) where we see that the experimental group appears to move to higher correlation (better matching) with the professionals at a faster rate than the control group during the time of the five class LSBL intervention.



Event	Control			Experimental		
	Sample Size	Tau Correlation	Standard Error	Sample Size	Tau Correlation	Standard Error
Pre-Test	35	0.496	0.058	18	0.477	0.07
Post-Test 1	35	0.55	0.062	18	0.584	0.069
Post-Test 2	35	0.612	0.054	17	0.602	0.062
Post-Test 3	25	0.63	0.058	13	0.606	0.066
Sample size = 20 for the professionals in all tests						

Figure 7. Combined Bootstrap Kendall's Tau Rank Comparison Values Over Time

## Survey Part II.

The second part of the survey contains 27 Likert scale questions (5= Strongly Agree, 4=Agree, 3=Neither agree nor disagree, 2=Disagree, 1=Strongly Disagree) relating to design. Results for both the experimental and control groups were compared to the professional responses using Kruskal-Wallis for the Pre-Test, Post-Test 1 (end of the LSBL/Control classes), Post-Test 2 (end of the first semester), and Post-Test 3 (end of the design course). There were nine questions that had statistically significant results to the 95% alpha level over the course of the study. Table 9 contains these statistical results at each of the study milestones (pre-test, post-test 1 etc.). The reader is reminded that the additional post-test survey administrations after the

first post-test were done in order to determine if there were any long term differences between the experimental and control groups as measured by the design conception survey. In addition, the control group results provide insight into how the regular Virginia Tech aircraft design class changes students' aircraft design conceptions.

The experimental and control group results were also analyzed separately using the Mann-Whitney U test as explained in Chapter 3. The Pre-Test results were compared to all of the subsequent Post-Tests individually for both the experimental and the control groups. In both analyses, each question was analyzed as a separate statistical test. In the case of the Mann-Whitney U test, the student groups were compared as a whole as opposed to treating the analysis as a series of individual related samples comparisons looking at each individual participant. As explained earlier, this was done since results of the survey were tracked from a group level and not on the individual participant level. As such, the results presented reflect changes in the study groups as a whole but do not necessarily capture individual performance, where for instance one respondent might switch in view on a particular item from a positive Likert scale response to a negative for one while another respondent might have made a similar change but in the opposite direction from negative to positive. The net effect of that would be that the two results neutralize each other from a group statistic standpoint even though there were individual changes.

Table 9. Design Conception Survey Part2 Statistically Significant Results

Pre-Test		Post-Test 1	
Sig Pair	H	Sig Pair	H
<u>Question</u>	<i>p</i>		<i>p</i>
1	H(2,N=74) = 7.18	P-E	H(2,N=73) = 9.71
2	H(2,N=74) = 9.74	P-E,C	H(2,N=73) = 19.91
7	N/A		N/A
10	N/A		N/A
11	N/A	P-C	H(2,N=73) = 6.01
13	N/A		N/A
17	N/A	P-E	H(2,N=69) = 7.68
22	H(2,N=74) = 9.24	P-E	H(2,N=71) = 11.76
23	H(2,N=74) = 12.31	P-C	H(2,N=72) = 8.14
	P=Professional, E=Experimental, C=Control		

Post-Test 2		Post-Test 3	
Sig Pair	H	Sig Pair	H
<u>Question</u>	<i>p</i>		<i>p</i>
1	H(2,N=72) = 7.76	P-E,C	H(2,N=58) = 6.50
2	H(2,N=71) = 8.32	P-C	H(2,N=58) = 10.54
7	H(2,N=72) = 8.62		N/A
10	H(2,N=72) = 7.24		N/A
11	N/A		N/A
13	H(2,N=72) = 6.01	P-E,C	H(2,N=58) = 17.33
17	N/A	P-E	H(2,N=57) = 9.84
22	N/A	P-E,C	H(2,N=56) = 9.52
23	N/A	P-E,C	H(2,N=58) = 19.01
	P=Professional, E=Experimental, C=Control		



As mentioned previously, of the 27 questions, there were nine statistically significant results all indicating statistically significant difference (with a 95% confidence level) between one or both of the student groups and the aerospace industry professionals. Figures 8 – 16 illustrate the changes in experiment and control group attitudes towards the questions asked in Part 2 in relation to the professionals. The professional mean response is provided for comparison to the student mean responses at each of the study milestone periods (pre=Pre-Test, p1=Post-Test 1, p2=Post-Test 2, p3=Post-Test 3). The statistically significant pairings are signified by an asterisk and coincide with the results presented in Table 9. The arrows on the charts illustrate the trend of the student responses over the course of the study. For example in Figure 8 (aka question 1), the pairing Experimental Group/Professionals was strongly statistically significantly at the Post-Test 1 (p1) milestone to the  $p=0.008$  level (obtained from Table 9). The mean Experimental Group value was 1.61 while the mean Professional value was 2.6 for this question. In this example at the Post-Test 2 milestone, the experimental group-professional pairing (Experimental Group mean value of 1.76) was also found to be statistically significant to the 95% alpha level.

- Question 1: “Good designers get it right the first time”

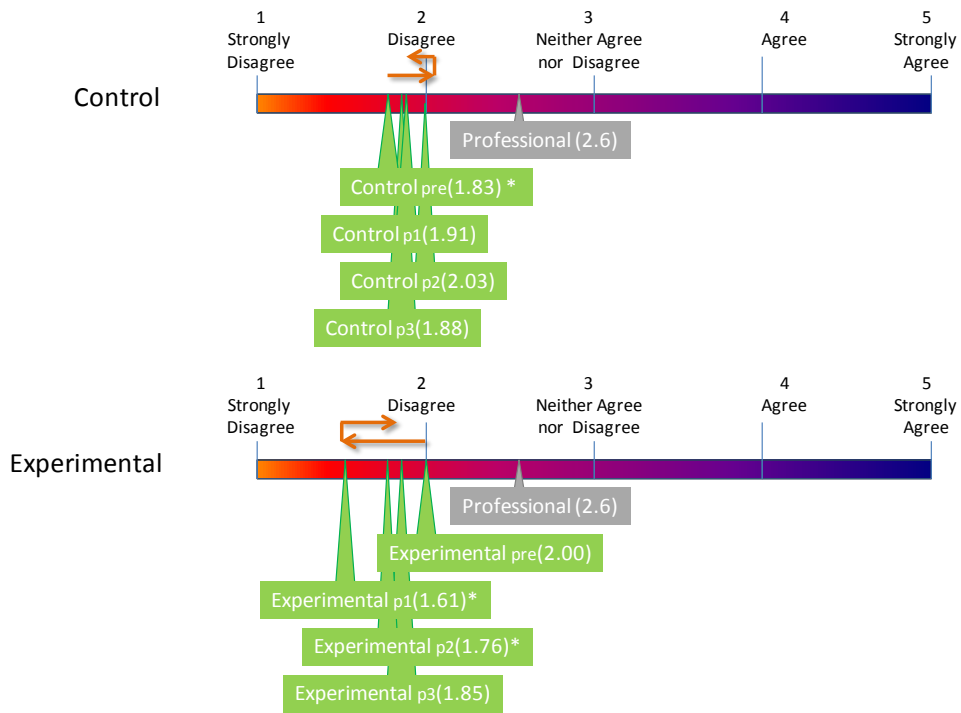


Figure 8. Design Conception Survey Part 2, Question 1 Results

- Question 2: “Good designers have intrinsic design ability”

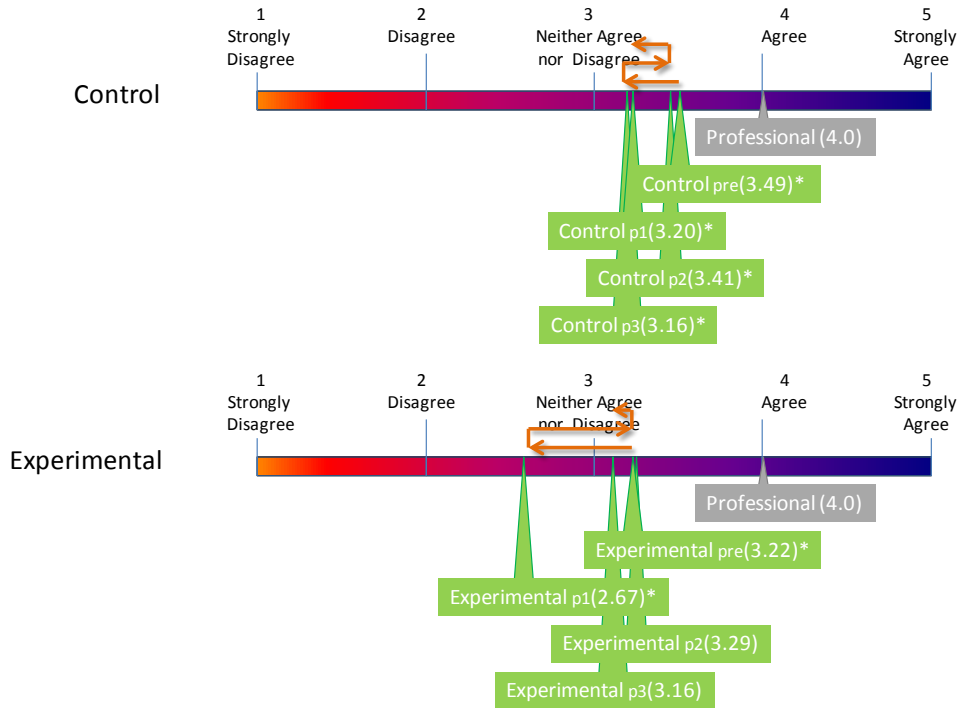


Figure 9. Design Conception Survey Part 2, Question 2 Results

- Question 7: “Design begins with the identification of a need and ends with a product or system in the hands of a user”

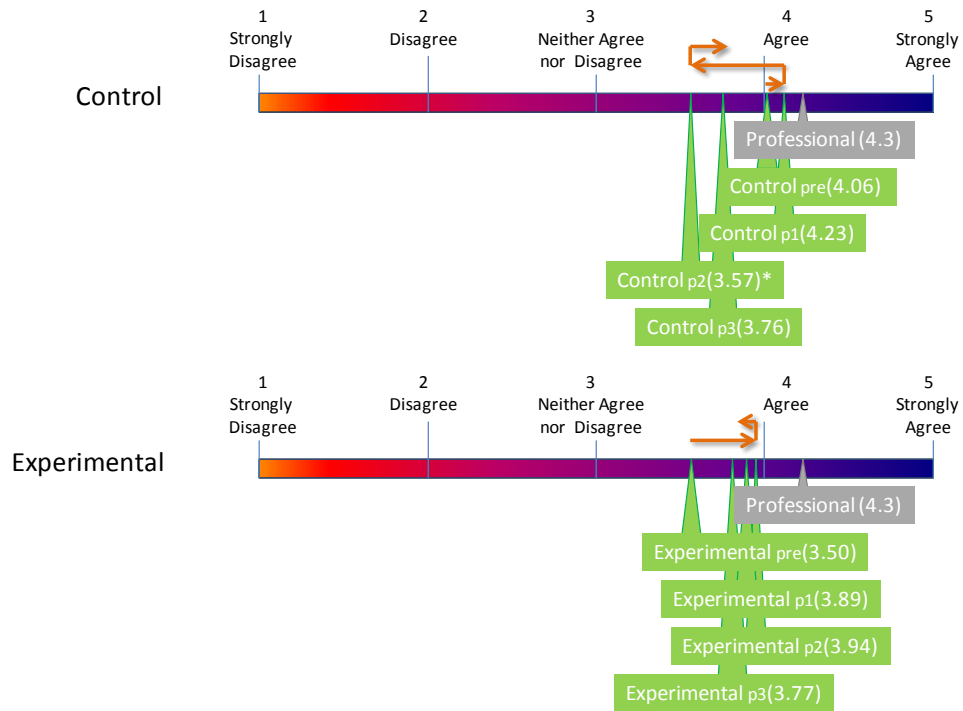


Figure 10. Design Conception Survey Part 2, Question 7 Results

- Question 10: “Design is as much a matter of finding problems as it is of solving them”

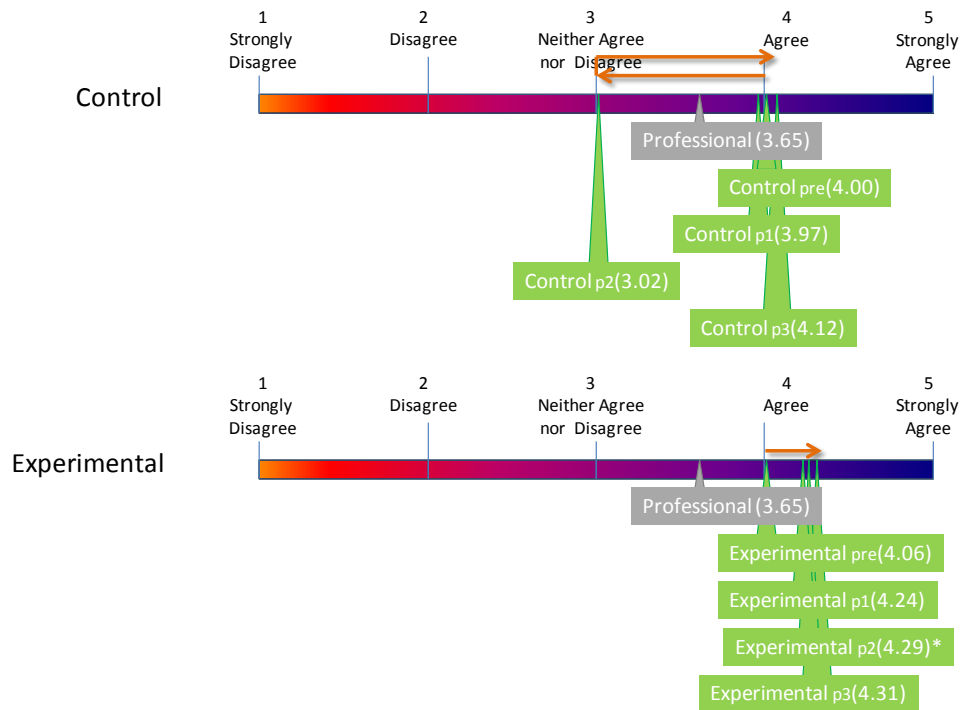


Figure 11. Design Conception Survey Part 2, Question 10 Results

- Question 11: “In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem”

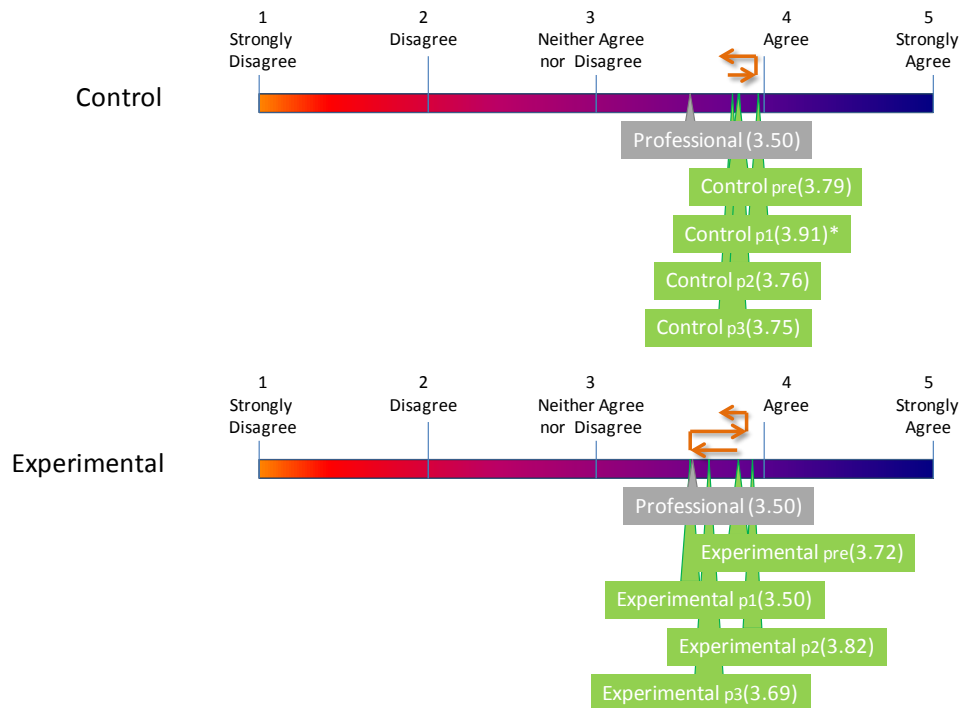


Figure 12. Design Conception Survey Part 2, Question 11 Results

- Question 13: “Designing as a conversation with the materials of a situation”

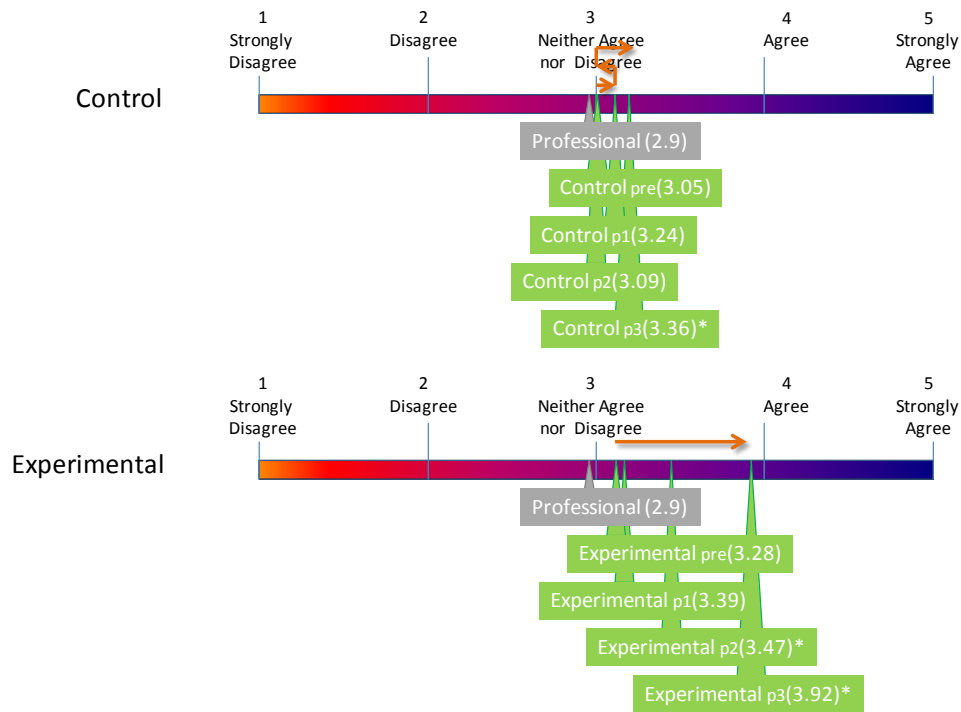


Figure 13. Design Conception Survey Part 2, Question 13 Results

- Question 17: “In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a ‘surprise’ that drives the originality streak in a design project”

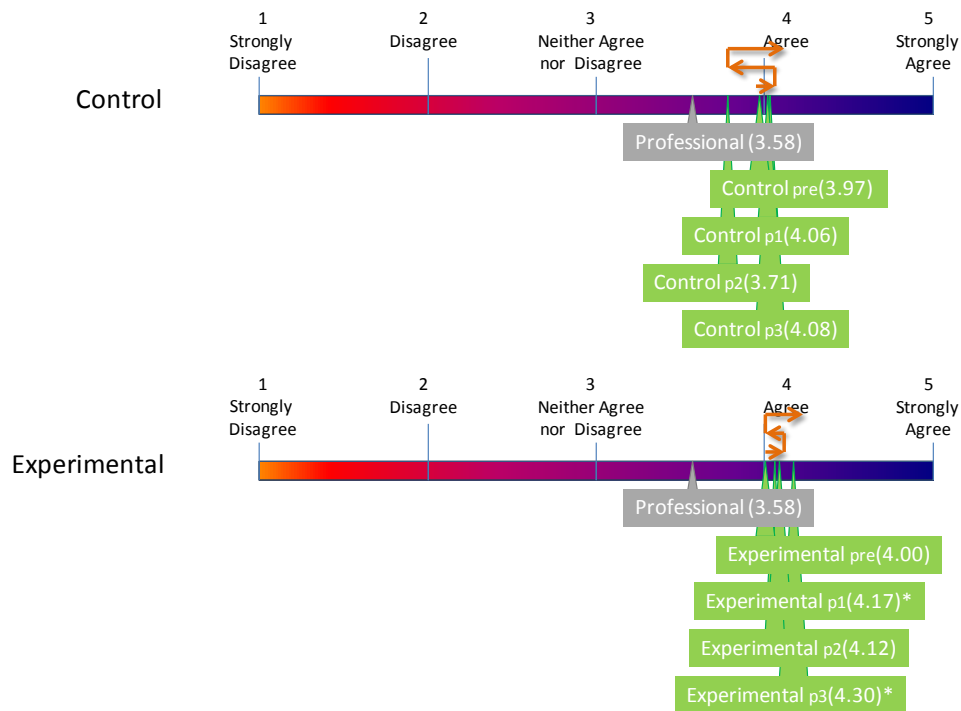


Figure 14. Design Conception Survey Part 2, Question 17 Results

- Question 22: “A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency”

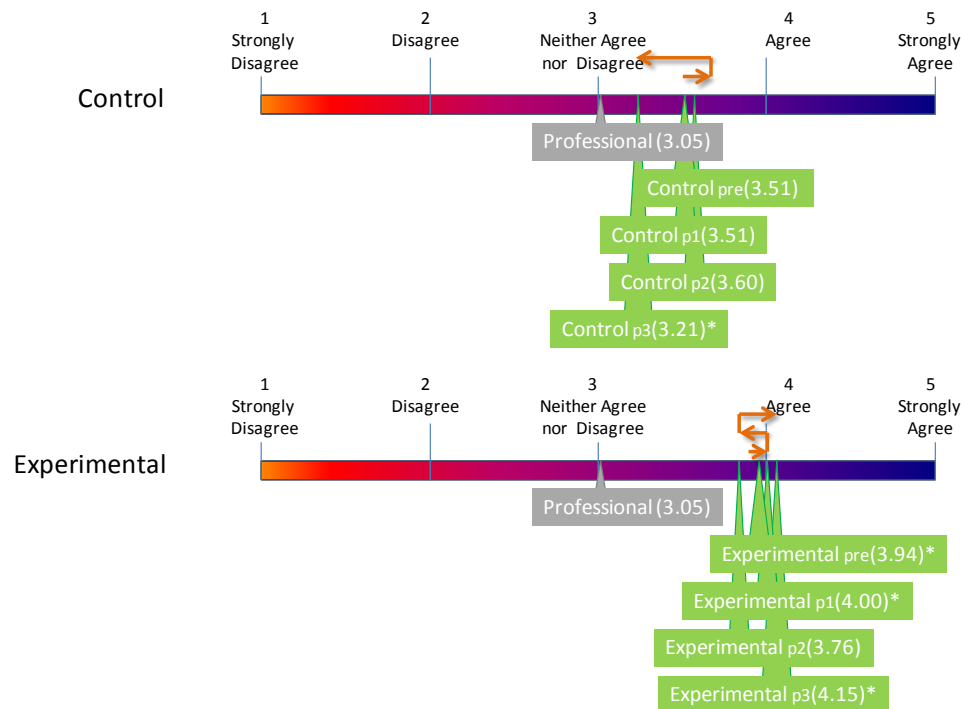


Figure 15. Design Conception Survey Part 2, Question 22 Results

- Question 23: “Design is “world” creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools”

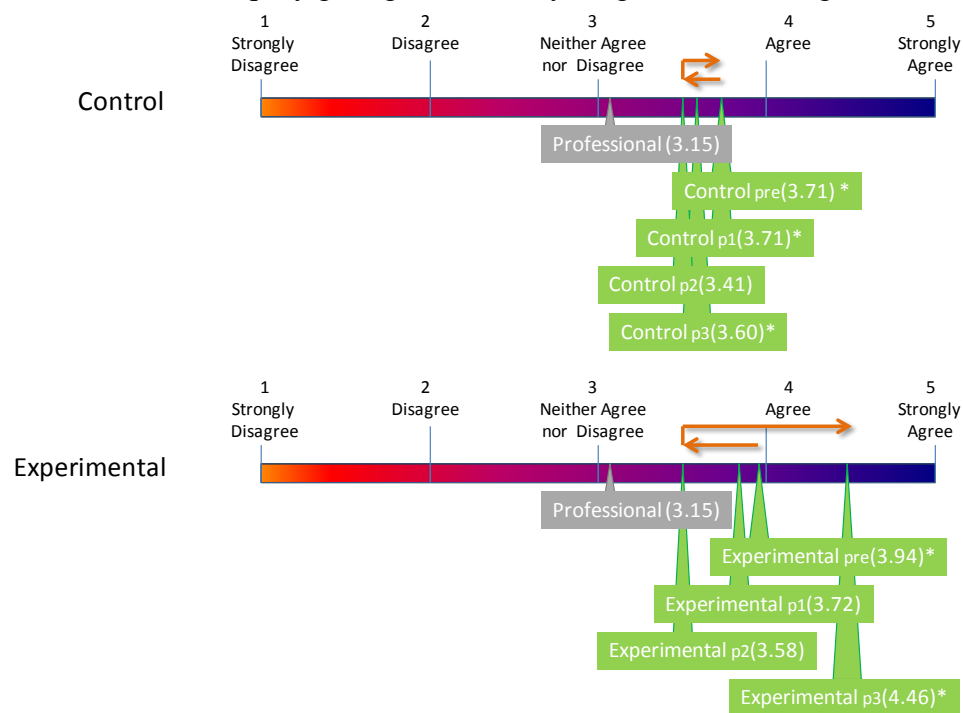


Figure 16. Design Conception Survey Part 2, Question 23 Results

When examining each student group individually for the period from Pre-Test to Post-Test 1, we find that there were only two statistically significant pre-post pairs illustrated in Figures 17 and 18:

- Question 4 regarding “Visual representations are primarily used to communicate the final design to a teammate or the client” for the experimental group with the result  $U=137.5$ ,  $N=37$ ,  $p=0.0172$ .

