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An Experiment in Live Simulation-Based Learning in Aircraft Design and its Impact on Student Preparedness for Engineering Practice

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Abstract

In the near future, engineering practice in America will be at a crossroads as a large portion of the engineering workforce, the baby boom generation, retires. Filling the void created as a result of this exodus of talent and experience in a timely manner will be challenging. Coupled with this pending shortfall in talent and experience is a belief by some that the scientist engineer approach to training young engineers, developed in the early 20th century and followed by most American engineering programs today, does not fully meet the needs of the 21st century industrial environment. This creates a "gap" in engineering student preparation. Some in industry and academia feel that this model of engineer preparation needs to change in order to better address today's industrial work world complexities. A new model for student preparation, centering on engineering design, called the Live Simulation Based Learning (LSBL) approach was developed based upon the theories of situated learning, game-based learning, epistemic frames, and accidental competencies. Quantitative and qualitative results of a study of the application of LSBL in a two term capstone design class in aerospace engineering aircraft design are discussed with emphasis on the impact of the approach on student's design related professional and technical skills as measured by multiple survey applications and one-on-one interviews. Results indicate that the participants found the LSBL experience to be more engaging than the traditional lecture approach and did help students respond and begin to think more like aerospace engineering practicing professionals. It is felt that such efforts begin to address the "gap" between academia and industry.

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. 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. This paper explores the origins of this disconnect or gap and proposes and presents results of an attempt to address this problem called the Live Simulation Based Learning (LSBL) approach. A more in depth discussion of this LSBL study and approach may be found in the dissertation entitled *The Impact of Simulation-Based Learning in Aircraft Design on Aerospace Student Preparedness for Engineering Practice: A Mixed Methods Approach*.[1]

Background: Engineering Education's Evolution in America

Engineering, as with many professions, is evolving as it responds to the constantly changing 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 provides an excellent synopsis of the changes in American engineering education from the late 1800s to 1965.[2] 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. 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.[2] 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. This new emphasis was furthered with the release of the Grinter Report in the 1950s and the trend continued in engineering education into the 1990s.[3] By then 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."[4]

Industry requested changes to the engineering curriculum in order to handle the mismatch between their needs and the skill sets of engineering graduates.[5] 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.[6] 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."[7] Universities have adopted capstone design courses to address this requirement. Among the modern teaching approaches adopted by some programs is project based learning (P_JBL) which is a student centered approach that emphasizes "the development of cognitive and practical skills" as students typically produce a product design or process as part of the course.[8]

Results of this change have been mixed. Lattuca et al. 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. In the same study, however, it was also found that these same employers, thought that engineering programs needed to pay more attention to building skills, such as communication, teamwork and use of modern engineering tools.[6] They also noted that graduates lacked the understanding of constraints and the context of their work. 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. They expressed a concern for an acceleration of the "disconnect between the system of engineering education and the practice of engineering."[9] This acceleration of the disconnect was and is 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.[9] In 2011, Dunsmore, Turns, and Yellin noted that this concern continues and that there is "a desire for students to emerge from their degree programs thinking more like working engineers."[10]

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. Such sentiments have been expressed by major defense contractors such as Boeing.[11] Why is the present outcomes-based accreditation system not quite 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?

Study Purpose

The intent of this study was to better understand the impact of simulation based learning environments that emphasize "realism through simulation" on capstone design students' conceptions and views of engineering design (and indirectly engineering as whole). A model for live simulation based learning (LSBL) based in educational theories such as situated learning was proposed and tested on an aerospace engineering capstone design class at Virginia Tech.

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. 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.[12] Engineers help to make all of this happen and are considered one of the company's key resources.

The present day model of engineering education tends to emphasize engineering science where engineering classes and design are taught only after a solid background in science and mathematics has been established. 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."[13] 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.[13]

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.

The Competency Dilemma

Walther and Radcliffe examined the gap between academia and industry and proposed a reason behind it.[14] They named 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. 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.[14] These differences in culture clash in the implementation of the outcomes-based form of accreditation.