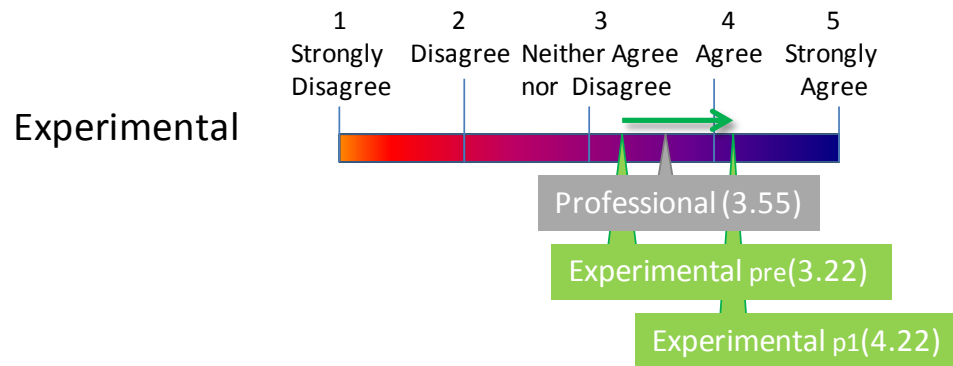


Figure 17. Design Conception Survey Part 2, Question 4 Experimental Group Pre-Post Results

- Question 14 regarding “Design defines engineering. It’s an engineer’s job to create new things to improve society” for the control group with the result  $U=764.0$ ,  $N=69$ ,  $p=0.029$ .

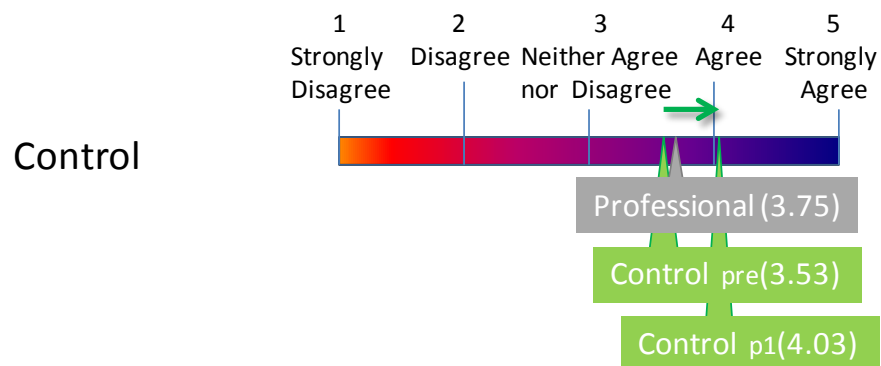


Figure 18. Design Conception Survey Part 2, Question 14 Control Group Pre-Post Results

When examining each student group individually for the period from Pre-Test to Post-Test 2, we find that only statistically significant pre-post pairings existed for the control group (none for the experimental group) as shown in Figures 19 to 22:

- Question 3 regarding “In design, a primary consideration throughout the process is addressing the question “Who will be using the product?”” for the control group with the result  $U=459.5$ ,  $N=70$ ,  $p=0.04$ .

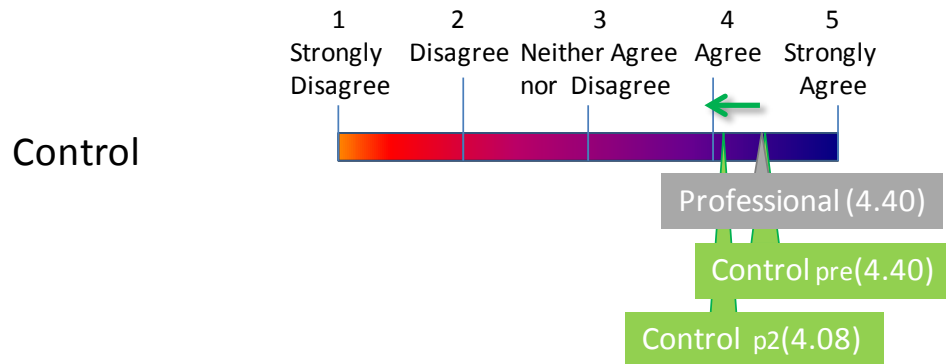


Figure 19. Design Conception Survey Part 2, Question 3 Control Group Pre-Post Results

- Question 7 regarding “Design begins with the identification of a need and ends with a product or system in the hands of a user” for the control group with the result  $M=0.486$  with  $U=446.5$ ,  $N=70$ ,  $p=0.028$ .

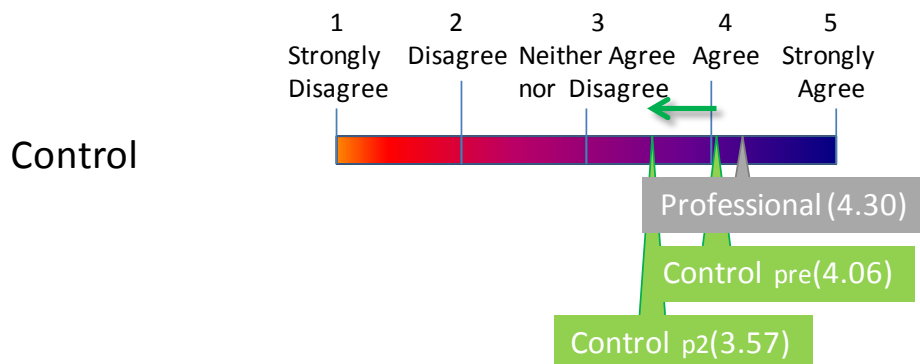


Figure 20. Design Conception Survey Part 2, Question 7 Control Group Pre-Post Results



- Question 12 regarding “Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers” for the control group with the result  $U=432.0$ ,  $N=69$ ,  $p=0.036$ .

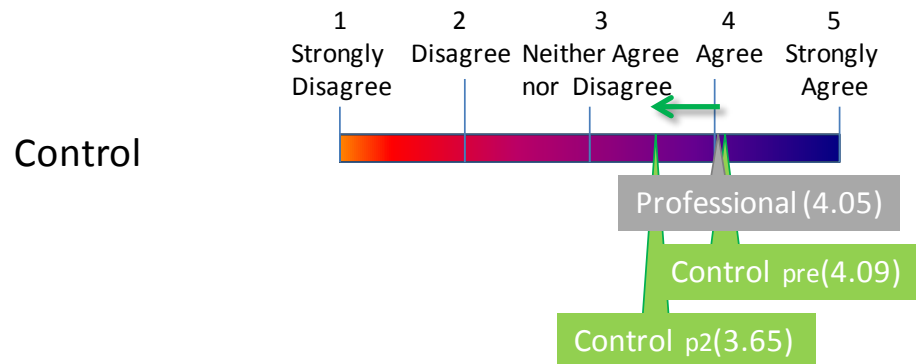


Figure 21. Design Conception Survey Part 2, Question 12 Control Group Pre-Post Results

- Question 20 regarding “Creativity is integral to design, and in every design project creativity can be found” for the control group with the result  $U=422.0$ ,  $N=70$ ,  $p=0.012$ .

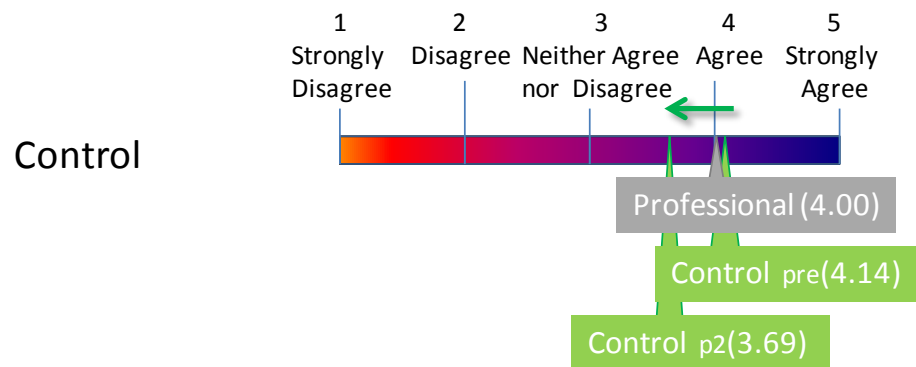


Figure 22. Design Conception Survey Part 2, Question 20 Control Group Pre-Post Results

When examining each student group individually for the period from Pre-Test to Post-Test 3, we find that there were only two statistically significant pre-post pairings with one for the control group and the other for the experimental group. These are illustrated in Figures 23 and 24:

Question 13 regarding “Designing as a conversation with the materials of a situation” for the experimental group with the result  $U=182.5$ ,  $N=32$ ,  $p=0.013$ .

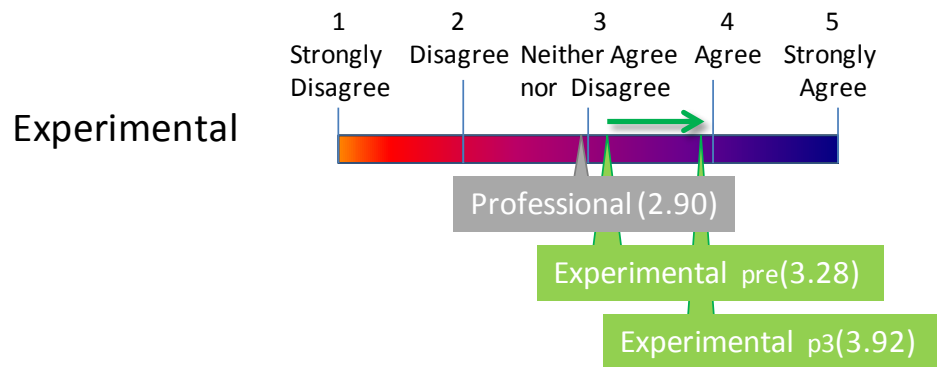


Figure 23. Design Conception Survey Part 2, Question 13 Experimental Group Pre-Post Results

- Question 20 regarding “Creativity is integral to design, and in every design project creativity can be found” for the control group with the result  $U=270.5$ ,  $N=59$ ,  $p=0.01$ .

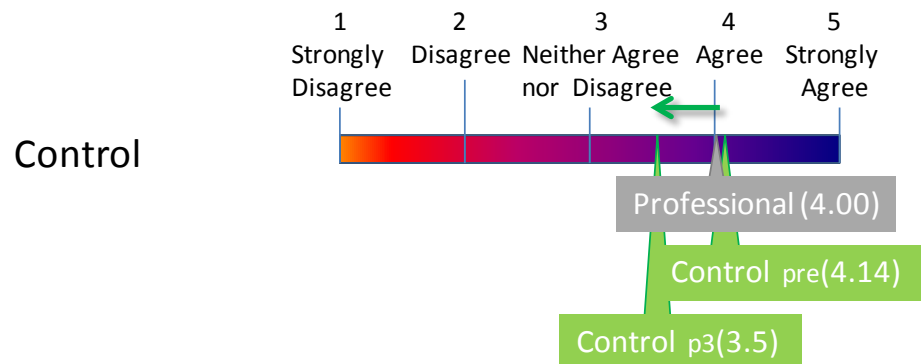


Figure 24. Design Conception Survey Part 2, Question 20 Control Group Pre-Post Results

In addition to responding to the 27 Likert scale questions, the respondents were asked to select the statements that they most identified with. The statement most identified with by the professionals was ““In design, a primary consideration throughout the process is addressing the question “Who will be using the product?”” The statement least identified with by the professionals is a tie between “a critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency” and the statement “good designers get it

right the first time.” Experimental group students considered “Information is central to designing” most identifiable for the Pre-Test and Post-Test 1 while shifting to “design is iteration” by Post-Test 2 and remaining with that choice for Post-Test 3. The experimental group least identifiable statement was consistently for all tests “good designers get it right the first time.” For the control group, the most identifiable statement consistently for all tests was “Design is iteration” and the least identifiable was the same as the experimental group for all tests, “Good designers get it right the first time.”

### ***Design reports and presentations.***

Following the five class intervention, all student study participants (both control and experimental) were merged back together into a single class to continue with the balance of aircraft design capstone course. The instructor of record for the class resumed instructional duties and the students formed six different design teams for their senior design projects. Students were allowed to freely select and suggest a design project. The resulting project selections ranged from the *Design, Build and Fly* (DBF) annual competition where students design and build a small RC airplane, to the Human Powered Airplane (HPA) with the goal of building a human powered airplane to compete for the Kremer Prize, to a number of conceptual design level airplane studies for supersonic commercial transport, to military transport airplanes and military attack aircraft. All teams had members of both the experimental and control groups though one team did have a majority of experimental group members.

The design reports and design presentations of these groups were evaluated at the end of the first semester of design using the modified TIDEE rubrics discussed in Chapter 3. All design reports were evaluated by the lead researcher while half of the design presentations were evaluated by the lead researcher and half were evaluated by a member of the aerospace design

industry brought in to observe and provide feedback to the students about their projects. Though it was planned to have an outside researcher review all of the presentations, a last minute cancellation prevented this from happening and only three of the six design teams was reviewed by the industry representative.

The modified TIDEE rubrics utilize a 5-point scale for evaluation of a project where 1=Novice, 2=Beginner, 3=Intern, 4=Competent, and 5=Expert. Details describing the particular characteristics of each level for a particular evaluation criteria such as Content, Visual Aids, Impact for the Design Presentation Evaluation and Executive Summary, Stakeholder needs etc. for the Design Report evaluation are provided in Appendix B. Table 10 contains the tabulated mean scores for the six teams along with the percentage composition of experimental and control group team members. The team numbers in the table are not tied to particular projects in order to further protect the identity of the student participants. The table indicates that Team 4 with over 90% control group participants had the highest overall average evaluation scores beating its closest competitor by 0.52. The second placed team was Team 3 which contained 55% experimental group participants. Team 4 has a large number of members with design and industry experience and it is believed that this experience is playing a role in these results. This is discussed in more detail in Chapter 5.

Table 10. *Aircraft Design Team Presentation and Report Evaluations*

	AOE Aircraft Design Teams					
Characteristic	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6
% Experimental /% Control & Non-	30/70	30/70	55/45	9/91	33/67	20/80
<b>Design Presentation</b>						
Content	3	2.67	3.25	3.63	3.25	2.5
Visual Aids	3	3.5	3	4	3.5	2.5
Impact	3	2	3	3.75	3.5	2
Evaluator	Lead Researcher	Industry Reviewer	Industry Reviewer	Lead Researcher	Lead Researcher	Industry Reviewer
<b>Design Report</b>						
Executive Summary	3	3.13	3	3	2.75	3.5
Stakeholder Needs	2.83	3	N/A	3	2.5	2.67
Concepts Generated	3.3	3	3.8	3.7	2.875	2.8
Solution Specifications	3	3.17	3	4	3.17	3
Concept Selected	3	3	3.33	4	2.92	2.8
Proposed Solution	3	2.92	2.8	3.56	2.83	2.5
Written Communication	3	3.21	3.07	4	3	3
Evaluator	Lead Researcher	Lead Researcher	Lead Researcher	Lead Researcher	Lead Researcher	Lead Researcher
<b>Overall Total Average</b>	3.01	2.96	<b>3.14</b>	<b>3.66</b>	3.03	2.73

### 4.3 Qualitative Results

Interviews were conducted with eight student participants (four experimental group students / four control group students) and five aerospace engineering professionals using the protocol discussed in Chapter 3. All interviews were voluntary and as mentioned earlier, student interview participants were compensated for their time for giving the interview. Both student interview groups (experimental and control) consisted of three males and one female. All participants were encouraged to speak freely and honestly about the exercise experience and their views of engineering design. Interview durations ranged from 22 minutes to 44 minutes and were recorded for later transcription and analysis. All but one of the aerospace professionals interviews were conducted via email exchange with the remaining professional interview being conducted over the phone and recorded for transcription and later analysis. All of the professional interviewees possessed greater than 23 years of professional design experience. Resulting interviews produced over 100 pages of transcription. The following sections provide a

summary of the main views of the professional and student group views obtained from these transcripts.

The professionals held the following views about design as revealed by the interviews:

- Communication, teamwork (design is a “team sport”), and compromise can be considered inseparable in the design environment and are a must for successful design. Team leaders need to create the environment for this to be achieved.
- Analysis and Design are intertwined (a “feedback loop”) and are essential tasks.
- The professional aerospace design environment emphasizes the customer (both wants and needs). These wants and needs are not always defined or known and part of the job of design is helping the customer in defining them which in turn become the requirements and specifications of a given project. These help to manage the expectations of the customer.
- The “aircraft design process” itself is a broad term and can be interpreted in different ways. It is more than a set of steps, however, a very basic set of steps/features that characterize it are a customer request, brainstorming, initial sizing & lay out, analysis/trade studies (which inform decisions), iteration, design closure, preliminary design, detail design and fabrication and test. Some of these steps may be repeated multiple times in a program.
- Some design skill can be taught/learned but there is a certain element that has been called “art” or a “view of the world” that a particular designer might have and can differentiate the good designer from the great designer.
- One will find new problems during design but the emphasis must be on working through them or working in a way to avoid them from occurring to get a solution.

The experimental group held the following views about design as revealed by the interviews:

- Most of the students recounted the steps of the class experience when asked to describe the design process. Basic steps included: Requirements>goals>ideas(brainstorm) >model>analyze>prototype>test>production >iterate as necessary.
- All felt that requirements bound the design problem and make it manageable.
- Analysis is integral to design and lets one know how one is doing with one's design. It was felt that it should be done throughout the process. Trade studies were viewed as either being a review of previous work and approaches or as "trade-offs" on different aspects of a design. In either case they were a means to achieving the necessary or optimal design.
- Teamwork and compromise are also very important to design allowing design to be accomplished and providing a means of bringing together different ideas and merging them into a solution. Communication is essential to achieving this.
- Most thought understanding the problem was the most important design task (it let you know what you needed to do and what the customer wanted)while one felt that communication was most important since that was necessary in order to understand the problem in a team environment.
- Some felt it was difficult to select a single least important task and all interviewees selected a different one. Least important tasks selected were visualizing, generating alternatives, abstracting, and building.
- Most felt that some basic level of design skill can be developed over time but that there is also a certain level of untaught talent or art-like ability that one can possess.

- Most agree with the statement that *design is as much a matter of finding problems as it is of solving them*. This is due in part to the belief that initial designs usually have problems and one needs to identify and fix those problems. Anticipation of those problems is also necessary.

The control group held the following views about design as revealed by the interviews:

- All described a design process based upon their experience base. Thus those with internships, co-op experience, or previous aircraft design experience recounted the process in a way reflecting those experiences. Basic steps included: RFP>preliminary design>more detail-mockup/model>testing>prototyping>acceptance of the proposed solution>production.
- All thought specifications and requirements were very important and that failure to meet them costs time and money. They also felt that specifications and requirements provide boundaries for the design problem and let you know what the customer wants.
- All feel teamwork is a huge part of design and that no one engineer has all the requisite knowledge to do an aircraft design. One expressed a need for a leader to enable a team and two felt that the ability to work in a team was a necessary skill.
- They viewed analysis as a way to validate and invalidate a design approach and thought it was very important. One felt that enough of the correct upstream decisions can minimize the amount of analysis required downstream.
- All felt compromise plays an important role in design and is a way to resolve conflicting approaches or design details which can include cost and time.



- Half felt trade studies were the review of previous work and approaches while the others viewed them as “trade-offs” on different aspects of a design. Most felt they were very important part of developing a new design.
- Half thought understanding the problem was the most important design task while the other two interviewees split between iterating (in order to meet the requirements) and using creativity (in order to be different than others) as the most important tasks. Most thought it was not an easy decision to choose one activity as the most important.
- Half felt that sketching was the least important design and that it was covered by other tasks that were on the list or was not as important in the modern design environment. Generating alternatives and planning were the selections of the remaining interviewees. One felt the selection of a single least important activity a difficult one.
- Half did not feel that good designers have intrinsic design ability and felt that one could be trained to be a good designer or engineer. One did agree with the statement while the other was neutral about the statement. Both of the latter interviewees felt that one can have a knack or view of the world that impacts design ability in a positive way.
- Half agree that design is as much a matter of finding problems as it is of solving them. This is due in part to the belief that problems easily come up as one designs and they must be dealt with in order to achieve a solution. One disagrees with the statement and feels that the problem is already established when design begins. The remaining interviewee was neutral about the statement and felt that one must keep the bigger picture in mind when designing in order to not get bogged down in solving unimportant small problems.

From analysis of both sets of student interviews, a number of consistent themes emerged from the two student groups. These overall themes included a view of industry, a view of university, the gap between university and industry, engagement, disengagement, lecture benefits, new technical understanding, experimental class areas for improvement, lecture class areas for improvement, and inductive learning. The following provides a definition of each of these themes along with examples of each theme taken from the interview transcripts. Figure 25 illustrates the relationship between the aforementioned themes.

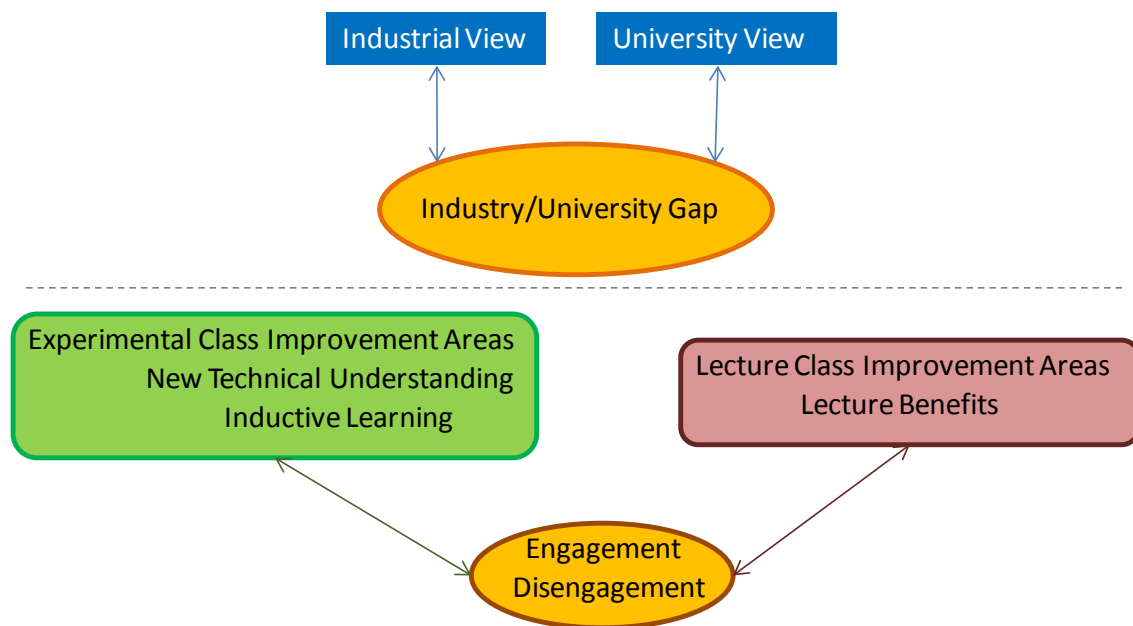


Figure 25. Relationship Between Major Interview Themes

*Industrial View (IndView)*. This theme covers items that express a view of industry, working in industry, being a practicing engineer in industry, and views of what engineering design is in industry. Each of these coverage areas forms a subtheme for the IndView overall theme.

*View of industry*. Interviewee #4 of the control group expressed a view that aerospace companies come to specific universities for recruiting because they like the way a university teaches certain subjects like design:

“As opposed to this is the generic map that you will follow once you get hired by somebody. Which I think for anybody who’s had an internship should hopefully be all of us, I know it’s not, but should hopefully be all of us, we already know what the generic map is and it should be a, you know...Lockheed Martin comes to five colleges in the country, and only five colleges, and we’re one of them, and it’s because they like the way we teach design and here’s the way we teach design, you know, and that kind of thing.”

*View of engineering design in industry.* Control Group Interviewee #4 also expressed thoughts on how industry conducts design:

“...never once have I been given a, or heard of a person, even like high up in the Chief Engineer was given an “ok, here’s \$3million go have fun, design something that does this.” You know just a vague thing. It’s always been there are very strict product definition lines that more or less take precedence over whatever romantic ideas you would have about what the design process is...”

*View of being a practicing engineer in industry.* Control Group Interviewees #6 expressed a view on what it is to be a practicing engineer as expressed in this excerpt:

“Ques: Ok. Ok so you took more away from the actual group work. What you do in the design...”

Ans: Yeh., Yeh because that is what it’s going... that is what is in the real world about being a practicing engineer, working in groups like that and you’re going to have to work together on projects all the time...I mean always you do sit in listen in meetings and take notes and that’s a very important aspect to learn but one of the biggest things you’re going to be doing is can you work in a group and can you take what you learn and apply it to a group setting, which is where I feel like I learn the most.”

*View of working in industry.* Experimental Group Interviewees #1, provided insight into that individual’s view of what it would be like to work in industry. This interviewee did not have industry experience.

“Well if you’re working for a company, you’d be using that software, that type of software. You’d be working in teams like that. And to get a kind of sense of that before we were actually graded within our course I think that is really good. I think only good things can come of it really.”

*View of University (UniView)*. This theme covers items that express views of academia and how things function in a university environment and what is expected of students.

Interviewee #1 (experimental group) expressed a common view that many engineering classes are learning theory and that those are different from a design class which is practical.

“Ques: Ok. Would you like other engineering classes to use this approach?”

Ans: Eh... it’s a bit different because aircraft design, like design classes in general are more...obviously they are more practical, you’re designing something. Whereas, a lot of other classes you are learning theory.”

Interviewee #6 (control group) illustrated a “university life mindset” or view consistent with getting the best performance in the academic setting when this individual expressed an opinion that it would have been preferred that the control class been taught by the instructor of record as opposed to the more experienced instructor that actually did teach the five lecture classes. The interviewee felt this way even though the instructor that did teach the five lectures had more experience both in aircraft design in industry and in teaching the aircraft design course. Though this interviewee had a number of internships with a government agency, as is implied by the comments below, it was deemed more important by the student to have instructor continuity (most likely to optimize the grade potential) than to have the more experienced and applicable instructor. (Note the instructor of record’s real name has been replaced by *Dr. C*)

“...I didn’t like, I think I would have preferred had it been taught by “C” because I’m going to have him for the rest of the semester. So it’s almost like I got started out learning at a different...I mean not all professors are the same so learning and taking notes in Dr. Mason’s class is different than learning and taking notes for Dr. C. They’re completely different. So I think even though Dr. Mason knows exactly what he’s doing since he’s taught the class before, I think it would have been nice and better flow for the class if it were taught by the same professor over and over again, instead of always being introduced to all these new people who aren’t just guest lecturers. He talked for, he didn’t just teach one class and give you know a talk about UAVs or helicopters. You

know he taught a series of important lectures. So I think I would have rather had it be by Dr. C.

Ques: Ok. Just to maintain that style of learning...

Ans: It's a two semester class too so it's not like I'm just going to have "C" this semester. I most likely will have him for next semester as well because it's 4065 and 4066."

This response is consistent with sociologist Howard Becker's (1972) belief that "a student culture which advises grade-getting as an optimal strategy decreases the likelihood that students will attempt other strategies, though it does not make that impossible" (p.94) as expressed in *A School Is a Lousy Place To Learn Anything in*.

*Engagement (Engage)*. This theme covers items relating to being engaged in class.

Interviewee #7 of the control group talked about an engaging class experience that this individual had outside of the design class at the time of the interview. The interviewee's comments were part of a response to the question of how the five lecture classes compared to other classes the interviewee had taken. The interviewee indicated it was comparable, but the response depended upon the class one was talking about (the instructor's names have been replaced by Dr. Y and Dr. T):

"...It definitely helps when you have a teacher who's really into it and really enthusiastic about it, really will get kids, you know, into it... you know, Dr. Y does a really good job of that. He's teaching our ship dynamics class right now. Now it's an 8:00 AM class. No one's awake but he still gets us into it and gets us going...and it's just something that I feel is different from teacher to teacher. You know Dr. T kind of teaches more this is what's on the slide, Y's, he's writing all over the board, you have to take notes so you have to be interactive, um so it's just kind of along those lines."

*Lecture Disengagement (LectD)*. This theme covers items relating to not being engaged in a class both in the exercise and in general. A number of respondents felt that lectures in general were not engaging and that they tended to be "talked at" and didn't feel encouraged to ask questions during such classes.

“Where a lecture is just someone talking at you. I mean just like people sitting in meetings in companies, they get bored, fall asleep or need coffee and you know...so stuff like that.” (Interviewee #8, experimental group)

“It was...there was nothing there to pull me in, to rope me in. It was just, here it is take it or leave it. You know that’s how it is. You know, no input there from us.” (Interviewee #5, control group)

Interviewee #3 (experimental group) also notes that large lectures tend to not promote community among the students and instead tend to encourage pre-existing cliques.

“Like in a lecture class you just kind of go and sit. If you have friends I guess you go and sit by them or whatever but in a small class you really get to know your classmates.”

*Lecture Benefits (LectB)*. This theme covers items relating to the benefits of the lecture format. As mentioned previously, when experimental group students were asked if the LSBL approach would be applicable to classes outside of design, all felt that the lecture was the only way to teach certain subjects, especially those dealing with theory or mathematics:

“Like aerodynamics. I don’t see how you could really do... I guess you could go in like a lab and do tests and stuff but um and like comp methods. That’s an AOE course, not really... so classes like that I mean you just have to... that just has to be a lecture style format, I think.

Ques: Why do you think that would have to be a lecture style format for classes like that?

Ans: I just don’t see how much hands-on stuff you could do with either aero or compressible aero.” (Interviewee #3, experimental group)

*Gap between University & Industry (GapUI)*. This theme covers items dealing with a perceived gap between the university and industry in how students are trained. Interviewee #8 (experimental group) provides the bulk of the explicit commentary on a perceived gap between university and industry

“...I liked mostly the hands-on part. Actually getting to use the software and being able to actually see in industry how they design and go about the design of airplanes instead of just strictly here’s the theory behind it but not really a way to apply it. I think this experimental group sort of bridged the gap of here’s some of the theory, here’s, you

know, what you're going to go off and do in an aerospace company designing your plane.”

*New Technical Understanding (NTU)*. This theme covers items relating to a new insight gained during the exercise in relation to a previously introduced technical concept. Interviewee #2 in the experimental group noted of the experience:

“...We didn't have much time to actually work with the optimization part of ModelCenter. We could only go through it once...It was good to see if we swept the wing or made it longer or if we changed different parameters how it would affect the end product.”

*Experiment Area for Improvement (EAI)*. This theme covers items indicating where the experiment with the experimental group, as executed, could be improved. These suggestions involve the additional software scaffolding, a slower pace for the exercise, and more time for the entire exercise. Below is an example where Interviewee #2 (experimental group), when the interviewee was asked about desired changes in the five class exercise, the interviewee made the suggestion that the exercise to be conducted for a longer period of time at a slower pace with additional in-class scaffolding for the software:

“I think it was extremely fast paced... due to the necessity of a lot of material. But having a few mechanical...let me put it, like instructions on how the mechanics of how the software works to give us better foundations then we could work outside of class... if we could go through the software at a slower pace, during class so that we could have more time to absorb it...I mean it took a few hours outside of class to become moderately proficient at it. I feel like a lot of that time could have been saved had we had a little better foundation in class, so we could have been more productive outside of class.”

*Lecture Area for Improvement (LAI)*. This theme deals with items indicating areas where the lectures given to the control group of the experiment, as executed, could be improved. Interviewee #4 (control group) provides a quote desiring the class contain more technical content:

“There was a mention of FAR and mil requirements, but we never once saw an example of one. We never actually talked about here’s where you’d go find them. It was just, oh by the way there’s these things out there that you’re supposed to design too.”

*Inductive Learning (INDUCT)*. This theme covers items indicating inductive learning.

“The lectures were formatted as a boss giving it to the intro project engineers. The way he had us work in teams instead of just throwing us information. He was just really letting us learn”

The combined themes and specific interview responses provide an overview and insight into the thoughts of the study participants. When combined with the survey results, one can form opinions and conclusions about the effectiveness of the LSBL approach and make suggestions on ways to improve it. The next section covers this discussion and conclusions.



## Chapter 5: Discussion and Conclusions

What is the meaning of the choices the students and the professionals made and what can we conclude about the LSBL approach based on this implementation? Subsections 5.1 through 5.6 present a discussion of the results presented in Chapter 4 aligned with the research questions. A brief summary of the responses is provided along with a restating of the research question for each section. Subsection 5.7 discusses limitations of this study. Subsection 5.8 states the major research contributions of this study and suggestions for future research. This is followed by subsection 5.9 which presents conclusions that can be drawn from the results of this study.

### 5.1 Research Question 1 Response

*Can the use of live simulation-based learning (LSBL) in aerospace capstone design alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design?*

- *LSBL appears to alter student conceptions of engineering design and help students to respond like industry professionals in the area of aircraft design. In the experiment, LSBL experienced students made more rapid improvements in ranking the importance of various design activities than the control group students when compared to a sample of aerospace industry aircraft design professionals.*
- *Both groups exhibit comparable survey responses with the experimental group more aligned with the industry professionals in design activity ranking immediately after the LSBL intervention. Both groups leveled off in correlation with the professionals after the first semester of design.*
- *Students tend to more strongly agree or disagree with design statements of Part 2 of the survey than the professionals. These student views evolve over the course of the design class.*

The results of the experiment appear to indicate that LSBL can have a positive effect on the ability of students to respond similarly to design professionals as indicated by the design conception survey. The results also indicate that though there is difference between the groups as measured in this experiment, it is not always a statistically significantly different one to the 95% alpha level as measured with the instrument. Relative to the selection of the most and least important design activities, both the experimental and control groups started off at a moderate

level of correlation with the professionals. Such a result is encouraging as a starting point for the experiment given that the students were seniors who had already completed three years of training to become aerospace engineers. From this relative common starting point, we see that both sets of students do progress during the year of design to have a higher correlation with the professionals moving from the moderate level of correlation in the beginning to a relative strong level of correlation by the end of the school year. The rate at which this change occurs, however, is different between the experimental and control groups. Whereas the control group follows a nearly linear change from the beginning of the year to the end of the first semester of design, the experimental group immediately after the intervention follows a higher sloped or higher correlation path with the professionals. They were selecting more of the same “least and most important” design activities with the same ranking in common with the professionals than the control group. Neither group was greatly different than the professionals throughout the study. It may be noted that after the intervention, by the end of the first semester of design, the students more closely matched each other in correlations relative to the professionals, further showing a difference in how students responded with and without an active LSBL experience.

Given that the emphasis of this study was on the impact of the LSBL approach, the bulk of the discussion and explanation of the Part 2 survey questions will focus on the Pre-Test and Post-Test 1 where the material presented to the students was controlled and the students were interviewed providing multiple sources of information on the same events. For the Post-Test 2 and Post-Test 3 results, there was no interview data collected and lead researcher interactions with the students were limited or non-existent and thus discussion of why certain results occurred after the base study period (Pre-Test to Post-Test 1) is limited in this discussion.

As with the Part 1 questions, we see an impact of the LSBL approach but we also see some changes in the control group as the study progressed from the intervention time till the end of the design course. Consistent with Part 1 results, we find that the experimental group students and the control group students each had three statistically significantly different results from the professionals in the Pre-Test. This increases to four statistically significant results for the experimental group at Post-Test 1 (all being differences with two of them being carry-overs from the Pre-Test) while the control group had three statistically significant results (all being differences and two being carry-overs from the Pre-Test). By Post-Test 2, we see that all student groups reduce in the number of statistically significant differences from the professional sample with the experimental group having three statistically significant differences with the professionals (one carry-over from the Post-Test 1 period and two new differences from the professionals) and the control group having two statistically significant differences from the professionals (one a carry-over from the Post-Test 1 period and one a new difference between the compared groups). In Post-Test 3, we regress somewhat with four statistically significantly different results from the professionals for both groups, all being items that had been statistically significantly different from the professionals at different times in previous post-tests (i.e. Post-Test 1 and Post-Test 2). Having a result of no statistically significant differences or only statistically significantly similarities (i.e. nearly the same response) would be the ultimate success in this study using this instrument. It would signify that at least in this measure, students and professionals are making very comparable decisions when faced with the Part 2 survey statements. Thus over the course of the year of the design class, the students do evolve in their conceptions of design. We also see that LSBL was able to have an impact on the students' design thinking.

There were nine overall results that were statistically significantly different when comparing the student groups to the professionals in Part 2. Most results fall in the category of responses where the professionals had a view that fell between being neutral and leaning towards agreeing or disagreeing with the statement about design. Two of the statistically significant results involved the professionals having a firm stronger than neutral opinion about the design statement. In these cases the professional opinion was at the agree or slightly stronger than agree level. These statements were number 2 (“Good designers have intrinsic design ability”) and number 7 (“Design begins with the identification of a need and ends with a product or system in the hands of the user”). In the case of statement 2, the interviews reveal that though the professionals do feel that some basic engineering design skill can be taught, there is still an element of talent or an art aspect that cannot be taught but that an individual must possess and that this is the element that can differentiate a good designer from a great designer. Relative to statement 7, we see a statement that clearly states the basic reality of design in industry; identify a need and provide a product or system to satisfy it. The production of this product or service is the main purpose of most engineering companies and as such it does make sense that practicing engineers working for companies to make a livelihood would more strongly identify with this statement.

In the case of statement 2, we see that the experimental group tended to feel more neutral with a leaning towards agreement about the belief in intrinsic design ability. Following the intervention, the experimental group swung counter to agreeing with the statement and turned to disagreement with the statement while the control group maintained a statistically significantly different position from the professionals in all tests. By the time of the Post-Test 2 and Post-Test 3, the experimental group has swung back in the direction of its pre-test state while the control

group has decreased in its agreement with the statement to a level away from the professionals and below that of the pre-test. It is believed that the large changes at the Post-Test 1 reading may have been due to the fact that the students were introduced or partook in a full, but abbreviated design experience. For the experimental students, as one expressed regarding aircraft design “I would have never realized that there is so much into it” and thus seeing all of the steps laid out, taking away some of the mystery that may have existed for them on how a plane gets designed, may have changed their views on what design really is and that maybe all of it can be taught.

Interviewee #2 in the experimental group noted that relative to this survey question, this individual’s views did change and that this individual no longer believed in the intrinsic aspects of design:

“I think we want that to be correct, because we want to have good design without having to put the work into it. But as we worked through the project we were able to see that none of us are really inherently good designers. It takes a lot of history, knowing old things, past aircraft and an open mind to really, to be a good designer to have those qualities.”

At this juncture, all of this information about design is new to the students, by the time we reach Post-Test 2 and the students themselves have more design experience gained through their senior projects and they learn and probably experienced team members possibly having more of a “knack” for certain design activities than some others, we see that the students start to progress towards the response that the professionals (most with 20 years experience) gave. Both groups however, diverge again at the last post-test indicating less of a belief in this statement. Their disagreement with this statement, however, is less this time than it was at Post-Test 1 (the most negative response) for the experimental group and comparable to the most negative response of the control group (which occurred at Post-Test 1).

In the case of statement 7 (*design begins with identification of a need...*), we see that the experimental group leaned more towards a neutral view of the statement before the exercise but that after exposure to LSBL at Post Test 1, which seeks to foster this industry way of thinking (need and product), we see that the experimental group moves closer to the professional's mean response and continues to increase until Post-Test 3 (end of the semester) when it decreases. In both the Pre-Test and Post-Test 1, the control group was closer in mean value to the professionals. On the other hand, at the time of Post-Test 2, we see the control group shift to statistical significance at a level similar to the near neutral leanings of the experimental group at the time of the Pre-Test. This then shifts back at Post-Test 3 with a value close to the experimental group. Why this shift occurred is uncertain given that the students were not observed after the five class intervention. Overall the students' mean responses come closer to the professionals just after the five class intervention with the experimental group making a larger improvement (i.e. better matching the professionals) than the control group. Both groups diverge as the class goes on after the five class intervention with the control group diverging more than the experimental group.

The following seven Part 2 statements were also found to be statistically significant results and are presented with some discussion on a reason for the significant result. In all cases the professionals tended to have a near neutral view of the statement at hand. The difference between the students' more definitive responses versus the professionals can partially be attributed to the relative level of experience that the students have versus the professionals. Following Perry's (1970) cognitive development model, the inexperienced students' responses could be characterized as the students being in the *dualism* stage of development where thinking is very black or white or right or wrong. The professionals with much more experience, had seen

more shades of grey experiences, acknowledge that there are multiple interpretations of events and topics and chose a plausible interpretation that rings true to them which Perry calls *relativism within commitment* and this tended to be neutral in their beliefs relative to the statements (Svinicki, 2008). As the survey results indicate over time, in a number of cases, the students' responses move more towards the neutral as they gain in experience.

1 - *Good designers get it right the first time.* Here the both the experimental and control groups had a shift in views on this statement over the course of the design class with the control group initially moving towards the professional response initially and then diverging in the end while the experimental group does the opposite and diverges initially and then moves towards the professional's mean response. It is believed that here the experimental group may have had a strong reaction to the exercise as they experienced first-hand that most of their initial designs in the exercise were not best answers off the bat but that iteration was needed to get to the best solution. It may also be noted that in the class, the students were also told that often the first design is not the last design though it is not impossible. It is believed that this result reflects a change in their views as a result of the LSBL experience. By Post-Test 3, we see that the level of disagreement with the statement by the experimental group becomes less and moves closer to the professional response. It is believed that further design experience with their projects in both groups most likely tempered their view on getting it right the first time.

10 - *Design is as much a matter of finding problems as it is of solving them.* This was statement that was explored in the interviews. Professionals agreed with the statement but felt that emphasis should be placed on solving the problem. Students also agreed with the statement and felt more strongly about it, though the control group did briefly hold a neutral view of it at Post-Test 2. Many mentioned that one has to find problems in order to be able to solve them and

that it wasn't difficult to do that in design and part of the task is to be proactive in preventing problems. This proactive view is consistent with the professionals emphasizing the end product and taking the necessary steps to ensure a quality product that is delivered on schedule which requires planning and thinking ahead. As an experimental group student noted:

“...understanding the problem is one of the biggest things you have to do. When you don't really know what the issues to solve are, you have a hard time solving them. So you have... from what we experienced we had to narrow down the problems and really figure out what concretely needs to be fixed, so we could actually address those.”