Walther and Radcliffe 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.[15] 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 are unintended consequences of the curricular environments in which engineers are educated while accidental competencies are "abilities important to performance in professional practices that are not linked to targeted instruction of the stated learning outcomes of the course."[15]

An example of a critical incident involving accidental in-competency is discussed in the Walther & Radcliffe 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."[14] 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.[14] 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.

Alternative Approaches to Address the Gap

In response to the continued concerns in student preparation, there have been a number of efforts which have attempted to change the field. On the institution level, the efforts include the *Learning Factory*, the *Conceive, Design, Implement, Operate* (CDIO) Initiative, and Singapore's new engineering university centering on innovation and design called the Singapore University of Technology and Design (SUTD). These efforts have attempted to change or establish an engineering program where tailored design labs and/or a new curriculum are employed in an effort to produce more industry ready graduates.[16,17,18,19] On a smaller scale, the Boeing A.D. Welliver Faculty Summer Fellowship program was created to expose a small number of competitively selected professors from U.S. and international universities to the key elements and the business realities of industry.[20,21] All of these efforts have recognized a need for and have attempted to build a better connection between academia and industry. In some cases the full impact of the changes 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.

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 mentioned approaches that could be deployed now and make a positive 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 be very effective.

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."[22] Live simulations involve real people operating real systems. This portion of the review solely examines 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 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. Fletcher 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."[23] 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 needed to be remedied quickly. Live simulation has also played a role in the training of medical personnel in the military. Johnson, Flagg, and Dremsa 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.[22] Ziv, Wolpe, Small, and Glick present a commentary on the benefits of simulation-based medical education (SBME).[24] Steadman et al. 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.[25]

The literature on the use of live simulation in engineering education is sparse. Papers by Russell, Brestovansky, and McCullough and Debelak and Roth detail experiments in simulation in chemical engineering courses in the early 1980s, many years prior to the EC2000 ABET changes.[26,27] In 2007, McManus, Rebentisch, Murman, and Stanke explored the effects of live simulation on teaching Lean Enterprise Thinking at CDIO Initiative participant MIT.[28] Each of these studies notes increased engagement by students using simulation along with additional work required by instructors to implement such an approach.

The literature as a whole indicates that simulation can be an effective tool to replicate real life experiences and provide the student with opportunities to develop complex skills. There are very few research papers discussing the impact of this approach in engineering education. The research that was conducted as part of a dissertation effort attempted to address this issue by examining the impact of LSBL on aerospace engineering students in a capstone design class.

Research Questions

The basic questions addressed by this research were:

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

Theoretical Perspective

Situated learning theory as described by Johri and Olds 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."[29] This perspective was assumed in this study because the central aim was to address a problem with how recent engineering graduates were 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 was 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 LSLB model is also guided by the epistemic frame as described by Shaffer.[30] 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 the 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.

Implementing LSBL follows what Gee 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.[31]

The LSBL experiment attempted to address the issue of professional skills which are interconnected to the technical skills under the Accidental Competency lens. A small duration intervention of five class periods during one semester of a capstone design class was conducted in 2011. During the balance of the 2011 to 2012 academic year, student participants were surveyed and interviewed to assess the impact of this intervention. The experiment provided 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.

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. The data that was obtained provided insight into the participant'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 instruments used for the mixed methods approach included an engineering design conception survey (taken by all participants), semi-structured interviews (conducted with a sample from each of three study group participant sets), and design presentation/project assessment using a rubric (for only the student study groups). These instruments were administered to a combination of students (an experimental and control group) who were the major focus of the study and aerospace industry professionals who's responses formed a benchmark upon which the students were compared.

The survey was administered to the professionals once and served 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 participation 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 Experiment

In the live simulation, the students experienced being an aircraft design engineer for a fictitious aircraft company called *Ace Aero*. 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 included 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 the fictional 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 engineering at *Ace Aero*. The experimental 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 keeping the experience as real as possible, the Broad Agency Announcement (BAA) used was a real Defense Advanced Research Projects Agency (DARPA) BAA that was issued in 2008 for a submersible airplane. 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. The experience started with the students working individually but very quickly being organized into 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 in this study had not completed a course on aircraft propulsion at the time of the intervention. Students could assume multiple roles. The experience allowed the students to gain experience in teamwork in a design environment to solve a difficult design problem.