In the end both groups trended towards full agreement with the statement as opposed to the professionals' neutral to agreeing stance.

11 - *In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.* Students tended to respond closer to the professionals from the start relative to this statement. The experimental group actually matches the professional response at the Post Test 1 milestone (just after the five class LSBL intervention) while at that same milestone the control group moved further away from the professional response, agreeing with it more strongly than the experimental group. It is felt that dealing with the complex submersible airplane problem may have made this statement more real for the students since development of a submersible aircraft had many conflicting challenges such as the benefits and drawbacks of vehicle weight relative to the sea and air environments but also students were able to discover synergisms between the two types of vehicles such as the desire for a sleek shape with works well with the medium of water and the medium of air. In the period after the five class intervention, both groups diverge from the professional mean response but make progress moving back towards the professional response by the end of the design course.



13 - *Designing as a conversation with the materials of a situation.* It is believed that the experimental group agrees with this statement more than the professionals or the control group because of the students' exposure to design tools in the LSBL experience where the students used the CAD program CATIA and ModelCenter. During the time of the five class intervention, the students, as novice designers, were new to the design tools and a fairly complex real world design problem (even by experienced aerospace designer standards) and as they learned the tools and more about the problem and how to work with the tools to solve the problem, it is possible that each of the students had their own internal conversation on design as they were starting to advance from being novice engineers to being more experienced, hence they identified with the statement. For the control students, their response to the statement was close to the professionals from the start. At the end of the first semester and at the end of the design class (Post-Test 3) they diverged away from the professional response. This could be due to their regular design group experiences where their views may be varying as the successes of their design group vary over the course of the year long design class.

17 - *In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.* Here both the experimental and the control groups felt more strongly about this statement than the professionals who were moderately neutral in their view of it. This statement has elements that are similar statement 10 ("design is much a matter of finding problems as it is of solving them") which was discussed earlier. There the experimental interviewees expressed a general agreement with the statement and felt that one has to find problems in order to be able to solve them and that it wasn't difficult to do that in design and part of the task is to be proactive in preventing problems. As the

students experienced aircraft design first-hand for the first time, in most cases, they themselves did experience a new understanding of the problem, especially in the case of a flying sub for the experimental group, and with that new understanding came new insights that could be considered ‘surprises’ to the novice designer. Hence it is understandable that the experimental group would identify well with this statement. In the case of the professionals, especially experienced professionals and masters at their craft, knowing paths to take for optimal success is a trait highly valued by companies and the mark of an expert (Bransford et al., 2000). The design experts are paid to be creative, see ahead and not be ‘surprised’ per se by what transpires during design. Since many new designs can be broken down into variations on previous solutions, especially in a relatively mature industry such as aerospace, experience can make one aware of many different ways to approach or solve design problems. Control group students followed a trend similar to that of the experimental group students but made larger shifts in their views in the period after the five class intervention. This may be due to the control group students having the same reaction to the statement as the experimental group students, but having it happen as a result of experiences in the regular aircraft design projects as opposed to the experimental group students encountering it in the LSBL intervention initially.

*22 - A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.* Students were asked explicitly about this statement during the interviews. Most of the experimental group students agreed with the statement but had a complex view of it. All of them thought it was important and being asked for by the public, especially in today’s world but that other factors such as money (it pays to be “green”) may be driving such efforts. A number of them acknowledge that if another factor of greater importance

were to come along, eco-design would lose some of its relative importance. The professionals surveyed mostly come from the defense industry where eco-design is desirable but secondary to doing what is necessary to create an effective weapon. As such the interviews reveal the students to be closer the professionals in view than the survey indicates. A professional regarding this statement said:

“Nice to have but not critical. I know people who design and build nuclear weapons – possibly one of the highest tech things in the world, and none of those apply. Ditto for most military weapons. Green is becoming more important for civil transport – reduced fuel burn is both green/energy efficient and money saving (that is the real driver for airlines to go green).”

On the student side, Interviewee #7 from the control group who had had internships with the Navy felt:

“...I see working towards the environment is a good and handy thing but the moment it’s going to compromise my ability to have my ships go do something and reduce its effectiveness in defending the country, I can pretty much say that the environment is going to go out the back door for a temporary period of time.”

Control group students initially felt more strongly about the statement but trended back towards the professional response as the class went on and they gained experience.

*23 - Design is "world" creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools.* Both student groups made a change on this statement by the end of the exercise. Statistical significance (a difference with the professionals) existed for both groups during the pre-test with both groups believing this statement more strongly than the professionals. By Post-Test 1, the experimental group dropped in statistical significance with the professionals while the control group stayed at the same mean value relative to the professionals and thus remained statistically significant. All statistically significant differences with the professionals drop by Post-Test 2 for both groups. By the end of

the class at Post-Test 3, both groups diverge from the professional's response and trend towards stronger agreement with the statement. As with other Post-Test 2 and Post-Test 3 findings, the exact cause of this shift cannot be determined by the available data.

Over the course of the study, only nine different Part 2 questions showed statistically significantly different results when compared to the professionals. When the student groups were independently compared to themselves, only eight items were found to be statistically significantly different from the Pre-Test to one of the three post-test periods. For the Pre-Test to Post-Test 1 period statements 4 and 14 were found to be statistically significant from the pre to the post-test period. Statement 4 was statistically significant for the experimental group. In statement 4 ("Visual representations are primarily used to communicate the final design to a teammate or the client") it is believed that the experimental group reacted to this statement strongly because of the students' recent exposure to the tools in the LSBL experience (CATIA, FLOPS and ModelCenter) at the time of Post-Test 1. Whereas the use of such programs is an everyday experience for the professionals sampled (hence the fairly neutral rating of the statement) the programs were new to most of the students and it is believed that the novelty of the exposure to such tools accounted for the difference with the professionals. It may be noted by Post-Test 2, the novelty of the software tools appeared to have worn off and the statistically significant difference went away.

Statement 14 was statistically significant for the control group. In statement 14 ("design defines engineering. It's an engineer's job to create new things to improve society") was found to be significant for the control group. The students in the control group more strongly believed in this statement after the control class exercises than they did in the pre-test. It is possible that the

enthusiasm of the experienced instructor may have influenced the students' views of this statement.

When looking at the Pre-Test / Post-Test<sup>2</sup> results for Part 2 of the design conception survey, it may be noted that only the control group has statistically significant results. The statements that were found to be statistically significantly different in this case were:

- In design, a primary consideration throughout the process is addressing the question “Who will be using the product?”
- Design begins with the identification of a need and ends with a product or system in the hands of a user
- Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.
- Creativity is integral to design, and in every design project creativity can be found.

In all cases the students originally held a view that was close to that of the professionals who in turn firmly “agreed” with each of these statements. By the end of the first semester, the control group students moved away from these views and became a little more neutral in their feelings about these statements. Why the control group is statistically significantly different on these items at Post-Test 2 versus their Pre-Test views cannot be fully determined by the data available. It could be conjectured that the LSBL experience for the experimental group, which has shown higher correlation with the professionals (who firmly agreed with the four statements) on the design activities part of the survey, may have been the experience that made enough of an impact on the students that they didn't diverge enough from their initial positions on these statements (which were close to the professionals) while the lack of such an experience for the control students may have been why the control group changed from views that originally were close to the professionals, to views that were less so at the time of the Post-Test 2 milestone. It may be also noted that the control group found communication to be the most important design activity

at the time of Post-Test 2 and three of the four statements involve communication of some sort dealing with identifying a customer, the customer's need and being creative in the solution that is shown to a customer. The fact that the control students started to agree less with the statement regarding design being a "highly complex and sophisticated skill" and not a "mystical skill" may be an indicator of some problems occurring during the course design projects. One is reminded that most of the design teams contain a majority of control group students. This conjecture could not be verified without interviewing the students which was beyond the planned scope of this effort.

For Pre-Test / Post-Test3, only two statements, 13 ("design as a conversation with the materials...") for the experimental group and 20 ("Creativity is integral to design...") for the control group, show up as statistically significantly different results when comparing each group to itself at two different time checks. In both cases the students move from positions that were close to the professionals in the pre-test to a position further away from the professionals and the students' own original position. For statement 13, the experimental group grew in its agreement with the statement while the control group lessened in its agreement with statement 20. Interviews could have provided some insight into the cause of these changes but again this was beyond the scope and emphasis of this study.

As with the Part 1 results showing moderate correlation with the professionals, in the totality of the study time, there were no more than nine different questions total (some of these nine repeated in statistical significance during the study) out of 27 questions that were found to be statistically significantly different when compared to the professionals. This further indicates, as measured by this instrument, that the students are already largely thinking like the

professionals before they enter the design class which is also consistent with results observed in industry that today's graduates are still very capable but there is room for improvement.

Following the intervention classes, we see that the experimental group students regress to correlation levels similar to the control group class. This appears to indicate that the impact of the five LSBL classes was not as strong long term when compared to the impact of the rest of the design class where students primarily worked on their senior design projects following a more classical project based learning approach with minimal instructor interaction in this case. Interviews indicate that the experimental group students preferred the hands-on approach and interaction with the instructor provided with the LSBL approach to a classic lecture and desired to have the experience last longer. A number of interviewees expressed a desire that the LSBL approach continue to be used in the design course. One felt that he was more of hands-on learner and that the LSBL approach complimented his preferred way of learning. Given the statistical results obtained immediately after the experiment, we see that the experimental students were selecting more like the professional sample. It remains to be seen if the experiment had continued, would the students have continued on the accelerated path or would it have leveled off. A longer experimental period is suggested for future work.

Comparison to the previously published results of Mosberg et al. (2005), show comparable responses between the dissertation study aerospace professionals and the professionals of the Mosberg et al. study. The sample size of both groups is comparable with the Mosberg et al. results having 19 professionals and this study having 20 professionals. The experience level is also comparable with the Mosberg et al. respondents averaging 19 years of experience and 65% of the aerospace professionals having over 20 years of experience. The Mosberg et al. sample is more diverse containing six different engineering fields. In the

Mosberg et al. study, the top six most important design activities, starting with the most important, are understanding the problem, identifying constraints, communicating, seeking information, brainstorming and evaluating. This list contains many of the same terms in nearly the same order as the present study with the exception that the aerospace professionals placed making trade-offs in a higher ranked position and did not consider “evaluating” to be a top six most important activity. Relative to the six least important activities, the Mosberg et al. study listed in order from the top least important activity, decomposing, abstracting, building, synthesizing, imagining, and a tie between visualizing, prototyping, and modeling. Again the responses of the aerospace professionals are comparable.

Relative to Part 2 of the survey, the aerospace professionals shared the same least identifiable statement that “Good designers get it right the first time” but differed in the most identifiable where the aerospace professionals ranked “design is iteration” as number one, the Mosberg et al. sample ranked “in design, a primary consideration throughout the process is addressing the question “Who will be using the product?””.

Relative to the students, Atman et al. (2008) provides results from the Academic Pathways study which followed a set of 89 study students with varying engineering specialties from freshman through senior year. The six most important design activities (in order of importance starting with the most important) were: understanding the problem, communicating, identifying constraints, brainstorming, testing and making decisions. The report did not provide the list of six least important design activities of the Academic Pathways sample. Though not necessarily in the same order of importance except for the top most important activity, these results are very similar to ones obtained in this study with the aerospace students. Thus the



student and professional responses of this study are comparable to previous implementations of the instrument which also addresses the reliability of the results.

## 5.2 Research Question 2a Response

*How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?*

- ***Both LSBL and lecture based students with design or industry experience hold comparable views of aircraft design to the aerospace professionals.***
- ***Aerospace design professionals view aircraft design as a mixture of science and art. They view teamwork, compromise, and communication as all playing an important part in the mix of design and analysis.***
- ***Both sets of students interviewed valued communication, interpersonal skills, professionalism and compromise as key parts of teamwork. Where teamwork is viewed as the only way to do design in the aircraft industry.***
- ***All groups provided descriptions of the design process based upon lived experiences indicating the importance of these experiences to forming views of the field aircraft design.***

Examination of the interviews of all the participants shows some similarities and some differences between the professionals, the experimental and the control groups. The professionals, consistent with expert views have great deal of content knowledge (built through experience) that is organized in a way that reflects a deep understanding of engineering design (Bransford et al., 2000). One professional interviewee started his response to the question to briefly describe the design process with the statement “broad topic...the art and science of developing a design that will satisfy the needs of the users. First step is to determine if a new design is required ...” Professionals see many aspects of design as intertwined and essential to the performance of design on the industrial scale such as communication and teamwork and analysis balancing out design. This communication is essential in the industrial work environment since the designs developed today are too complex to be developed by a single individual and the contributions of many with different skills and expertise working together as one team is required in order to do the job. They note a special importance in working with the

customer to define the needs of the user and that often in conceptual design, the requirements that come from customer needs are often ill-defined or non-existent. This requires good communication with the customer and cultivating the business. As one professional noted that if requirements that feed out of a customer need were a surprise to the company “...in this business, it probably means that they failed to do their job shaping it on the front.”

The professionals see design also as being more than just a set of processes. The core phases of need identification, requirements development, concept definition, preliminary design, detail design (with iteration of the proceeding steps as necessary), and fabrication and test are aspects that one can learn but there is also the aspect that involves untaught skills and ways of viewing things that can differentiate good designers from great designers. This art is expressed not only in the creativity of a solution but is also expressed in the way the designer utilizes compromise among the groups that contribute to the design. The professional group interviewee mentioned at the beginning of the last paragraph noted that the way the compromises are achieved can be the “art side of design – it takes a careful balance of all requirements to make an aircraft work. In the end, every successful flying machine is a complicated, interlocked set of compromises.”

The students of the study had some similar views of design though not with the same level of expressed affection for the subject. Relative to the importance of requirements, analysis, trade studies, teamwork, and compromise, both groups expressed similar beliefs to the professionals during the interviews. All saw those elements as important and one of the experimental students made the statement “every step of design is integral” (Interviewee #3, experimental group). When describing what trade studies bring to the process, a control group member noted “they let you see what works, what’s been done before and hasn’t worked and

why it hasn't worked and people's justification for why they'll go and use something else as opposed to ...something that's been used and failed" (Interviewee #7, control group).

The noted similarity of importance placed by both the control and the experimental groups can be accounted for in part by the backgrounds of the interview participants. Whereas the experimental interview group contained mostly people with limited internship and co-op experience save one interviewee, the control interview group contained people who had either multiple co-op or internship experiences or had participated in design as an underclassman on the *Design, Build and Fly* (DBF) design competition. As such the control group interviewees had experience outside of class that would have great influence on their professional skills and their technical skills. Thus in this case one cannot compare the interviews of a student whose introduction to aircraft design was the LSBL experience and one whose introduction was the control class lectures. Given the fact that the less experienced LSBL interviewees gave responses indicating the same level of importance for various design aspects as the more experienced control group interviewees has the potential to indicate that LSBL may have played a part in the formation of these views.

One observation of the responses to the question of describing the design process is that all respondents described a process based upon their experience. In the case of the professionals, one sees a recalling of their lived familiar design experience with various details added for various stages (conditionalized knowledge of an expert). The experimental group students all recalled the steps of the LSBL experience with the exception of Interviewee #8 who recalled his industry exposure obtained during internships and then added elements of his LSBL experience to his explanation. All of the control group students did not provide a standard design process flow that was presented in the control group class but instead recalled their work experiences or

previous design experiences as was the case with the non-industry experienced DBF interviewee. The indicators for such an inference can be seen the choice of words used by the respondent to describe the design process. For example interviewee #4 of the control group had a number of internships with defense contractors and used phrasing such as “it starts with a customer’s need. If you can’t sell it, there’s no point in building it. If the customer is...DARPA or the Air Force, ok so you don’t have to sell it, but it’s some...like it’s a test-bed or an experimental...” From this passage alone we can see that the student is familiar with the industry mindset of selling a product (in order to make a profit) to meet a need and he knows that dealing with government agencies is different than dealing with commercial entities when it comes to design. The interviewee goes on to describe the rest of the process giving unsolicited examples to clarify points he feels may not be clear. The fact that all the study participants gave a response based upon a lived experience of some sort, I believe, gives some insight into the importance of these experiences. As such, real world experience given in an internship or in an LSBL experience can play a very important part in how the individual views engineering and what is required of engineers on the job which in turn also impacts their professional skills (and their technical skills) as exhibited by control group Interviewee #4’s communication of the design process.

Though internships and co-op experiences can provide the exposure to industry or government employee life (and those technical and professional skills) that such employer’s desire, not all experiences are the same and some can be detrimental to a new engineer. In the case of control group Interviewee #4, we find that though the student had a number of internships, the interview reveals that the student had an experience that appears to have negatively impacted both his view of engineering and his role in industry (touching upon the *View of Industry* theme):

“But I feel like there was...the very first thing that happened to me when I went out and got my internship was, I was disenchanted with engineering because I had this romantic idea of what engineering was and it’s, you know, design and it’s sketching things and it’s choosing, you know configurations, and making all these beautiful things work and then, you know the peons go and do it. Well what I didn’t realize was I am one of those peons. And will always be, you know. And even, it’s really, the people who flunk out of architecture and then they become industrial design majors, they’re the ones who are doing the romantic ideas of design. They sketch it, they hand it to us and then they’re done. And I kind of really feel like that’s what happened, that’s what the attitude was here, in this class. It was more the romantic idea of design whereas engineers, we’re the ones who actually make it work.”

Here it is believed that an unintended consequence has occurred where youthful enthusiasm has been replaced, at least partially, by cynicism that one might hear from a more experienced, most likely mid-career professional. The LSBL approach is designed to address issues like this that can occur in real internships by providing a realistic and balanced simulated work experience so that individuals can come away from the simulated experience with a realistic but hopeful view of how practicing engineers function in the workplace. Such support is often critical and is a part of mentoring practice that one might see in the workplace.

Some further examples of comparable thoughts and expressions between the professionals and the student groups on the topic of aerospace design are listed below:

- Interviewee #4 from the control group noted “...the job of the designer is to take everybody’s opinions and everybody’s priorities about that and mesh them together into something that works elegantly...” This expression of the role of a designer is comparable to one professional’s statement that “the role of the conceptual designer is to make all groups equally unhappy...this can be the art of design-it takes a careful balance of all requirements to make an aircraft work”
- A professional noted relative to requirements and trade studies

“If you can’t assess the difference in your design as requirements change or as your baseline assumptions change, cause they always do... you really are not doing the full job of aircraft design. I mean look at it right now even, in proving out a vehicle in flight test like F-35, they’re doing a lot of things that they didn’t understand until they had them in that point in the envelope. And that’s the same with any system. You could say the same thing about the 787 if you want...so unless you’re doing those trade studies to become somewhat prepared, you’re just walking in the dark.”

Interviewee #8 (experimental group) noted relative to requirements:

“So if you’re designing, you’re designing towards that requirement and I think you sort of have to future proof it because through my conversations with other people, requirements are always changing. What the requirements were for F-35, when it originally came out compared to where it is now is probably you know very different in that it’s hard to evaluate that airplane...to the old requirements and the new requirements, you always have to keep in mind that requirements or specifications can change and so you’re design has to be fluid in a point that you can meet these ever changing requirements or specifications.”

From these transcript excerpts, we can see that the students do have some similar thoughts and use of terms that are similar to the professionals. The language is most similar among those who have had previous industry or government experience as opposed to those with just the LSBL experience or just the control class experience. It is believed that this is due in part to the relative duration of the design class intervention in this study versus the duration of an internship.

Whereas an internship can last a month or more and is a full-time job with the student living the experience 24/7, the study exercise here only lasted five class periods totaling a little over six hours. A longer duration exercise under the LSBL environment should help the student without the internship experience to pick up more of the language of the working professional.

### 5.3 Research Question 2b Response.

*How do (aerospace) engineering students describe their experiences with realism through simulation in relation to their previous academic experiences?*

- *LSBL students describe LSBL as an engaging experience that is preferable to lectures and provides insight into the world of the practicing aerospace engineer.*
- *A number of students feel that the LSBL experience should be continued in aircraft design but should be expanded beyond the five class period duration of the study.*
- *Control group lecture students found the lectures comparable to previous classes and not as engaging as they would have liked.*

The overall views of the student relative to the exercise are summarized below. The experimental group interviews indicate:

- All of the students liked the LSBL experience and that the use of actual software, working in teams and open communication environment helped to make it an engaging experience.
- All understood the class time constraints of the experiment but thought that the pace was a little fast for learning the software. All desired the experience to be longer, possibly the entire semester. Recommendations included a slower pace, adding assistants to the class to deal with software questions or more class time with the software.
- All felt that the experience gave them insight into being a practicing aerospace engineer. Features of the experience that contributed to that belief include the use of a real world complex problem, using industry tools, working in teams, instructor demeanor that was conducive to open discussion and feedback. This was a different experience than their other classes and they felt more engaged as they started applying knowledge.
- All felt the LSBL approach could be applied to other classes but not all classes. Most applicable classes included those that dealt with practical issues, had hands-on aspects,

and elements of “no right or wrong answer.” It was felt that classes that involve theory needed to be taught as lectures such as an aircraft structures class.

The control group interviews indicate:

- Half of the interviewees did not like the lecture class and thought it was too general and half liked the way it was put together and found it informative. Most thought it provided a good general overview of aircraft design. Nearly all expressed a respect for the experience and knowledge of the instructor.
- Nearly all had comments that there was not the level of instructor/class engagement that they would desire in a class. Some wanted more detailed instructions on how to design an airplane to be presented. One thought that both a commercial and government design process should be presented.
- Half felt the class and insights from the instructor gave them insight into being a practicing aerospace engineer while the other half felt that insight was gained through either their own engineering work experiences or engineering project work.
- All thought the class was similar to other lecture classes that they had had in their academic experience. Some noted that they observed some students “tuning out” at times during the classes as engagement was low. Some expressed the importance of the design class as a whole as being important to providing experience to apply knowledge that has been gained through previous classes.

The experimental group students had a positive response to the LSBL experience and preferred it to the traditional lecture. The students found the experience to be engaging and one where they felt free to ask questions and engage with the instructor and the fellow students. The



following exchange details experimental group Interviewee #2's view of the experience and illustrates the themes of *View of Industry* and *Inductive Learning*:

“Ques: Do you feel the experiences have given you insight into being a practicing aerospace design engineer?”

Ans: I do. I feel... it was...the BAA was just very hard. It was a task that really had never been done before. To try and tackle that head on really made us work together as a team to utilize each other's weird and different ideas and actually give them a weight. Hey we got to try everything...And then the environment he created really helped foster a sense of an actual start-up company. So it was we had motivation to do it.

Ques: Ok. How did he foster that environment?

Ans: Um by the way he organized the class. The lectures were formatted as a boss giving it to the intro project engineers. The way he had us work in teams instead of just throwing us information. He was just really letting us learn.”

Interviewee #1 (experimental group) felt that the environment of the LSBL experience was one where questions could be asked and was one where it was possible to learn more and touches upon the *Engagement* theme:

“...this kind of experiment...he was explaining a lot of stuff to us but we were...I don't know but I felt more comfortable asking questions because we were going at a really fast pace and it was very new the stuff and it was meant to be an interactive experience. So ... I felt that was good, I felt that I learned more because of that.”

This same Interviewee did not share this view of typical lecture classes where the tendency was to feel disengaged at times (touching upon the *Lecture Disengagement* theme):

“...it's different because when you're sitting at a desk listening. It's not very interactive. Like you're listening, you're taking notes and... you could ask questions but you're basically getting talked at.”

“Like sometimes in class, even though they say you can interrupt and ask questions, you don't always want to... because you don't want to interrupt the flow, whereas it wasn't really like that there [the experimental class].”

Interviewee #3 (experimental group) noted “Well I loved the fact that we were in a smaller class and we got to do the hands-on stuff as opposed to just listening to somebody lecture about it.”

Interviewee #8 felt that the combination of open communication and using industry tools in the experimental group side of the exercise was of great benefit in the class:

“... you know using the software at least myself was a more stimulating experience than sitting there and just listening to someone talk to you. It’s, okay he talks to me, but then I go get to actually do something. That’s sort of exciting, oh you’re sort of building an airplane in a sense and then you come back and say, okay I have a problem and you have that communication back and forth and then you go off and do it again, so it’s I guess the constantly changing aspect of okay you’re talking to someone, you’re actually going and doing something, talking again and doing something.”

Interviewee #2 noted how the use of the industry tools brought a new technical understanding to some concepts presented earlier in his academic career (deals with the *New Technical*

*Understanding theme*):

“...sizing and performance issues back in sophomore year. You can give us a lecture and say here’s how changing the size of the wing will affect the endurance, but it’s just head knowledge at that point. If you actually play around with the data in ModelCenter, and see how it affects the outcomes, that, that was neat to see, I think.”

Here the student is gaining experience and understanding of how to physically make changes to an airplane design and have an idea of how the plane will perform after having made those changes. In an aircraft advanced design environment in industry, designers and analysts with experience use this skill repeatedly and it is a desired attribute of engineers in that environment. In that environment, requirements can be ill-defined and a designer often has to make judgment calls on various parameters of a design in order to advance it. Knowledge of how various courses of action might impact a result become critical in the design pursuit. The deeper meaning that the student has gained during the LSBL experience can help to develop this skill. As noted in Chapter 3, the LSBL approach encourages the facilitator to provide industry and

professional rules of thumb and build a basic understanding of concepts in addition to using real world tools. The skill described is also important to analysts helping them to make educated guesses on the impact of various trades before committing more serious analysis resources such as computer codes to analyze a problem. This same deeper understanding also becomes valuable when analyzing results of an analysis program. Instantly the engineer can look at certain results and see if they make sense based on the deeper understanding of the parameters at play. For example the engineer could look at trade study results of changing the aspect ratio of a wing in an optimization program and see if the results make sense or if there may have been a problem with the code or the inputs.

Students were not completely satisfied with the class and thought that its short duration and fast pace could be areas where the experience could be improved (the *Experiment Area for Improvement* theme):

“...how would I change it? I would have maybe, obviously, if possible, do over like double the length of time...take it a bit slower, have more time to play with the software, between periods like have half the period learning and half the time period, you know like playing with software...having little projects on it, rather than just seeing it, learning it, and then the next thing coming around and trying to use it...like to design a model straight away.” (Interviewee #1, experimental group)

“I think it would be a lot more beneficial if you could go through the whole process a lot slower at the speed where you could really take away what has to go into what steps and stuff like that.” (Interviewee #3, experimental group)

When comparing this approach to other classes and being asked if they would like the LSBL approach used in other classes, Interviewee #1 responded (this also touches upon the *View of University* theme):

“...it’s a bit different because aircraft design, like design classes in general are more...obviously they are more practical, you’re designing something. Whereas, a lot of other classes you are learning theory.”

This response indicates that the students view many of their other classes as being theory and that a “hands-on” approach like LSBL would not necessarily be applicable. This view that other classes are more theory and less practical is also expressed by the control group member Interviewee #6 who said when discussing taking notes in a lecture “...just listening, I feel like a scholar and whereas when I’m in my [design] group afterwards I’m an actual practicing engineer.”

Along the lines of these viewing lectures as being the way they are shown theory, all of the experimental group students felt that lectures were the best way to learn certain topics. As experimental group Interviewee #2 noted (this is also an example of the *Lecture Benefits* theme):

“There’s a lot of places where you just have to do lecture-based teaching. You’ve just got to...someone has just got to physically teach you...What comes to mind immediately, is the structures classes, where it’s very mathematical...Someone’s just got to show you an example, you’ve got to go home figure out how to do the calculations yourself, write the code, do all that gritty work.”

As can be seen by the comments of the participants, the LSBL approach was found to be more engaging than the lecture approach. They felt as though they were part of a real company and were engaged by a combination of the instructor demeanor, the use of real industry tools and being divided up into teams and taking a group approach to solve a problem. An aim of the LSBL approach was to foster this sense of industry life among the participants and the students appear to feel that it does. These LSBL results are also consistent with the findings reported by Mills and Treagust (2003, p. 12) on project-based learning that students were motivated by the approach and had a better understanding of the application of knowledge in practice and the other complexities that come with practice.

### 5.4 Research Question 3 Response

*What, if any, is the relationship between LSBL students, lecture-based students and aerospace industry professionals with regards to their conception and viewpoints of aerospace engineering design?*

- *There is a direct relationship between student views of aerospace and the level of real world engineering experience of the student. LSBL students with no industry experience provided views of design and aerospace engineering comparable to industry experienced students who in turn provide views comparable to professionals in general terms. (Professionals remain a little more nuanced in some responses versus the students)*
- *Industry experienced students have identified that there is a “gap” between their academic training and what is expected of them when they enter industry. Participants in both the control group and experimental group express this belief.*
- *Strictly leaving preparation up to industry in the form of internships and co-ops does not ensure that the student will receive the best preparatory experience and can have a negative impact on identity as an engineer as exhibited by a control group interviewee*
- *LSBL has been shown to help fill in this gap as described by an industry experienced experimental group student.*

The quantitative and qualitative results do give some indication that there is a relationship between the LSBL students and industry professionals. The results also indicate that previous experiences can play an important part in forming a student’s conception and viewpoints of aerospace engineering design. The coded themes of *View of Industry*, *View of University*, and the *Gap Between University and Industry* illustrate this tie.

Both Interviewee #4 (control) and Interview #8 (experimental) were participants in the study who had had internship experience. Interviewee #4 had worked for a couple of defense contractors while Interviewee #8 had worked for the Department of Defense. In both cases, the interviews revealed that the experience did have an impact on the students that in turn impacted their conceptions and viewpoints of aerospace engineering design. Interviewee #4 as mentioned in the Research Question 2b response noted how he had a “romantic notion” about design that was crushed by his work experience. This in turn led this individual to believe things such as:

“You can be an engineer and not be doing classical design in the sense that you’re sitting in a bar with you colleagues, you know smoking a cigar and then, on the back of an envelope that you know someone just happens to have right in front of them, you sketch the SR-71 like they did in the 1950s. [laugh] That’s never going to happen again, the heyday of aviation is over. That’s not the kind of problems that we’re going to be solving anymore...that’s not what engineering is anymore or at least in America. It might be different elsewhere, but the culture of America...American engineering is more we have a problem that the customer has given us, let’s understand that problem, and let’s solve it as cheaply as possible because we want as much margin as possible. It’s always a business decision. And I don’t think, and design for design’s sake, doesn’t really happen anymore. I don’t think.”

Though parts of this statement are true, others are not and have created a view of design that is slightly distorted. Problems are not always clear cut and provided by the customer and “design for design’s sake” never really has happened in the aviation industry. As with any business, there is usually a desire for product that can be sold and innovation can help to distinguish one competitor from another. This comment further illustrates how the experiences shaped the views of engineer at a critical stage of his or hers professional development and it is important to provide experiences where possible that can provide accurate views of the industry but also the correct level of encouragement as one begins the professional journey. It may be noted that this student himself said his internships shaped his views and not the “lecture series” as he put it.

Control group Interviewee #4 indicated that based upon his experiences, there is a difference or undeclared gap between working in industry and the training he has received in college. For instance he says:

“I think that risk management is actually, not touched on enough in school, but then I actually find it swings the other way in industry. We’re kind of now a risk adverse society, right? So we don’t want to , don’t want to take any risk and I really think, I guess this is because I’m still naïve, haven’t spent enough time in industry but I really feel like there needs to be a better balance between, you know, seeing what we can do to solve this problem, and then seeing what we know we’ll be able to do to fix this problem and then finding a, what, like a happy medium between...We can solve this problem with existing technology, and it’ll still work and it’ll be kind of cheap or we can solve

this problem using nascent technology and it's going to be awesome and it's going to advance the state of the art but it's gonna be super expensive. Or, we can take the time to advance the state of the art incrementally and improve what we have and then sell that. Far more expensive but proving the quality, proving the value to the customer in the long run. And I think that some of the major companies really do that but I don't think that, that is emphasized a lot in school... Which I can see arguments for and against anyway. Because this is supposed to be where we, you know, come up with our fundamental...base knowledge and then we go and learn how to be an engineer when we work for a company and they imprint their culture on you so you can fit into it and be cog in their machine. Ah, but at the same time, ah, it'd be cool to get a heads-up about that, I don't know."

A similar sentiment was expressed by control group Interviewee #5, with no internship experience, about the academic culture and its impact on the students. This participant said:

"...the actual engineering market place is not exactly how a class is set up, but it's good to get that little bit of insight that we can as much as possible before we get thrown into, you know, the big fish tank. Because right now we are just in our own little, college is nice little controlled area, where they can control all our environmental factors that affect us. But once we're out in the big world, it's not going to happen that way. So having...we talked a little bit in the class about how things work and I guess that was one thing Dr. Mason did actually bring to us. He could give us the insight; he did give a little insight occasionally on how like the actual workplace works."

Interviewee #5 noted how the comments of the instructor of the control group (an industry experienced engineer and retired aircraft design instructor) positively impacted his view of what was like to be a practicing engineer. The LSBL experience seeks to take this type of insight to the next level by providing simulated exposure. Interviewee #8 of the experimental group provides insight on the impact of LSBL on one with some industry exposure and how it helps to address what this study participant literally calls the "gap" between industry and academia.

The following quote illustrates how Interviewee #8 felt somewhat unprepared for his internship experiences and he identifies this as a "gap" between industry and academia and how he feels LSBL helps to bridge that gap:

“...other classes in general. In my thin walled structures or aerostructures or stability and control, that doesn't really give you a feel for what it would be like to sit in an office at Lockheed Martin or Boeing or Northrop or Raytheon...I think that's where it's a big gap, where it's okay, I'll graduate and go work for one of these companies and there's nothing to connect the two.

Ques: Ok. How did that class help bridge the gap? You mention the word, like the term “bridge the gap.” Can you describe how it did that?

Ans: So I've had internships over the summer where I've come in and it's sort of...you've never learned what they do or you know these companies have been so specialized, I was doing test and evaluation for the Navy and you know you come in and it's just a fire hose to the mouth. You've got no idea, you know, from your classes how to go in and work with the company. I mean you've got that critical thinking ability and the analytical skills but it's still like there's such a huge gap between some of the internships I've had...I think sitting down, especially if you're going to be a designer, sitting down going through this software, and saying, okay this is how you use CATIA or this is, you know you've got Excel spreadsheets and then ModelCenter and then you use CATIA sort of those three help you when you're going to be sitting at a desk designing part of an airplane or a piece or something. That's really going to be what you're going to be doing in the future at a company more so than sitting down in a desk and having someone lecture to you for 90 minutes. So I think that's more of how it was bridging the gap or at least how I use it.”

Interviewee #8 goes on to say relative to both the LSBL experience and the capstone design class in general:

“I think ultimately what this class and what the future will hold is that design is always going to be a group effort. I think through the classes that I've taken before hand design or these class works have always been individual and not group work. Um so I think that's another big issue which with what we've been learning of what we'll be doing in the real world is there's going to be a big jump of, okay you've done everything as an individual in college to evaluate your skills, but then now you're going to jump into the company and everything is going to be group based. You're group's going to be the one that swims or sinks. I think in this aspect, you know we use the software and we came to some design decisions as a group. You know we all had our individual sketches that we did by ourselves, we came together as a group, evaluated each one, ultimately chose the final design as a group and then, you know, used CATIA as a group and that transfers over to our senior design project where it's a whole group basis trying to put together a final package to deliver to the professor and ultimately, we're the Group Z, so we're going to try to build something. But I think the skills gained in using this teamwork will



definitely jump over to working in industry, because that's how from my experience, it's going to be working in teams." (The interviewee's regular design class team name was replaced with "Group Z" in this quote to help protect the student's identity.)

Thus the aerospace students themselves in the study have experienced and described the gap between industry and academia that is discussed in the introductory material of this dissertation. One of these students was able to take the LSBL experience and feel that he was being better prepared to enter the community of practice of the aerospace engineer that he had had brief experience with, as an intern. Such experiences are important and can shape student conceptions of engineering and in this case engineering design as evidenced by control group Interviewee #4. The following sections look at other aspects of the LSBL and lecture experience such the view of teamwork and communication and how the students perform aircraft design in light of the LSBL experience.

### 5.5 Research Question 3a Response

*How do LSBL students, lecture based students, and aerospace industry professionals compare on the professional skills of communication and teamwork?*

- ***LSBL, Lecture, and Professionals show comparable views of the importance and link between communication and teamwork.***
- ***Industry experience outside of the classroom can have a large impact on student abilities in this area and LSBL students have been shown to have comparable skills as those industry experienced students in this study.***

The measure of communication and teamwork in this study was accomplished by a combination of the survey and the interviews. Communication was one of the design activity terms listed in the most important design activities portion of the survey. For the professionals, communication ranked 3<sup>rd</sup> in its importance of the 23 terms listed. For the student groups, communication ranked just as high and moved to a higher position at times during the study. In the pre-test survey, both the experimental and control groups listed communication as 3<sup>rd</sup> in importance just as the professionals had. In the case of the experimental group, this ranking

changed from 3<sup>rd</sup> to 2<sup>nd</sup> in Post-Test 1 and back to 3<sup>rd</sup> for Post-Test 2 and tied for first on Post-Test 3. For the control group, this ranking changed from 3<sup>rd</sup> to 2<sup>nd</sup> in Post-Test 1 and up to 1<sup>st</sup> for Post-Tests 2 and 3. The importance of communication was expressed in both the control class lectures and in the experimental class exercise and it is understandable that the students would have seen how communication is essential to design work. The later shifts in importance are most likely tied to the progress the students are making in their design projects as they experience the positive impact of good communication and the negative impact of poor communication on a design team.

In the interviews, the professionals commented on the link between teamwork and communication. It was noted by one professional that:

“Modern aircraft are too complicated for any one individual to do everything. All modern aircraft require a team, ranging from 3-5 people for light civil aircraft (Burt Rutan style) to many thousands (Boeing 787, F-35, A-380) to do all of the design, analysis, certification, test, software development, and hardware procurement. Communications among a team is the key to success. Throwing information over the wall to the next guy will not get the job done. Clear, precise communication (drawings, charts, data, vu-graphs, verbal and written) is key to making a team achieve success”

The students similarly expressed the importance of teamwork and communication. For Interviewee #1 of the experimental group, communication was the single most important design activity because

“...at the end of the day, if you’re working in a team if you don’t communicate with each other, you’re not going to get anything done, people are not going to understand each other, some people will be working towards different things when their thinking their working towards the same thing.”

A similar sentiment was expressed by Interviewee #3 of the experimental group:

“[Communication] is another huge one because you can’t design something by yourself. It would take forever, you would get frustrated, and it just...I don’t think it’s even plausible. So you need to be able to work in a team to get something done...communication

is the biggest thing. Teamwork has to be, you have to be able to work in a team... just being able to communicate and work with your peers is the only way you can successfully go through the design process because like I said you can't do it alone"

It may be noted that both of these participants did not have co-op or internship experience prior to the exercise. This expressed value in teamwork and communication was also expressed by some of the control group members as is exemplified by the following comments of Interviewee #7:

"Teamwork is everything. You have to divide it up into groups you know. People are responsible for a certain section. You have to be able to work with teams; you're never going to design a plane, a ship, anything big on your own outside of ... just for fun, your house. Ah if you can't work in a team you, you're pretty much in deep trouble in this industry I feel... You have to be able to work, rely on other people that they can get it done and the interaction with other people is just really important."

Interviewee #5 of the control group noted that the control group instructor stressed in class the importance of teamwork in design. Interviewee #4 of the same group also noted the importance of leaders setting a tone for teamwork which was also mentioned by the professionals:

"...it [teamwork] plays a huge part in design. I think that team leaders need to be enablers rather than dictators. And I think that by being enablers and encouraging discussion amongst lots of engineers rather than a few, you get a larger, more colorful understanding of the problem"

From this we can see that both the experimental and control groups valued communication and team work in a way that is comparable to the professionals of this study. Both measures, the survey and the interviews, reveal an understanding of the relationship of communication and teamwork in a way that is similar if not the same as the professional sample. It may be noted that relative to the interviews, interviewees with no industry experience in the experimental group expressed views of teamwork and communication that were similar to interviewees that had some industry experience.

It was observed in the experimental class by the lead researcher that the design teams did exchange ideas and worked together to develop their concepts. Each team member was requested to develop an initial concept in response to the BAA and then work with the rest of their design team to come up with a single team concept. All of the concepts presented by the teams showed elements of different individual designs in an effort to get the best team design. As experimental group Interviewee #2 noted on teamwork when dealing with the submersible airplane challenge:

“...it [teamwork] plays a crucial role. It’s easy to ignore people who have quirky ideas or who aren’t really going with the flow but those are the ideas that we found out really had some importance, because it was such an oddball design that we really had to take into account everything. There was no one in the group who could say I’ve got all the ideas. Everybody contributed something to be looked at from a different perspective. We really had to use that in our design.”

Thus it is believed that the LSBL intervention did have some impact the student’s views on teamwork and communication though the survey indicates that the students did place high value on communication before the exercise started. This is most likely due to a combination of personal experiences and previous engineering class experiences such as the freshmen cornerstone design experience at Virginia Tech.

In terms of actual measures of communication skill, this study is limited to observations of the students in the experimental design class, the interviews, and the presentations and design reports of all students in their capstone design teams. The next section discusses the students’ capstone design reports and presentations and provides further insight into the students’ communication skills.

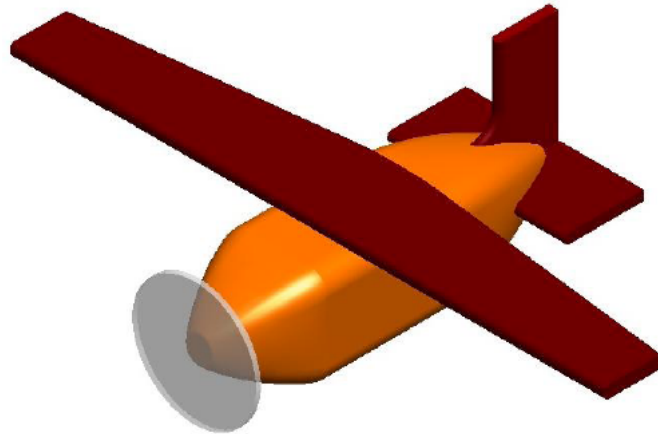
### 5.6 Research Question 3b Response

*How do predominantly LSBL student design groups and predominantly lecture-based student design groups compare on the professional skill of problem solving as exhibited in an aircraft design project?*

- *Mostly LSBL and mostly Lecture student composed design groups show comparable aircraft design skills in this study. A mostly experimental group design team developed a concept, design report and presentation that were comparable to a mostly control group design team with a large number of previously experienced (either in design or industry experience) members*
- *Again non-academic experience plays an important part in development of design skills.*
- *All teams developed viable initial concepts.*

None of the class design teams contained exclusively control group or experimental group participants thus it is impossible to compare the impact of LSBL versus the control groups exclusively. However, there were two teams, Team 3 and Team 4 that had the largest percentages of experimental and control group students, respectively. Both of these teams chose design projects with the aim of building some form of aircraft that would actually be flown. Review of the presentations and the design reports using the modified TIDEE rubrics revealed that these two teams were the better performers than the other design teams with Team 4 (the mostly control group members) scoring highest. Team 4 scored highest both in the design report and design presentation. Most of the design reports read with what I refer to as a “tutorial voice” meaning the author assumes that the reader needs to be taught about the scientific and engineering principles behind any analysis that the author presents. The one exception to this finding was the design report of Team 4 which read more like a professional industrial report where data was presented in a concise manner with appropriate explanation when needed. Claims were supported by analysis. Figure 26 is sample of the Design Team 4’s work.

Choosing a target empty weight and then designing an aircraft around it that can still complete the missions required is a departure from the traditional aircraft sizing and design methods but is necessary to build a competitive aircraft for this competition. Given the target weight and the evaluations of the submitted conceptual designs, the concept that was selected to take into Preliminary Design is represented by a rough CAD model here:

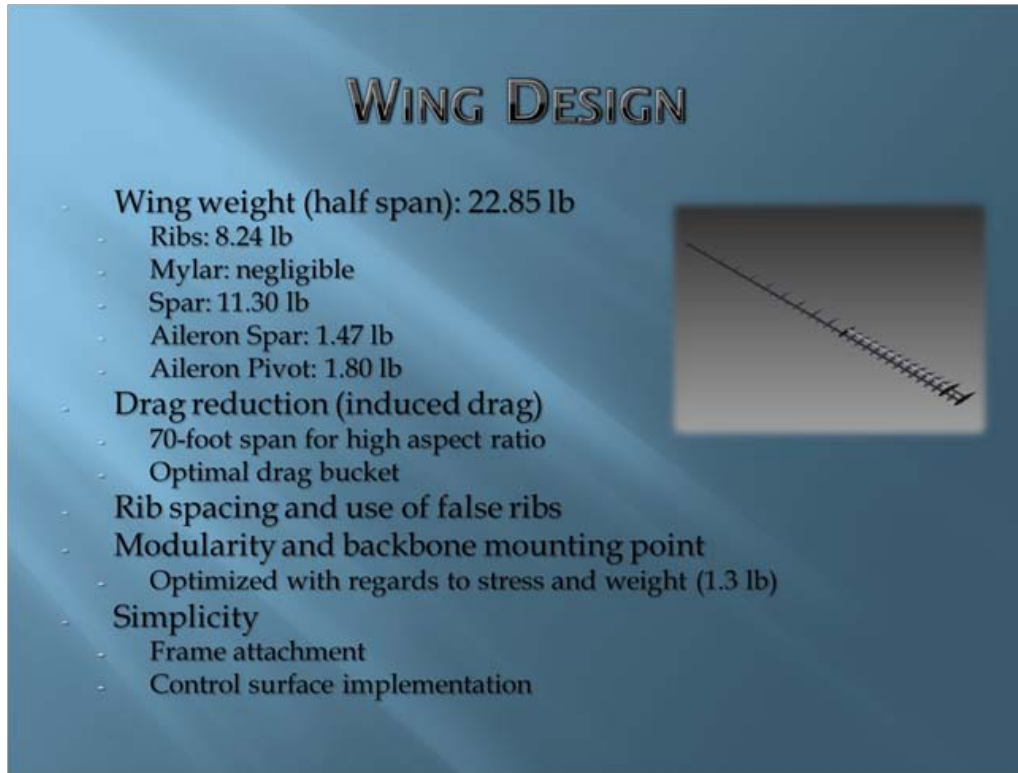


**Figure 3.3:** Conceptual Design

The design features a single tractor propeller, a high tapered wing, and a conventional tail. This configuration beat out other designs with multiple motors.