The instructor or facilitator for LSBL 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, it is best that the individual have recent work experience in that arena or access to those with such experience. In this study, the LSBL instructor had extensive industry experience.

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 is 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.

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. In addition to the lectures, the students also saw a portion of a television mini-series that fairly accurately portrayed the aerospace industrial design environment. The instructor for this group also had extensive industry experience in addition to extensive aerospace design class teaching experience.

Cross-talk between groups and outside influences could not be totally eliminated in the experiment 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.

The participants of the study were members of the 2012 senior class in Aerospace and Ocean Engineering at Virginia Tech 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 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 compliance with Institutional Review Board requirements. 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. Facility limitations forced the uneven split of participants between the control and experimental groups. The students stayed in these groups throughout the five class period exercise.

The professional aerospace industry participants took part 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 were 20 industry participants on the survey and five participants in the interviews.

<u>Quantitative Work</u>

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. An example of the examination of conception relative to engineering design has been the work by Mosberg, Adams, Kim, Atman, Turns, and Cardella which assessed the conceptions of the engineering design process with advanced practicing professionals.[32] As part of this study, the authors created a survey that was derived from the efforts of Newstetter and McCracken which explored novices' conceptions of design.[33] 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 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.[34]

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 with the Likert scale questions of Part 2 of the survey. Limitations of the survey were that even though the survey was designed to measure conception, the respondent was 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 did provide the option for the respondent to provide additional comments and add design activities.

The questions used in the survey addressed content validity in that they presented a student's knowledge of design; construct validity in that selection of the most and least important design activities gave some insight into the student's reasoning; and criterion validity in that we also gained some insight into how the students might perform in the future by comparing their responses to the aerospace professionals.[35] The instrument also provided insight into the student's views of the professional skills.

The statistics program SPSS was used for a large portion of the statistical analysis of the survey results. 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 the Laboratory for Interdisciplinary Statistical Analysis (LISA) at Virginia Tech using code that was written in the R programming language.

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. The Mann-Whitney U test was used 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.

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. (Due to the structure of the regular design class it was not possible to have 100% experimental student and 100% control student design groups for the balance of the design course following the intervention period.) A modified version of rubrics geared towards capstone design courses and developed under the Transferable Integrated Design Engineering Education (TIDEE) Consortium effort were used to evaluate the reports and presentations.[36]

Qualitative Work

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. A 16 item protocol was created, tested, and modified during a pilot study. The 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. 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. The interviews were conducted by experienced engineering education interviewers with aerospace engineering backgrounds.

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.

After the interviews were conducted, they were transcribed. A discourse analysis was then used. 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 were merged with the quantitative results.

Initial codes developed by the lead researcher during discourse analysis were cross-checked by two other independent researchers 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.

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 was used. 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.[37]

As described by Creswell and Plano Clark, challenges to validity for the merged data could be categorized under the headings of data collection, data analysis, and interpretation.[37] 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.

Findings

Quantitative findings indicated that the LSBL intervention did have an impact on the student conceptions of aerospace engineering design while the qualitative findings indicated that students found the LSBL approach engaging and that they also had maturing views of aerospace engineering design that were greatly influenced by a combination of their academic experiences and their engineering work experiences such as co-op experiences and internships. The results also indicated that the basic P_JBL approach of the regular aircraft design class can help the students to respond in similar fashion to the aerospace professionals over the course of a 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.

Survey Part 1

Figures 1 and 2 illustrate the participant responses during the second milestone of the study where the four key milestone periods of the study were the Pre-Test (just before the five class intervention), Post-Test 1(right after the five class LSBL intervention period), Post-Test 2 (end of the first semester), and Post-Test 3 (just before the end of the year long regular aircraft design course). The arrows indicate shifts in ranking of the design activities between the Pre-Test and Post-Test 1. 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* remained a top or near top selection by all groups for most important while *abstracting* was a common selection for the least important design activity.