*Figure 26.* Design Team 4 Design Report Excerpt

Design Team 3 also had a very professional looking presentation which was reviewed by the industry observer. Graphics and CAD work were very professional and charts were comparable to those observed in industry by the lead researcher. On the day Design Team 3 presented, the industry observer rated Team 3, the predominantly experimental group in team membership, the highest in its presentation above Teams 2 and 6 each of which had a majority of control group members. Figure 27 provides a sample of this design team's presentation.



*Figure 27.* Design Team 3 Design Presentation Sample

Though Team 3 had an engaging presentation, the design report as graded with the modified TIDEE rubric was not as well done as the Team 4 report. In industry, it has been the experience of the lead researcher that design reports or proposals contain a combination of scalable drawings and isometric shaded pictures of the proposed concept in addition to figures and plots supporting various analyses of the concept. The Team 4 report contained such items including a scalable general arrangement drawing of the baseline concept, the only team to do that at the time of the presentation. Though Team 3's report did contain many of the graphics used in the presentation, the lack of a drawing of the proposed concept did hurt the strength of the report. It may be noted that though Team 4 contains mostly control group members without the LSBL experience, many of its members have had prior design experience on this type of design concept through involvement in the senior design team as underclassmen. In this capacity the team members had exposure to industry contacts that support the design effort as noted by

control group Interviewee #5 of Team 4. In addition, this team also contains a number of members who have had co-op or internship experience, as such it is felt that these experiences have had a positive impact on the design products of this team.

Aside from the reports and presentations of Teams 3 and 4, the other four design teams had presentations and reports that were fairly comparable and predominantly had the tutorial voice mentioned earlier. Below is an example of the tutorial voice type of text found in the other design team reports. In this case the team leads off the discussion of the stability and control aspects of their design with the following paragraph:

“Stability analysis is the study of reactions to a perturbation. Stability occurs in the longitudinal as well as the lateral directional axes (Sultan). A system can be either stable or unstable. The conditions for stability are static and dynamic stability. Static stability refers to the initial tendency of the aircraft to return to equilibrium after a perturbation. Dynamic stability is the tendency of an aircraft to return to equilibrium in finite time. Control is the action of using external moments and forces to change the attitude of the aircraft.”

The paragraph provides a basic tutorial on stability and control instead of actually discussing the stability and control aspects of the proposed design. It has been the professional experience of the lead researcher that design reports in the industry would not contain such explanations except when there is a deviation from the assumed norms of stability and control analysis. At the professional level, it is assumed that the reader is a reasonably experienced engineer and the point of a design report is to provide information on the design in a concise manner. For comparison, the following is an excerpt from Deputy Program Manager John Patierno’s 1974 AIAA paper describing empennage integration and sizing on the Northrop YF-17 fighter aircraft that competed against the General Dynamics YF-16 in the U.S. Air Force Lightweight Fighter competition:

“The approach in integrating and sizing the empennage surfaces was to provide inherent stability and control and spin resistance with the basic aerodynamic design



without stability augmentation. Advanced augmentation systems were then incorporated to achieve refined flying qualities.

The horizontal tail is located below the wing to provide increasing longitudinal stability at high angles of attack approaching maximum lift, and to preclude buffet from the wing wake at high-g conditions. High angle of attack controllability and spin resistance are thereby enhanced.

As a corollary to the fundamental stability criteria described above, the desire to minimize maneuvering trim drag was accomplished on the YF-17 by adopting two unconventional techniques not applied to contemporary designs.” (p. 4)

Patierno’s passage is concise and to the point describing the design of the YF-17’s tail configuration and its design rationale. One is educated on what the feature does and told about any deviations from standard practice. There is no explicit explanation of stability and control and their relation to the sizing and positioning of the YF-17s tail set. The provided example of the tutorial voice is not unique to the class that was studied (it has been seen in aircraft design reports submitted for aircraft design competitions from other universities) and could be an example of an accidental competency where design reports that stress the discussion of the theory behind a result as opposed to emphasizing the result itself and what it means to the designer is more common in an academic environment. It cannot be determined in this case if the performance of Team 3 can be attributed in some way to the LSBL experience of its members, however, these overall results do exhibit the impact of industry exposure on student presentation and report skills and also illustrates some of the unintended impacts of the academic environment on student professional skills.

## 5.7 Limitations

This study provides some insight into student thinking about aircraft design and aerospace engineering in general. It also provides some indication of the effectiveness of the LSBL approach. As with any study, there are some limitations. The study was only conducted for five class periods and attempted to provide a fairly thorough overview to the aircraft design

process. As such, not everything in aircraft design could be covered during the class periods. The study thus provides information on the impact of a brief intervention with LSBL. The LSBL study group contained 18 students due to facility limitations. Future work should include larger numbers and appropriate facilities in order to accommodate a larger number of students. As expressed in the experimental group interviews, more time to allow the subjects to be covered in more depth and time to allow the students more time with the software would be preferable for any future expansion on this approach. Though the AOE student class is fairly representative of the aerospace engineering students in the United States, a larger sample size with individual tracking of all participants is recommended to better address the generalizability of the results (the number of students responding to the survey was reduced by 30% at the last survey). Large sample size would allow potentially allow the use of stronger statistical analysis approaches than the non-parametric analyses utilized in this study. It is also suggested that the exercise be done at a variety of schools and programs to also address generalizability. Use of a larger professional sample would also strengthen the power of the results of the study.

In this study, the lead researcher was a participant in instruction in addition to assuming the role of principal analyst of the data. As such, every attempt was made during the study to eliminate or reduce bias in the conducting of the experiment, collection of data, and interpretation of the results. As noted in the previous sections of this dissertation, existing and proven instruments such as the Design Conception Survey and the modified version of the TIDEE design rubrics were utilized for assessment. As will be discussed further in this section, an outside observer not tied to the effort was brought in to observe the conduct of the instruction to see if there were any instruction biases. Interviews were conducted by engineering education trained PhD students experienced in aerospace and engineering education research who were not

involved in the experiment or the instruction. Themes that emerged from analysis of the interviews were also reviewed by independent experienced engineering education PhD students. Statistical analysis was reviewed by outside parties, representatives of LISA. Interview questions were developed and tested during the pilot study and additional questions were added to the interview protocol in order to provide triangulation with the Design Conception Survey results. Instructional materials were developed by the same researcher, but reviewed independently of the instruments utilized in the study. A professional benchmark was established with members of the aerospace industry from a number of different companies (this data was collected concurrently with the student data to prevent knowledge of the professional benchmark results ahead of the student instruction). An industry observer was also brought in to observe the student design team presentations.

Even with these precautions in place, it is beyond the researcher's ability to control all of the factors and conditions of the study. Students come into the study with a variety of backgrounds and have freedom to select from a variety of design projects for the course. Student response rate to surveys can vary between administrations. Researcher bias can potentially creep into analyses even with the best of intentions and outside influences beyond the researcher's control, as will be seen in the next paragraph, can impact results. Lessons can be taken from this experience and used in future work to create a more robust study as is discussed in the Future Work section of this dissertation.

During the study there were some unforeseen events that occurred that altered the way the exercise was executed. In one case, the original study plan called for a single experienced instructor to present the control class material. The instructor of record was to simply observe the class during the study period. During the actual execution of the study, the instructor of

record did participate in the class and altered the plans for homework during the study for the control class. These interjections were noted by the participants and did show up in some of the comments of a couple of the control group interviewees. In addition, efforts were made keep the experimental group and control groups separate both in the physical location (separate classrooms were used for each group) but also to keep the material separate for both groups during the five class intervention period. Here, the instructor of record provided the control class slides on a Scholar website to all of the design class students including the experimental group. Based upon inputs from the interviews and subsequent discussions with experimental group participants, it is believed that the experimental group did not look at the control group slides during the study though this cannot be guaranteed. Finally, as was mentioned earlier, an outside industry observer was to rate all of the design presentations presented by the students but was only able to be present for half of the presentations due to a last minute scheduling conflict. The lead researcher was present to review all of the design teams and a combination of lead researcher and observer results (both using the modified TIDEE rubrics) were used for analysis.

The study was conducted with two separate instructors. Attempts were made to minimize the impact of different instructors by having one person, the lead researcher, create the material for both classes. (The reader is also reminded that a large portion of the class material for the control class was derived from class material that the control class instructor, Dr. Mason, used in teaching the design class for many years.) As was discussed in Chapter 3, an outside observer from CIDER was brought in to observe both instructors and determine if there could be instructor influence on the results. Below is an excerpt from the report that was sent to the lead researcher on this matter after observing each instructor for one class period a piece (a longer excerpt of this letter is located in Appendix F):

“Given that the instructional treatments in both classes were very different, the approaches of the instructors varied greatly. Your approach was far more interactive. Dr. Mason rarely interacted with the students, though on three occasions, he posed questions and engaged in brief dialogue with a student in the front row of the class.

While both instructors evoked their professional experiences beyond higher education in meaningful ways throughout their instruction, Dr. Mason was ultimately more remote and seemingly less approachable than you. I could imagine that some students might feel somewhat intimidated by him. This might be due partly to his age and demeanor, but Dr. Mason’s instructional approach likely magnified this perception, further reducing engagement by students in his lecture-based class. Comparatively, you were quite warm, approachable, open to questions, and shared context-specific information in response to the work students were doing. In truth, these are key characteristics and strategies of those who successfully employ problem-based learning.

While the instructional approach certainly impacted student behaviors in these classes, one might argue that any significant learning differences discerned between the two classes could be partly attributed to the aforementioned classroom persona/personality differences of the two instructors; however, similar personality differences might be perceived between any two instructors employing the two instructional strategies in question.”

Thus the higher level of engagement in the LSBL class could be due in part to both the LSBL approach itself and the instructor being more approachable and the lack of engagement in the control class could be due to both the nature of the lecture class itself and the more reserved teaching style of the instructor. The exact impact of each of these elements individually cannot be determined.

## **5.8 Major Research Contributions & Future Research Suggestions**

An argument has been presented, supported by the literature, calling for modification to how engineering students are trained and molded to become practicing engineers in the 21<sup>st</sup> century. It has been shown that the LSBL model developed in this research does provide students simulated industrial world experience to help accelerate the transition from novice to expert in the professional community of practice. Tools such as the aircraft design synthesis

model tool utilizing a combination of the industry programs Microsoft Excel, ModelCenter, CATIA, and Flight Optimization System (FLOPS) were developed and utilized to aid in this transition and provide real world skills. The model may also be used in classes involving subjects that are separate subject matter expert disciplines in the professional world. These are the major contributions of the research that has been conducted and provide the ground work for a number of future research alternatives:

- Conduct the experiment again using two separate aerospace design classes with two different instructors and conduct the experiment for at least one semester to a year. Train both instructors in the LSBL approach and have the instructors switch between classes in order minimize instructor influences. Also have outside researchers not tied to the instruction analyze the data taken from the intervention in order to minimize any perceptions of possible bias in the analysis of the results.
- Since the LSBL approach is also somewhat of a philosophy, apply the LSBL approach to a non-design class such as performance or aerodynamics in the case of aerospace. In such courses, there are elements where the instruction can be couched in real world scenarios such as aerodynamicists and performance engineers working on a design team. The emphasis in such classes would be to introduce the students to subject matter from the perspective of the engineer who specializes in that area in the field.
- Apply LSBL to other engineering design courses and other classes outside of aerospace to confirm its applicability elsewhere. Application of the approach in other physical locations with a different population outside of the study institution would also help to address generalizability.

- Develop or discover other instruments to assess engineering professional and technical skills as they apply to design beyond the Design Conception Survey.
- Examine the use of computer based simulation in the LSBL approach. Can the combination of social media and game-based learning be applied to LSBL and provide a virtual VSBL (Virtual Simulation Based Learning) experience that would be deployable on a scale larger than the LSBL approach. How would the effectiveness of this approach compare to LSBL?

One of these suggestions or combinations thereof can help to further prove efficacy and strengthen the viability of the LSBL approach.

## 5.9 Conclusions

An experiment was conducted to examine the effectiveness of the LSBL approach on aerospace engineering senior design students. Table 11 below contains a summary of the findings and conclusions that have been drawn from the research for each of the research questions. This table combines the section summaries found at the beginning of subsections 5.1 through 5.6.

Table 11. *Summary of Dissertation Study Results*

Research Question	Industry Traits linked to Table 1	Conclusion
1. Can the use of live simulation-based learning (LSBL) in aerospace capstone design alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design?	Communication, Understanding of Design, flexibility and adaptability, analytical skills, interpersonal skills, multidisciplinary perspective (The listed items are covered in the survey.)	<ul style="list-style-type: none"> <li>- LSBL appears to alter student conceptions of engineering design and help students to respond like industry professionals in the area of aircraft design. In the experiment, LSBL experienced students made more rapid improvements in ranking the importance of various design activities than the control group students when compared to a sample of aerospace industry aircraft design professionals.</li> <li>- Both groups exhibit comparable survey responses with the experimental group more aligned with the industry professionals in design activity ranking immediately after</li> </ul>

		<p>the LSBL intervention. Both groups leveled off in correlation with the professionals after the first semester of design.</p> <ul style="list-style-type: none"> <li>- Students tend to more strongly agree or disagree with design statements of Part 2 of the survey than the professionals. These student views evolve over the course of the design class.</li> </ul>
<p><b>2a. How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?</b></p>	<p>Communication, Understanding of Design, flexibility, teamwork, interpersonal skills, professionalism (The listed items are addressed in the interview questions.)</p>	<ul style="list-style-type: none"> <li>- Both LSBL and lecture based students with design or industry experience hold comparable views of aircraft design to the aerospace professionals.</li> <li>- Aerospace design professionals view aircraft design as a mixture of science and art. They view teamwork, compromise, and communication as all playing an important part in the mix of design and analysis.</li> <li>- Both sets of students interviewed valued communication, interpersonal skills, professionalism and compromise as key parts of teamwork. Where teamwork is viewed as the only way to do design in the aircraft industry.</li> <li>- All groups provided descriptions of the design process based upon lived experiences indicating the importance of these experiences to forming views of the field aircraft design.</li> </ul>
<p><b>2b. How do (aerospace) engineering students describe their experiences with realism through simulation in relation to their previous academic experiences?</b></p>	<p>Not applicable</p>	<ul style="list-style-type: none"> <li>- LSBL students describe LSBL as an engaging experience that is preferable to lectures and provides insight into the world of the practicing aerospace engineer.</li> <li>- A number of students feel that the LSBL experience should be continued in aircraft design but should be expanded beyond the five class period duration of the study.</li> <li>- Control group lecture students found the lectures comparable to previous classes and not as engaging as they would have liked.</li> </ul>
<p><b>3. What, if any, is the relationship between LSBL students, lecture-based students and aerospace industry professionals with regards to their conception and viewpoints of aerospace</b></p>	<p>Traits covered in questions 1 and 2a combined</p>	<ul style="list-style-type: none"> <li>- There is a direct relationship between student views of aerospace and the level of real world engineering experience of the student. LSBL students with no industry experience provided views of design and aerospace engineering comparable to industry experienced students who in turn provide views comparable to professionals in general terms. (Professionals remain a little more nuanced in some responses versus the students)</li> </ul>



engineering design?		<ul style="list-style-type: none"> <li>- Industry experienced students have identified that there is a “gap” between their academic training and what is expected of them when they enter industry. Participants in both the control group and experimental group express this belief.</li> <li>- Strictly leaving preparation up to industry in the form of internships and co-ops does not ensure that the student will receive the best preparatory experience and can have a negative impact on identity as an engineer as exhibited by a control group interviewee</li> <li>- LSBL has been shown to help fill in this gap as described by an industry experienced experimental group student.</li> </ul>
3a. How do LSBL students, lecture based students, and aerospace industry professionals compare on the professional skills of communication and teamwork?	Traits covered in questions 1 and 2a combined	<ul style="list-style-type: none"> <li>- LSBL, Lecture, and Professionals show comparable views of the importance and link between communication and teamwork.</li> <li>- Industry experience outside of the classroom can have a large impact on student abilities in this area and LSBL students have been shown to have comparable skills as those industry experienced students in this study.</li> </ul>
3b. How do predominantly LSBL student design groups and predominantly lecture-based student design groups compare on the professional skill of problem solving as exhibited in an aircraft design project?	Problem solving, collaboration, cost awareness, developing solutions, responsibility for decisions, creativity, analytical skills, understanding design, teamwork	<ul style="list-style-type: none"> <li>- Mostly LSBL and mostly Lecture student composed design groups show comparable aircraft design skills in this study. A mostly experimental group design team developed a concept, design report and presentation that were comparable to a mostly control group design team with a large number of previously experienced (either in design or industry experience) members</li> <li>- Again non-academic experience plays an important part in development of design skills.</li> <li>- All teams developed viable initial concepts.</li> </ul>

Results indicate that the basic aerospace capstone design course does help the students to begin to think like the professionals, at least as can be measured by the instruments in this study. The study results also indicate that the LSBL approach appears to help this transition (also as measured by the instruments used in this study) and the students find it to be engaging. Consistent with the accidental competencies lens, one also finds that for these seniors, the

previous three years of predominantly lecture classes do impact how students view the real world of engineering practice and not necessarily in a positive fashion where students can choose to tune out in class when bored and thus potentially miss out on information that could be useful later. This tendency to “tune out” can come about as students learn habits to get by in class (semi-pay attention and just follow along with the class notes) but not acceptable on the job where potentially lives and money can be impacted by the engineering decisions the now graduate of this system may make.

It is believed that the LSBL approach presented in this dissertation has the potential to be an effective tool in better preparing students to work in industry upon graduation. It has been shown that the literature indicates that there is a gap that students must overcome between their school experiences and working in industry. This gap is due in large part to the cultural differences between academia and industry. Interviews with students in the study, who have had co-op or internship experiences, indicate that they themselves have observed a gap in their preparation for becoming practicing engineers. Interviews also indicate that counting on co-op and internship experiences alone to prepare students for industry is also not necessarily the best way to prepare students as the type of experience the student has can have a great impact on how they approach engineering, where in addition to gaining good skills in communication, teamwork, and how engineering is practiced professionally, the students could also form negative and possibly distorted views of the profession if the student is given unfulfilling work assignments or is paired with a cynical mid-career mentor.

LSBL was proposed and tested to provide a non-academic work world experience that can build the necessary professional and technical skills for a practicing engineer and do it in a realistic but supportive environment. In this environment, mistakes can be made without a high

negative cost and the students can learn from these mistakes and be better prepared for the non-academic work environment. As Sheppard et al. note “like developing physicians, engineering students need experiences in which they can observe and imitate more expert practitioners who guide the novices’ progress through feedback and coaching” (2009, p. 183). The study results indicate that the students are more engaged and begin to think more like working professionals with the LSBL method. They engaged in an experience that built conditionalized knowledge of aerospace engineering design and engineering practice by dealing with a challenging problem and engaging in deliberate practice, with guidance as necessary, (Hoffman & Feltovich, 2010, p. 177) in order to bring them one step closer to expert level engineering performance, thinking and attitudes.

Referring back to Table 2 in Chapter 2 with the desired skills of an aerospace design engineer as expressed by Nicolai and Schrock, we see that the students had an experience (as expressed by them in the interviews) that required them to analyze and develop a strategy to address the requirements (the submersible airplane problem). They developed sketches of their concepts and made the necessary tough decisions for the conflicting requirements of the design problem (efficient aircraft and sea vessel) and had to defend these choices to their teammates and the facilitator. They gained skills with industry tools as they developed initial configuration drawings following sizing of the basic concept and made a presentation of their concept as documentation of their work. It is with these results in mind that it is believed that the live simulation based learning approach should be further pursued and deployed in engineering programs as a way bridge the gap of academia and industry to help better prepare students for their engineering working careers and to be better able to meet the engineering challenges of the 21<sup>st</sup> century.

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**Footnote for Table 1**

<sup>1</sup>Note. Table entries were adapted from:

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*Graduate Attributes and Professional Competencies*, by International Engineering Alliance, 2011. Copyright 2011 by International Engineering Alliance.

*The engineer of 2020: Visions of engineering in the new century*, by National Academy of Engineering, 2004, pp. 53-57. Copyright 2001 by the National Academies Press.

## Appendix A: Sample Experimental & Control Class Material

This appendix contains the Experimental and Control formal class material. See the attached files.

Sample Experimental Class Material:



### Scenario

- Year: 2012
- All of you have just graduated Virginia Tech and have been hired into the aerospace giant *ACE Aero*. *Ace Aero* is a defense contractor first created in the 1990s after the first Gulf War by the company founder Steve “Ace” Carter, an aeronautical engineer and fighter pilot during the War. *Ace Aero* typically hires retired military pilots into leadership positions throughout the company.
- You are all part of the Engineering Leadership Development (ELDP) program. Only those with potential get into this program and it is designed to educate you on all of the engineering aspects of the *ACE Aero* Company. To that end, all “ELDPers” are required to be on rotational job assignments within engineering for two years.
- All of you have just been assigned to the Advanced Design Group for two months.

Figure A1. Scenario for the LSBL exercise.



## Initial Key Design Specifications

- Vehicle will operate in three modes.
  - Platform will transit into theater, insert, extract personnel w/o refueling for total operational range of 1000 nm airborne, 200 nm surface, 24 nm subsurface
- Vehicle will be capable of sea state five between insertion/extraction (up to 72 hours)
- Vehicle will carry 8 operators + equipment (2000 lbs total payload)
- Vehicle will be able to operate at a relatively shallow depth and only have a snorkel affect the free surface
- Vehicle will complete a tactical transit in less than 7.5 hours ("1000 nm+100nm +12nm")

Figure A2. Key Specifications for the submersible vehicle



All,

We just heard from our Business Development (BD) representatives in Washington that DARPA will issue a new Broad Agency Announcement (BAA) for a submersible aircraft. A win on this effort will expand our business base into new areas. I have a copy of a previous BAA related to the effort (one we did not participate in) and I want get everyone together to discuss what it says and how we can use this information to prepare for the new effort. I think this a great opportunity for our ELDPer to see a program from the ground up. Review the old BAA and we'll have a meeting later today to discuss it. Thanks.

John Schwartz

Submersible Airplane Lead

Figure A3. Letter from the Submersible Aircraft Program lead



## Late Breaking News

- Press Release
- Ace Aero has decided to make a strategic decision and will use the Tri-Mode Propulsion System being developed by its Advanced Systems Division.
- The concept is derived from the Dual Mode Propulsion Concept and will allow a vehicle to operate in the air, sea surface, and sub-surface modes.

Figure A4. Notice of Late Breaking News during the exercise.



## Parametric CATIA Model

The image shows a CATIA software interface with a 3D model of a vehicle. On the left, a list of parameters is visible, including wing dimensions, tail dimensions, fuselage lengths, and nose angles. A callout box labeled 'Various Geometry Input & Output Parameters' points to this list. In the center, a 3D model of the vehicle is shown with a red dot representing the center of gravity. A callout box labeled 'Vehicle CG & aerodynamic center' points to this dot. Another callout box labeled 'CAD Model' points to the vehicle model itself. At the bottom left, a 'Master Submersible Airplane Data Sheet' spreadsheet is shown, with a callout box labeled 'Various Inputs used in analysis' pointing to the input columns and another callout box labeled 'Key Outputs' pointing to the output columns.

Figure A5. Design Tool Input Screens.

Sample Control Class Material:

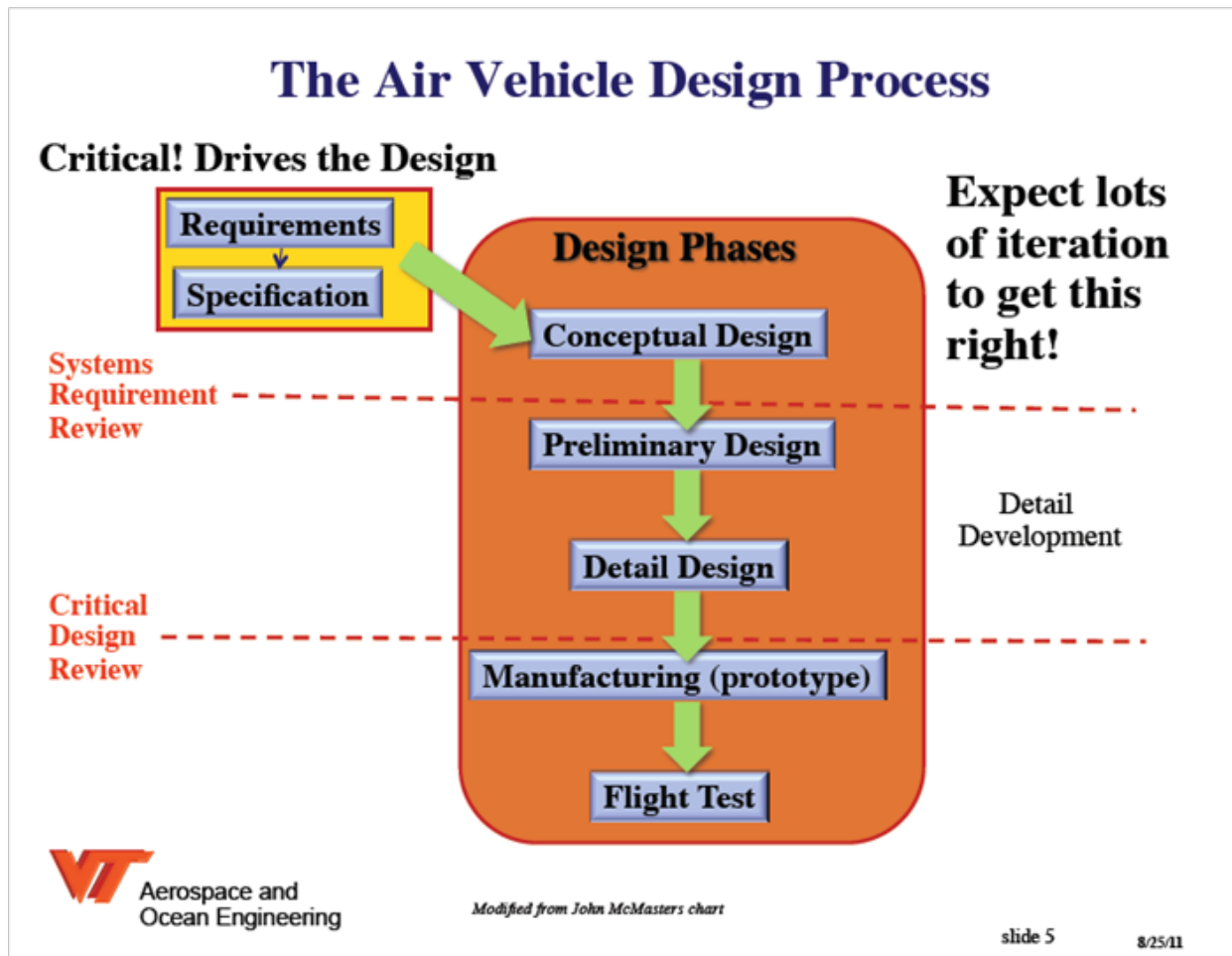


Figure A6. First Day Aircraft Design Process Chart, used with the permission of Mason, William H., 2009 class slides.

## To finish for today: some key thoughts

You may never design an airplane, *but*:

- “shaping up” the problem, figuring out the right questions
- collecting the key information
- making quantitative/qualitative trade studies
  - pro/con tables with quantitative ranking
  - carpet plots/parametric analysis
- using engineering-based analysis to make decisions
- recognizing social, legal and financial considerations
- selecting and refining the preferred concept

These are universally valuable, *this is* engineering

Typically taught only in design?



slide 24

8/25/11

Figure A7. Closing thoughts for Day 1 of the Control classes, used with the permission of Mason, William H., 2009 class slides.

### The Aspect Ratio Trap

$$D = qSC_D = qS \left( C_{D_0} + \frac{C_L^2}{\pi A R E} \right)$$

$$L = W = qSC_L$$

$$\text{or: } C_L = \frac{W}{qS}$$

$$\Rightarrow D = qSC_{D_0} + \frac{1}{\pi E q} \left( \frac{W}{b} \right)^2$$

*Span* plays a bigger role than aspect ratio



slide 26

8/30/11

Figure A8. Aspect Ratio in relation to aircraft design discussion on Day 2, used with the permission of Mason, William H., 2009 class slides.

## To Get $W_{EmptyAvail}$ , 1st Define Mission Segments

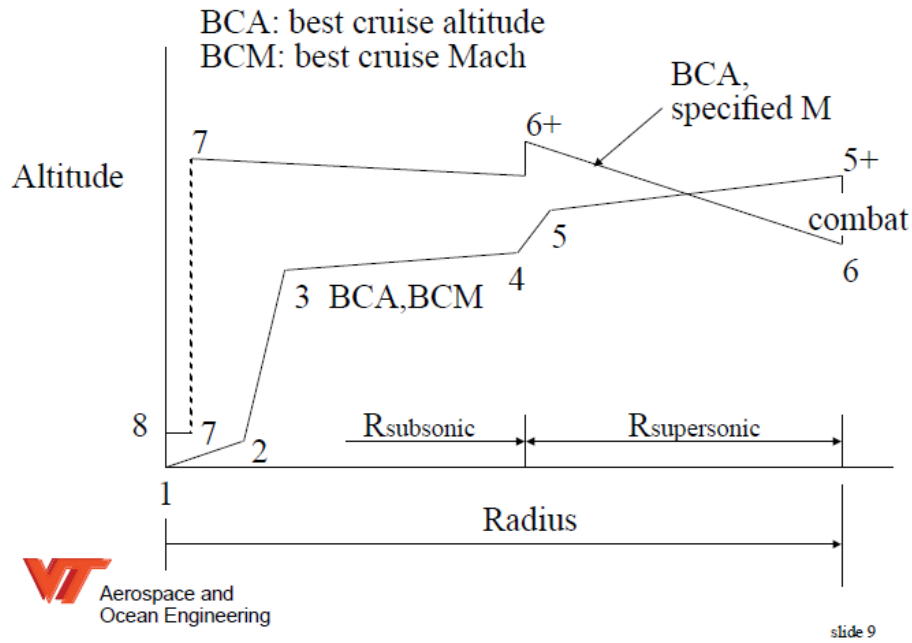


Figure A9. Class material supporting aircraft sizing discussion, used with the permission of Mason, William H., 2009 class slides.

## Now to Get $W_{EmptyAvail}$

- Compute fuel fraction for each segment of mission (only good if you burn fuel, not for electrics!)
- For Range segments (for a jet):

$$R_{i+1} = \frac{V}{sfc} \left( \frac{L}{D} \right) \ln \frac{W_i}{W_{i+1}}$$

**Note: Watch Units!**

or 
$$\frac{W_{i+1}}{W_i} = e^{-\frac{R \cdot sfc}{V(L/D)}}$$

For Loiter Segments (for a jet):

$$E = \frac{1}{sfc} \left( \frac{L}{D} \right) \ln \frac{W_i}{W_{i+1}}$$

or 
$$\frac{W_{i+1}}{W_i} = e^{-\frac{E \cdot sfc}{(L/D)}}$$

VT Aerospace and Ocean Engineering

**Equivalent formulas for props, read Raymer**

slide 11 9/1/11

Figure A10. Additional class material supporting aircraft sizing discussion, used with the permission of Mason, William H., 2009 class slides.

## Aerodynamicist

Defines the “design drivers.” What’s the best configuration to do the required mission from an aerodynamics point of view? Ensure the concept is aerodynamically efficient. Think *streamlined!*

- **Provide the neutral point** to the config designer (VLM Method, etc.).
- **Estimate zero lift drag**, including skin friction, wave, form and misc. drag. FRICTION is available for the skin friction and form drag estimate.
- **Estimate the induced drag**, establish a target span “e.” (LIDRAG, etc.)
- Select the planform and finally the specific airfoils and design the wing (twist) – typically details in the second semester preliminary design
- **Make the drag polars**, and make sure *they are trimmed*.
- Provide estimates of  $C_{Lmax}$  (*trimmed*) for landing and takeoff and **define the high lift concept required** to achieve that  $C_{Lmax}$
- Work with Stability and Control:  $C_{m0}$ , etc.



Does it Trim?

slide 15

9/6/11

Figure A11. Class material supporting discussion on aircraft design team roles, used with the permission of Mason, William H., 2009 class slides.

## Review: Engineering Design Approach

- evaluate (or define) the requirements
  - customers/regulations, constraints/performance goals
  - ask the customer “Why?”- *Communicate*
- understand current approaches (what’s done now?)
- think of some possible solutions (creativity)
- identify a variety of possible concepts (concept generation)
- concept evaluation (analysis)
- select a preferred concept for development (make a decision)
- do the detail design and make a prototype (analysis)
- test and evaluate-scrutinize
- continually refine the design until it’s a viable product

**Many of these steps are repeated, it’s an iterative process**



Figure A12. Last class material reviewing the aircraft design approach, used with the permission of Mason, William H., 2009 class slides.



## **Appendix B: Design Conception Survey**

The following pages contain screen captures of the Design Conception Survey that was administered to the students and professionals on-line using VT Survey. Used with the permission of Adams, Robin S. and Atman, Cynthia J. from the paper *Conceptions of the engineering design process: An expert study of advanced practicing professionals*, presented at the 2005 American Society for Engineering Education Annual Conference & Exposition.

# Aerospace Design Thinking Study 2011

## Instructions:

The goal of this survey is to provide insight into how you think about engineering design. There are no right or wrong answers. Simply select the option or options that best reflect your thoughts relative to the question or statement.

There are three parts to the survey:

Part I is demographic information

Part II involves selecting the most important and the least important activities in design from a provided list of items.

Part III involves 27 Likert Scale items relating to your definition of design.

The survey should take 10 to 15 minutes to complete. All responses are kept secure. Responses are anonymous save for demographic information identifying you as either a student or working professional and the group you may belong to in the study.

## Part I: Demographic Information

Select the category that best describes your role in this study?

- Undergraduate Student - Control Group
- Undergraduate Student - Experimental Group
- Undergraduate Student - Non-participant
- Aerospace Industry Professional
- other:

Which category best describes your level of experience in vehicle design? (If you are a student include co-op and summer internship experiences.)

- <1 year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- >20 years

## Part II: Your Ideas about Design

Of the twenty-three design activities below, put a check mark next to the SIX MOST IMPORTANT.

- a. Abstracting
- b. Brainstorming
- c. Building
- d. Communicating
- e. Decomposing
- f. Evaluating
- g. Generating alternatives
- h. Goal Setting
- i. Identifying Constraints
- j. Imagining

- k. Iterating
- l. Making decisions
- m. Making trade-offs
- n. Modeling
- o. Planning
- p. Prototyping
- q. Seeking Information
- r. Sketching
- s. Synthesizing
- t. Testing
- u. Understanding the problem
- v. Using creativity
- w. Visualizing

Are there any terms that are missing from the list?

**Of the twenty-three design activities below, put a check mark next to the SIX LEAST IMPORTANT.**

- a. Abstracting
- b. Brainstorming
- c. Building
- d. Communicating
- e. Decomposing
- f. Evaluating
- g. Generating alternatives
- h. Goal Setting
- i. Identifying Constraints
- j. Imagining
- k. Iterating
- l. Making decisions
- m. Making trade-offs
- n. Modeling
- o. Planning
- p. Prototyping
- q. Seeking Information
- r. Sketching
- s. Synthesizing
- t. Testing
- u. Understanding the problem
- v. Using creativity
- w. Visualizing

Are there any terms that are missing from the list?

## Part III: Your Definition of Design

Below are a number of statements people have made about design. We expect that different statements will appeal to different people.

In the section below, please indicate the extent to which you agree with the statement provided (i.e., speaks to you, resonates with you, you agree with it, etc.).

Select among the options of:

Strongly Disagree; Disagree; Neither agree nor disagree; Agree; Strongly Agree

**1. Good designers get it right the first time.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**2. Good designers have intrinsic design ability.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**3. In design, a primary consideration throughout the process is addressing the question "Who will be using the product?"**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**4. Visual representations are primarily used to communicate the final design to a teammate or the client.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**5. Engineering design is the process of devising a system, component or process to meet a desired need.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**6. Design in a major sense is the essence of engineering; Design, above all else, distinguishes engineering from science.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**7. Design begins with the identification of a need and ends with a product or system in the hands of a user.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**8. Design is primarily concerned with synthesis rather than the analysis, which is central to engineering science.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**9. ...design is a communicative act directed towards the planning and shaping of human experience. The task of the designer is to conceive, plan, and construct artifacts that are appropriate to human situations, drawing knowledge and ideas from all the arts and sciences.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**10. Design is as much a matter of finding problems as it is of solving them.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**11. In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**12. Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**13. Designing as a conversation with the materials of a situation.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**14. Design defines engineering. It's an engineer's job to create new things to improve society.**

Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**15. Design is not description of what is, it is the exploration of what might be.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**16. Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**17. In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**18. Design is a goal-oriented, constrained, decision-making activity.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**19. Designers operate within a context which depends on the designer's perception of the context.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**20. Creativity is integral to design, and in every design project creativity can be found.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**21. Engineering design impacts every aspect of society.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**22. A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**23. Design is "world" creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**24. Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**25. Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**26. Information is central to designing.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**27. Design is iteration.**

- Strongly Disagree  Disagree  Neither agree nor disagree  Agree  Strongly Agree

**Which statements do you AGREE WITH THE MOST? (Specify the statement numbers.)**

**Which statements do you AGREE WITH THE LEAST? (Specify the statement numbers.)**

### Appendix C: Modified TIDEE Design Rubrics

The following pages contain a modified version of the TIDEE Design Rubrics (Davis, Beyerlein, Thompson, Harrison, & Trevisan, 2009) used to assess the students' design reports and presentations. Used with the permission of Davis, Denny C. from the paper *Assessments for Capstone Engineering Design*, retrieved from [http://www.tidee.org/static/Information\\_Packet\\_TIDEE\\_Capstone\\_Assessments.pdf](http://www.tidee.org/static/Information_Packet_TIDEE_Capstone_Assessments.pdf).

#### Presentation Rubric:

		<b>Team Presentation Rubric</b>				
		<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
		<b>Novice</b>	<b>Beginner</b>	<b>Intern</b>	<b>Competent</b>	<b>Expert</b>
<b>Content</b>	Introduction	Absent, distracting, or inappropriate	Unappealing; incomplete; plain	Interesting; generally adequate	Inviting; largely adequate	Captivating; all aspects attractive
	Message Content	Largely unclear; lacks substance	Portions unclear; little substance	Mostly clear; good substance	Clear; points well supported	Abundantly clear; fully substantiated
	Message organization	Broken, confusing; disorderly	Difficult to follow; aspects unclear	Can be followed; minor confusion	Easily followed without difficulty	Abundantly clear; intuitive, engaging
	Conclusion	Absent or only inferred	Weak; largely missing; vague	Satisfactory; basic summary	Good summary, presents case	Gripping summary and call to action
<b>Visual Aids</b>	Quality	Poor; misleading	Ok; little information	Good; informative	Good; instructional	Superb; insightful
	Utilization	Very distracting	Minor distraction	Neutral to message	Aids message	Empowers message
<b>Impact</b>	Understanding	Very distracting	Minor distraction	Neutral to message	Aids message	Empowers message
	Audience response	Reject proposal	Not likely to act	May act favorably	Will act favorably	Embrace proposal
<b>Additional Comments:</b>						

#### Design Report Rubrics:

		<b>Executive Summary</b>				
		<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
		<b>Novice</b>	<b>Beginner</b>	<b>Intern</b>	<b>Competent</b>	<b>Expert</b>
<b>Problem or Opportunity</b>		Uninformed; too broad, narrow, or off-target	Vague understanding; questionable details	Fair understanding; some reputable detail	Good understanding; substantive good detail	Superb understanding; extensive proven detail
<b>Solution Envisioned</b>		Very vague idea; no vision for applicability	General idea; simple vision for usefulness	Good idea; reasonable vision for usefulness	Feasible solution; good vision for usefulness	Superb solution; clearly useful, feasible
<b>Benefits of Solution</b>		Unlikely or very limited benefits possible	Small benefits; very narrow beneficiaries	Moderate benefits; narrow beneficiaries	Good benefits; multiple varied beneficiaries	Many varied benefits; many beneficiaries
<b>Writing Quality</b>		Many errors; not understandable	Several errors; unclear; not interesting	Few errors; clear; somewhat interesting	Very few errors; clear; very interesting	Error-free; clear; highly attractive, compelling

		<i>Stakeholder Needs</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
<b>Understanding Needs</b>	<b>Users</b>	Narrow and very shallow grasp	Somewhat narrow and shallow grasp	Good grasp, possibly narrow or shallow	Very good grasp; few minor gaps remain	Thorough grasp; defensible data
	<b>Financial</b>	Narrow and very shallow grasp	Somewhat narrow and shallow grasp	Good grasp, possibly narrow or shallow	Very good grasp; few minor gaps remain	Thorough grasp; defensible data
	<b>Technical</b>	Omitted most or all important members	Included few important members	Included some important members	Included most key & some other members	Expertly sampled keymembers & others
	<b>Social</b>	Omitted most or all important members	Included few important members	Included some important members	Included most key & some other members	Expertly sampled keymembers & others

		<i>Concepts Generated</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
<b>Concepts</b>	<b>Number of Ideas</b>	Very few (1)	Small number (2)	Moderate (~5)	Many ideas (~10)	Very Many ideas (>10)
	<b>Relevance to Needs</b>	Vaguely related to overall need, not to components	Vaguely related to overall & few component needs	Moderately related to overall & some component needs	Clearly related to overall and most component needs	Well focused on overall and all keycomponent needs
	<b>Creativity in Ideas</b>	Little or no creativity evident in ideas	Moderate creativity in a few ideas	Moderate creativity in several areas	Good creativity in several areas	Impressive creativity in many areas
<b>Sources</b>	<b>External</b>	Little or no use of external sources	Very few outside sources used	Moderate use of few outside sources	Good use of several outside sources	Effective use of many outside sources
	<b>Internal</b>	Very little use of team and members	Moderate use of team or individual members	Moderate use of team & individual members	Good use of team & individual members	Effective, synergistic use of team members

		<i>Solution Specifications</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
<b>Quality</b>	<b>Clarity</b>	Ill-defined; not measurable	Vague; general expectations	Ok description, not quantitative	Clear targets, some measurable	Specific measurable performance targets
	<b>Abstractness</b>	Prevents any creativity, flexibility	Limits creativity and flexibility	Allows some creativity, flexibility	Enables creative approaches	Encourages creative approaches
<b>Completeness</b>	<b>Functionality</b>	Ignores most important needs	Addresses few important needs	Addresses several important needs	Addresses most vital needs, some others	Addresses all vital, many other needs
	<b>Financial</b>	Ignores financial needs, opportunities	Vaguely mentions cost limitations	Sets cost limits for project budget	Sets project budget and ROI target	Sets budget, ROI; targets opportunities
	<b>Feasibility</b>	Ignores most important issues	Addresses few important issues	Addresses several important issues	Addresses most vital issues, some others	Addresses all vital, many other issues
	<b>Social Impact</b>	Ignores major social & safety issues	Vaguely mentions social, safety issues	Defines some social, safety requirements	Cites important codes for compliance	Embraces all relevant codes & standards

		<i>Concept Selected</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
<b>Description</b>	<b>Clarity</b>	Vague, confusing; not understandable	Some parts ok; some parts unclear	Generally understandable	Overall and parts understandable	Very clear; gives deep understanding
	<b>Integration</b>	Relationship among parts very confusing	Several parts do not seem to fit the whole	Most parts fit into a working whole	All parts fit into an integrated whole	Integration of parts is effective, beautiful
	<b>Function</b>	No explanation how function will be met	Inferences that function will be met	Simple analysis that function will be met	Good analysis predicts function met	Solid case proves function will be met
<b>Justification</b>	<b>Financial</b>	No mention of solution finances	Unjustified claims that costs reasonable	Uses costs to justify concept	Uses cost/benefit to justify concept	Uses life-cycle cost/benefit of concept
	<b>Technical</b>	Ignores technical/ feasibility of concept	Lightly discusses feasibility of concept	Defends at least one aspect of feasibility	Defends multiple aspects of feasibility	Strong evidence for key feasibility aspects
	<b>Social</b>	Ignores social, legal, safety issues	Vaguely explains one social dimension	Defends concept in multiple social areas	Good defense in key social dimensions	Solid defense in all key social dimensions

		<i>Proposed Solution</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
	<b>Functions considered</b>	Very few, little breadth	Few, some breadth	Several, good breadth in types	Many, good breadth and measures	Many, insightful breadth & measures
<b>Proof of Performance</b>	<b>Analysis</b>	No analysis; opinions only	Little analysis; vague inferences	Some analysis; simplistic methods	Good analysis; valid methods	Extensive analysis; best methods
	<b>Strength of evidence</b>	No evidence to support claims	Shallow evidence to support claims	Good evidence for some claims	Good evidence for all critical claims	Defensible evidence for important claims
	<b>Development costs</b>	Major concern; not defined	Moderate concern; weak justification	Minor concern: need clarification	Reasonable; good justification	Attractive; sound; fully justified
<b>Proof of Profitability</b>	<b>Cost/benefit ratio</b>	Major concern; not defined	Moderate concern; weak justification	Minor concern: need clarification	Reasonable; good justification	Attractive; sound; fully justified
	<b>Market Potential</b>	Lacks potential to fit a market	Minor potential to fit a market	Some potential to reach a market	Good potential to serve a market	Likely to serve a growing market
	<b>Producibility</b>	Major concern; known problems	Moderate concern; expected problems	Minor concern: possible problems	No concern; known problems solved	Attractive; methods fully documented
<b>Proof of Feasibility</b>	<b>Useability</b>	Major concern; known problems	Moderate concern; expected problems	Minor concern: possible problems	No concern; known problems solved	Attractive; usability fully documented
	<b>Serviceability</b>	Major concern; known problems	Moderate concern; expected problems	Minor concern: possible problems	No concern; known problems solved	Attractive; servicing fully documented
	<b>Environment</b>	Possible serious negative impacts	Possible moderate negative impacts	Possible minor negative impacts	Likely only positive impacts	Certainly only positive impacts
<b>Proof of Impact</b>	<b>Legal/political</b>	Possible serious negative impacts	Possible moderate negative impacts	Possible minor negative impacts	Likely only positive impacts	Certainly only positive impacts
	<b>Health &amp; safety</b>	Possible serious negative impacts	Possible moderate negative impacts	Possible minor negative impacts	Likely only positive impacts	Certainly only positive impacts

		<i>Written Communication</i>				
		1	2	3	4	5
		Novice	Beginner	Intern	Competent	Expert
	<b>Completeness</b>	Major sections absent/incomplete	Several crucial elements omitted	Nearly complete; some omissions	Largely complete; minor omissions	Complete in every detail
<b>Content Effectiveness</b>	<b>Organization</b>	Unclear; confusing	Difficult to follow	Can be followed	Easy to follow	Intuitive, inviting
	<b>Effectiveness</b>	Nearly pointless	Unclear message	Understandable	Credible, effective	Explicit, compelling
<b>Writing Mechanics</b>	<b>Grammar, spelling, etc.</b>	Many serious errors	Several errors	Few errors	Almost perfect	Flawless
	<b>Style and tone</b>	Inappropriate	Distracting	Acceptable	Effective	Tuned to reader
<b>Professional Standards</b>	<b>Crediting</b>	No citations or all incomplete	Inadequate number and quality	Adequate in number and/or quality	Good number, quality, and use	Credible, complete; proficient use
	<b>Appearance</b>	Unacceptable	Amateurish	Common	Appealing	Professional

### Additional Comments:



## Appendix D: Interview Protocol

The following is a complete list of interview questions asked during the study. Students were asked the entire list while professionals were asked questions 8 through 17.