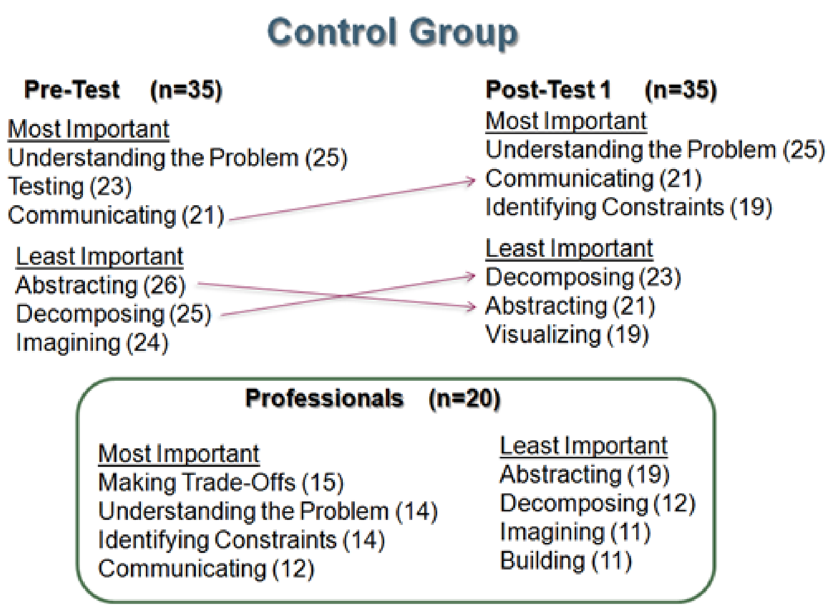


Figure 1. Control Group Least and Most Important Design Activities at Post-Test 1

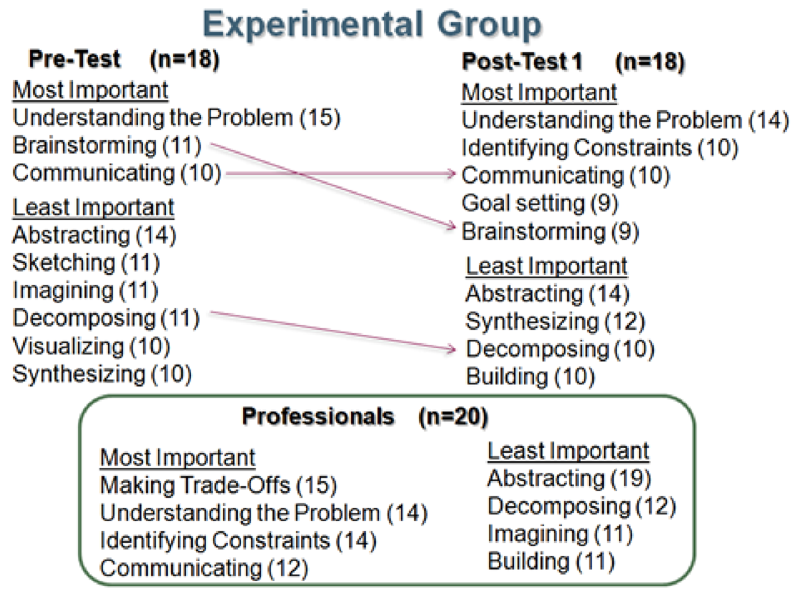
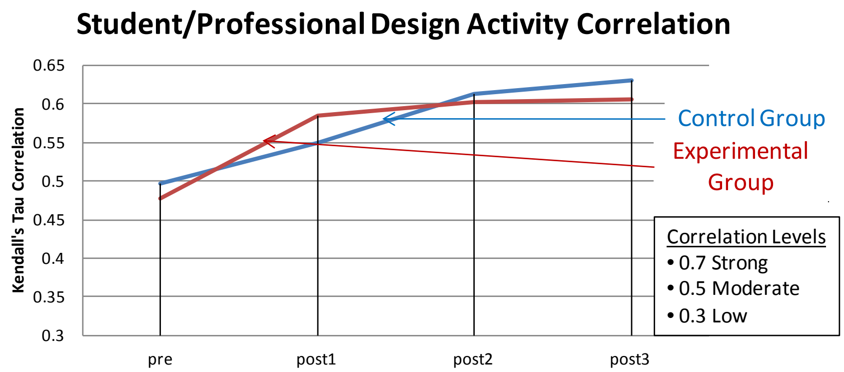