1. What did you like about the design exercise classes?
2. What did you not like about the design exercise classes?
3. Do you feel the experience has given you insight into being a practicing aerospace design engineer?
4. Can you give examples of the type of insight you've gained?
5. How did this experience compare to previous AOE classes that use traditional lecture methods such as slides?
6. Would you want other aerospace engineering classes to use this approach if applicable?
7. If you could design the simulation experience, how would you change it?
8. Briefly describe the aircraft design process?
9. Tell me about the importance of requirements and specifications in design?
10. Briefly tell me what kind of importance do you feel teamwork plays in design?
11. Tell me about the role analysis plays in design?
12. Does compromise play a role in design? If so what?
13. Are trade studies important? Why?
14. You answered a survey where you were asked to select the six most important and the six least important design activities (see list below). Looking at the list again, select what you consider to be the single most important design activity and the single least important design activity and explain your selections.

Abstracting

Brainstorming

Building

Communicating

Decomposing

Evaluating

Generating alternatives

Goal Setting

Identifying Constraints

Imagining

Iterating

Making decisions

Making trade-offs

Modeling

Planning

Prototyping

Seeking Information

Sketching

Synthesizing

Testing

Understanding the problem

Using creativity

Visualizing

These last questions are meant to elaborate upon some of the questions on the questionnaire that you answered on-line. Just briefly tell me what you thought when you read these questions.

15. Good designers have intrinsic design ability.
16. Design is as much a matter of finding problems as it is of solving them.
17. A critical consideration for design is developing products, services and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.

## Appendix E: Design Conception Survey Part 1 Results

Following is a table of all of the Design Conception Survey results from each of the administrations of the survey to the students and the aerospace industry professionals. The most and least important design activities are ranked in order based upon the selections of the respective participant group. The “m” and “l” in front of each design activity refer to “most” and “least”, respectively. (Thus “mdecomposing” refers to “decomposing, most list” and “lcommunicating” refers to “communicating, least list” etc.) The total number of respondents (n) for each administration of the survey is listed at the top of each table along with the number of respondents selecting a particular design activity as most or least important listed to the right of the activity. For example, in the case of the experimental group Pre-Test, 15 of the 18 respondents thought understanding the problem was the most important design activity.

Experimental_pretest		n=18		Experimental_posttest1		n=18	
mdecomposing	0	lcommunicating	0	mbuilding	0	lgoal setting	0
mimagining	0	lplanning	0	mimagining	0	lmake decision	0
msketching	0	lunderstand problem	0	mprototyping	0	lunderstand problem	0
msynthesizing	0	lbrainstorming	1	mvisualizing	0	lcommunicating	1
mvisualizing	1	levaluating	1	mabstracting	1	levaluating	1
mabstracting	2	lgoal setting	1	mdecomposing	1	lid constraints	1
mbuilding	2	lid constraints	1	msynthesizing	1	lseeking info	1
miterating	2	lmake decision	1	mevaluating	2	lbrainstorming	2
mprototyping	2	lmodeling	1	miterating	3	lgenerating alts	2
musing creativity	2	lseeking info	1	mplanning	3	lplanning	2
mgenerating alts	3	lmake trade-off	2	musing creativity	3	lmake trade-off	3
mseeking info	3	ltesting	2	msketching	4	lmodeling	3
mmake decision	4	lusing creativity	3	mtesting	4	ltesting	3
mevaluating	5	lprototyping	4	mgenerating alts	6	literating	4
mmake trade-off	6	lgenerating alts	6	mmodeling	6	lsketching	6
mmodeling	6	lbuilding	7	mmake trade-off	7	lusing creativity	6
mplanning	6	literating	8	mseeking info	7	lvisualizing	7
mgoal setting	8	lsynthesizing	10	mmake decision	8	lprototyping	8
mid constraints	9	lvisualizing	10	mbrainstorming	9	limagining	9
mtesting	9	ldecomposing	11	mgoal setting	9	lbuilding	10
mcommunicating	10	limagining	11	mcommunicating	10	ldecomposing	10
mbrainstorming	11	lsketching	11	mid constraints	10	lsynthesizing	12
munderstand problem	15	labstracting	14	munderstand problem	14	labstracting	14

Experimental_posttest2		n=17		Experimental_posttest3		n=13	
mabstracting	0	lbrainstorming	0	mabstracting	0	lcommunicating	0
mbuilding	0	lcommunicating	0	mbuilding	0	levaluating	0
mdecomposing	0	levaluating	0	mdecomposing	0	lgoal setting	0
mimagining	0	lid constraints	0	mimagining	0	lid constraints	0
msynthesizing	0	lmake decision	0	mprototyping	0	lseeking info	0
mtesting	0	lunderstand problem	0	msketching	0	lunderstand problem	0
mprototyping	1	lgoal setting	1	mmodeling	1	literating	1
msketching	1	lseeking info	1	msynthesizing	1	lmake decision	1
mvisualizing	1	lplanning	2	mtesting	1	lmake trade-off	1
mbrainstorming	2	ltesting	2	mvisualizing	1	lgenerating alts	2
mmodeling	2	lgenerating alts	3	mbrainstorming	2	lplanning	2
musuing creativity	2	literating	3	musuing creativity	2	lbrainstorming	3
mmake trade-off	5	lmake trade-off	3	mevaluating	3	lmodeling	3
mplanning	6	lusing creativity	3	mgenerating alts	3	ltesting	4
mgenerating alts	7	lmodeling	4	mliterating	3	lusing creativity	4
mgoal setting	8	lvisualizing	4	mmake trade-off	5	lbuilding	5
mliterating	8	lsketching	6	mseeking info	5	lsketching	5
mmake decision	8	limagining	8	mgoal setting	6	limagining	6
mseeking info	8	labstracting	10	mplanning	6	labstracting	7
mcommunicating	9	lbuilding	10	mlid constraints	8	lprototyping	7
mevaluating	10	lsynthesizing	11	mmake decision	9	lvisualizing	8
mlid constraints	10	lprototyping	12	mcommunicating	11	ldecomposing	9
munderstand problem	13	ldecomposing	14	munderstand problem	11	lsynthesizing	9

Control_pretest	n=35		Control_posttest1	n=35			
mabstracting	0	lid constraints	0	mabstracting	0	lmake decision	0
mdecomposing	0	lunderstand problem	0	mdecomposing	0	lunderstand problem	0
msynthesizing	1	levaluating	1	mimagining	1	lcommunicating	1
mvisualizing	1	lbrainstorming	2	mprototyping	1	lbrainstorming	2
mbuilding	2	lgoal setting	2	mbuilding	2	levaluating	2
mimagining	2	lmake decision	2	msketching	2	lgoal setting	2
msketching	2	ltesting	2	msynthesizing	2	lid constraints	3
mprototyping	3	lcommunicating	3	mvisualizing	3	lplanning	4
mgenerating alts	4	lplanning	3	mgenerating alts	5	ltesting	6
mliterating	4	lgenerating alts	5	mmodeling	5	lgenerating alts	7
musng creativity	4	lseeking info	6	musng creativity	5	literating	7
mmodeling	9	lmodeling	7	mvaluating	7	lmake trade-off	7
mmake decision	10	lmake trade-off	8	mmake trade-off	8	lseeking info	8
mseeking info	10	lusing creativity	8	mtesting	10	lmodeling	10
mmake trade-off	11	literating	9	mseeking info	12	lprototyping	12
mbrainstorming	12	lprototyping	9	mmake decision	15	lusing creativity	12
mvaluating	14	lbuilding	14	mplanning	15	lbuilding	13
mplanning	16	lsketching	16	mgoal setting	16	lsynthesizing	13
mid constraints	18	lsynthesizing	18	mliterating	16	limagining	18
mgoal setting	19	lvisualizing	21	mbrainstorming	17	lsketching	18
mcommunicating	21	limagining	24	mid constraints	19	lvisualizing	19
mtesting	23	ldecomposing	25	mcommunicating	21	labstracting	21
munderstand problem	25	labstracting	26	munderstand problem	25	ldecomposing	23

Control_posttest2		n=35		Control_posttest3		n=25	
mabstracting	0	lcommunicating	0	mdecomposing	0	levaluating	0
mdecomposing	0	lid constraints	0	mprototyping	0	lid constraints	0
mprototyping	0	lunderstand problem	0	mbuilding	1	lmake decision	0
msketching	0	lmake decision	1	mgenerating alts	1	lunderstand problem	0
mimagining	1	lseeking info	2	msynthesizing	1	lgoal setting	1
mbuilding	2	lgoal setting	3	mabstracting	2	lmake trade-off	1
msynthesizing	2	levaluating	4	mimagining	2	lcommunicating	2
mvisualizing	3	literating	4	msketching	2	lplanning	2
mgenerating alts	4	lplanning	4	mvisualizing	2	literating	3
musng creativity	5	lbrainstorming	5	mbrainstorming	4	lseeking info	3
mmodeling	6	ltesting	6	musng creativity	4	ltesting	3
mplanning	8	lgenerating alts	7	mmodeling	5	lbrainstorming	5
mtesting	8	lmake trade-off	7	mtesting	5	lgenerating alts	6
mmake trade-off	9	lusing creativity	8	mseeking info	8	lusing creativity	8
mbrainstorming	11	lmodeling	9	mliterating	9	lvisualizing	8
mevaluating	13	lsynthesizing	15	mmake decision	9	lmodeling	9
mseeking info	15	lvisualizing	15	mmake trade-off	10	lsketching	10
mliterating	16	lsketching	16	mplanning	10	lprototyping	12
mgoal setting	18	lprototyping	17	mevaluating	11	lsynthesizing	13
mmake decision	18	limagining	18	mgoal setting	13	limagining	15
mid constraints	21	lbuilding	22	munderstand problem	16	lbuilding	16
munderstand problem	21	labstracting	22	mid constraints	17	ldecomposing	16
mcommunicating	27	ldecomposing	24	mcommunicating	19	labstracting	17

Professional		n=20	
mabstracting	0	lcommunicating	0
mbuilding	0	lid constraints	0
mdecomposing	0	lunderstand problem	0
mprototyping	0	lgenerating alts	1
mimagining	1	literating	1
msketching	1	lmake decision	1
msynthesizing	2	levaluating	2
mevaluating	3	lmake trade-off	2
mtesting	3	lusing creativity	2
mgoal setting	4	lmodeling	3
mliterating	4	lgoal setting	4
mmodeling	4	lplanning	4
mbrainstorming	5	lseeking info	4
mplanning	5	ltesting	4
mvisualizing	5	lbrainstorming	5
mseeking info	6	lvisualizing	5
mgenerating alts	7	lprototyping	9
mmake decision	7	lsketching	9
musng creativity	7	lsynthesizing	9
mcommunicating	12	lbuilding	11
mid constraints	14	limagining	11
munderstand problem	14	ldecomposing	12
mmake trade-off	15	labstracting	18

## Appendix F: Outside Observer Letter

Below is an excerpt from a letter from the study observer Dr. C. Edward Watson, Associate Director for CIDER.



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September 9, 2011

W. Michael Butler  
Department of Engineering Education  
Virginia Tech  
Blacksburg, VA 24061-0218

Dear Michael,

I was asked to observe two AOE design classes as part of your dissertation experiment. On August 30, I attended the class you led that employed a problem-based learning instructional approach. On September 6, I attended the class led by Dr. Mason that employed a traditional lecture with PowerPoint approach. My charge was to take note of any instructor style issues that could impact the results of the study. What follows are my observations.

Given that the instructional treatments in both classes were very different, the approaches of the instructors varied greatly. Your approach was far more interactive. Dr. Mason rarely interacted with the students, though on three occasions, he posed questions and engaged in brief dialogue with a student in the front row of the class.

While both instructors evoked their professional experiences beyond higher education in meaningful ways throughout their instruction, Dr. Mason was ultimately more remote and seemingly less approachable than you. I could imagine that some students might feel somewhat intimidated by him. This might be due partly to his age and demeanor, but Dr. Mason's instructional approach likely magnified this perception, further reducing engagement by students in his lecture-based class. Comparatively, you were quite warm, approachable, open to questions, and shared context-specific information in response to the work students were doing. In truth, these are key characteristics and strategies of those who successfully employ problem-based learning.

While the instructional approach certainly impacted student behaviors in these classes, one might argue that any significant learning differences discerned between the two classes could be partly attributed to the aforementioned classroom persona/personality differences of the two instructors; however, similar personality differences might be perceived between any two instructors employing the two instructional strategies in question.

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Figure F1. Excerpt of letter from an outside observer of the study classes.

## Appendix G: Pilot Study Report

Participants in this pilot study, as in the dissertation study, were AOE seniors enrolled in aircraft capstone design. The population of the class was 55 students. Of the 55 students, the simulation study had a sample size of 25 students (24 males and one female). IRB approval of the research was required for the study. Though the sample size of 25 participants fell short of the, Rea and Parker (2005) suggestion of a sample size of around 28 students, it was felt that the study would provide valuable information on the simulation experiment design and provide an indication of results that may be encountered in the later rerunning of the experiment.

Participants were randomly assigned to the control and experimental groups with the control group consisting of 10 students (all male) with the remaining 15 in the Experimental group (14 male and 1 female). Of these students 10 had previous engineering experience as co-ops or interns while 5 had family members or family friends that were design engineers.

The experiment utilized the *Pre-Test-Post-Test Control Group Design* with a mixed methods research approach. Quantitative data was obtained through the use of a questionnaire along with qualitative data obtained through semi-structured interviews. As with the conducted dissertation research, the questionnaire instrument was applied to members of industry who have worked as aircraft design engineers. The responses of the industry professionals formed a benchmark upon which the results of the students were compared. The experiment was conducted over four class periods during the beginning of the design course. Students in the experimental group met in the Virginia Tech Ware Lab while those in the main class and the control group, met in a conventional classroom.

The simulation utilized the same background story of the fictional large defense contractor with the students playing new hires rotated into the Conceptual Design group. The



instructor served the role of facilitator/supervisor for the experiment. The simulation itself used CATIA and the students were introduced to ModelCenter®. Instead of the sizing program FLOPS, the students used the aircraft analysis tool Tornado, a visual vortex lattice method program used in design at the university level. This combination of tools was used by the students to develop an uninhabited aerial vehicle (UAV) that had the maneuverability of a manned fighter like the F-16.

The simulation had four stages: requirements development, brainstorming, conceptual level design analysis and CAD model development, and concept presentation. Instead of a real BAA, a mock Request for Proposal (RFP) was used. The students formed teams and worked with a parameterized CATIA aircraft model geared for the UAV design task and a combination of spreadsheet sizing tools in addition to the *Tornado* program for aircraft analysis. Students in the control group received formal instruction on the same topics using the lecture method. The material was presented by an experienced aircraft design professor with some aerospace industry experience.

A review of the literature at the time of the study had not revealed the existence of a proven close-ended questionnaire instrument designed to assess student's overall design thinking and professional skills. As a result, for the pilot study, a new instrument was created called the Professional Skills Questionnaire (PSQUES). The goal of this instrument was to provide a way to assess design thinking and professional skills in a format that would not take long for respondents to complete. The instrument was designed using findings of a combination of previous studies exploring the differences of experts versus novices along with addressing the desired traits that the aerospace industry has expressed as being desired in new engineers in the papers by Nicolai (1998) and McMasters (2006). This 23 item instrument contained a

combination of knowledge assessment questions and 11 opinion related questions using a Likert 5-point scale requiring the individual to consider the relative importance of a variety of topics encountered in design such as “awareness of trade-offs” and “cost.” The responses to these 11 Likert scale items relating to design were analyzed.

The PSQUES was also taken by 13 aerospace engineering professionals in order to provide a benchmark. An expert panel was employed to review the instrument and partially address the reliability of this new tool. The panel provided recommendations on ways to improve upon the initial instrument and the pilot study provided the initial field testing of this combination assessment and survey approach. Given the newness of the PSQUES, its complete reliability and validity were still being determined at the time of the pilot study. The PSQUES was administered manually as the participants filled out paper copies of the survey during the regularly scheduled design class time. These surveys were then collected before the end of class and the data was input into electronic form for subsequent analysis.

SPSS was used to analyze the Likert scale items contained on the PSQUES and given the small sample size, non-parametric testing using the independent samples Kruskal-Wallis method and the Related Samples Wilcoxon Signed Ranks test were used in analysis. Interviews were conducted using 12 of the same interview protocol questions that are proposed for this study. The interviews were reviewed to determine common themes among the interviewees.

Results of the Kruskal-Wallis Test for independent samples evaluating the experiment, control, and industry groups pre-intervention showed none of the 11 items to be statistically significant (with a 95% confidence level) except the for the item “Awareness of trade-offs / Design space exploration” where  $H(2) = 7.586$ ,  $p = 0.023$  (two-tailed). The significant pairing here was between the industry and the control groups. The Kruskal-Wallis Test between the

experiment, control, and industry groups post-intervention again showed none of the 11 items to be statistically significant (to the 95% confidence level) save for the item “Awareness of trade-offs / Design space exploration” where  $H(2) = 10.011$ ,  $p = 0.007$  (two-tailed).

Results of the Related Samples Wilcoxon Signed Ranks Test for related samples, examining only the control group before and after the intervention, indicated no statically significant difference between the two test periods for this group. In the case of the experimental group, there were also no statistically significant differences (to the 95% confidence level) between the test periods save for the two items of “Cost” and “Manufacturing” where  $Z = -2.807$ ,  $p = 0.005$  (two-tailed) for cost and  $Z = -2.124$ ,  $p = 0.034$  (two-tailed) for manufacturing.

The interviews revealed a positive response to the simulation experience by the experimental group. Common themes that appeared in the transcripts for the experimental group students were a preference for learning situations where the students could have “hands on experience.” A number of students expressed a personal preference for “learning by doing.” A uniform complaint was that the students felt the exercise was too short and rushed at times. (This became an expected complaint for the dissertation research study given its short duration.) The students desired more time to work with the tools such as CATIA. When asked if the students would prefer the simulation approach in other classes, uniformly the respondents felt that though this approach was great for design, it was not really appropriate for classes such as mathematics and there was a stated preference, in those instances, for the traditional lecture and teacher-centered approach most often used today. When asked to describe the basic aircraft design process, the experimental group interviewees tended to recall aloud the events of the exercise as the way to describe the process. One student when describing the experience stated that “instead of just sitting there reading off line after line...this is the design process, this is

what you do...we actually went through and did part of the design process. You know, little tidbits of it...I think I remember it better that way.”

Control group interviewees showed a comparable level of content knowledge to the experimental group when asked to describe the aircraft design process. A common theme among this group was a dislike for “being talked at” in a lecture format for extended periods of time. One student described the experience as “just having to sit there and being bombarded” while another mentioned “information overload.” Students indicated that they had been exposed to a number of different aspects of design and heard some rules of thumb by the instructor during the exercise but that hours on end of PowerPoint slide material could be boring. A number of students welcomed more interaction with the instructor while one member of the control group suggested that for future design classes that it would be beneficial to have a small design exercise at the beginning of the term to become familiar with the basics of aircraft design before beginning work on their major design projects for the class.

When asked about the importance of teamwork and compromise in aircraft design, both groups equally considered both items to be critical for design success. A student in the control group when speaking of teamwork stated “I think one of the biggest most important factors in good quality original design is having multiple angles of attack, so to speak. And I don’t think anybody can cite me an aircraft that’s actually been designed and built from the ground up by one person.” Both groups viewed analysis as being interrelated with design and as a way to validate one’s design and assumptions.

The results of the live simulation approach were promising. It was conjectured that differences in the quantitative results between groups from the PSQUES may have been due to the fact that the experimental group students had the experience of having to make trade-offs and

consider the design space, cost and manufacturing impacts during the exercise whereas the control group students were only exposed to those topics and told of their importance. Though there were not many statistically significant differences between the participants as measured with the PSQUES, there was a clear and understandable preference for educational experiences that were more engaging.

It was found that some in the control group wanted more interaction with the instructor as opposed to being lectured to, indicating a desire for a fuller class experience than the classic lecture style approach. Students in both approaches successfully learned the aircraft design process as a procedure that could be stated, but the experimental group students appeared to have gained the additional insight to a process that is usually gained through having real experience with the process. It is this insight that is a key part of the experienced engineer's repertoire and is sought by industry.