Figure 2. Experimental Group Least and Most Important Design Activities at Post-Test 1

Figure 3 graphically illustrates mean bootstrapped Kendall's Tau results. The bootstrap results in Figure 3 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.

Results indicated that the students were comparable during the pre-test period, diverged somewhat after the intervention and then merged back together at Post-Test 2 (end of the first semester) and leveled off around the 0.6 correlation range for the rest of the design course. The bootstrapping results, also showed 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 were 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.



	Control			Experimental		
Event	**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 3. Combined Bootstrap Kendall's Tau Rank Comparison Values Over Time

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 tau correlation change of 0.108) than the control group (a positive tau 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 leveled off or slightly decreased in correlation with the professionals. 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.

Survey Part II

The second part of the survey contained 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, Post-Test 2, and Post-Test 3.

The experimental and control group results were also analyzed separately using the Mann-Whitney U test. 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. 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.

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 4 – 6 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. The arrows on the charts illustrate the trend of the student responses over the course of the study. For example in Figure 4, the pairing Experimental Group/Professionals was strongly statistically significantly at the Post-Test 1 (p1) milestone to the p=0.008 level. 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.

- Survey Question 1: "Good designers get it right the first time"

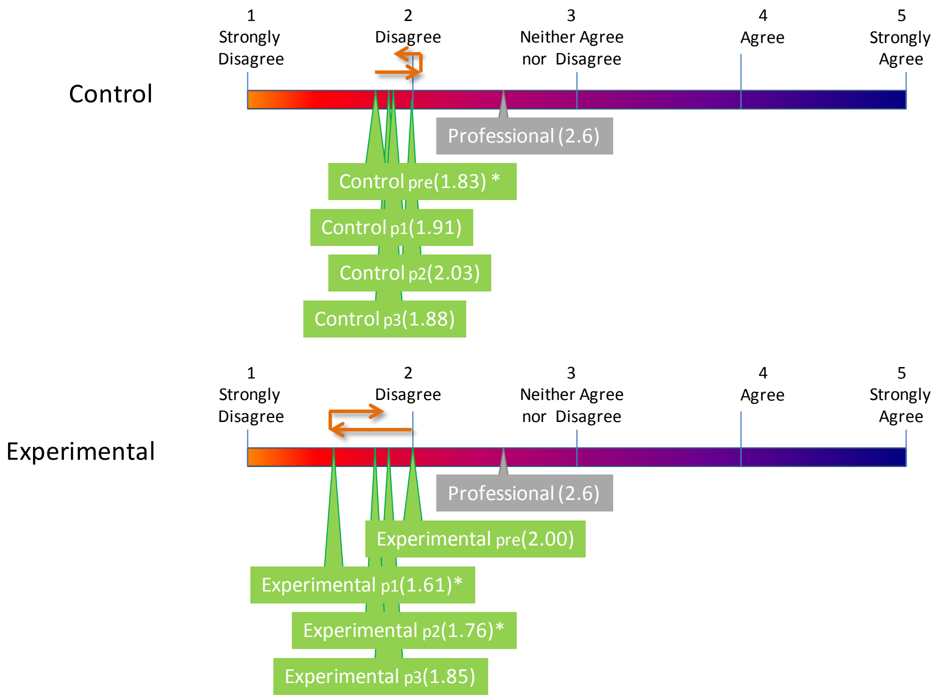


Figure 4. Design Conception Survey Part 2, Question 1 Results

When examining each student group individually for the period from Pre-Test to Post-Test 1, it was found that there were only two statistically significant pre-post pairs illustrated in Figures 5 and 6:

- Survey 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.

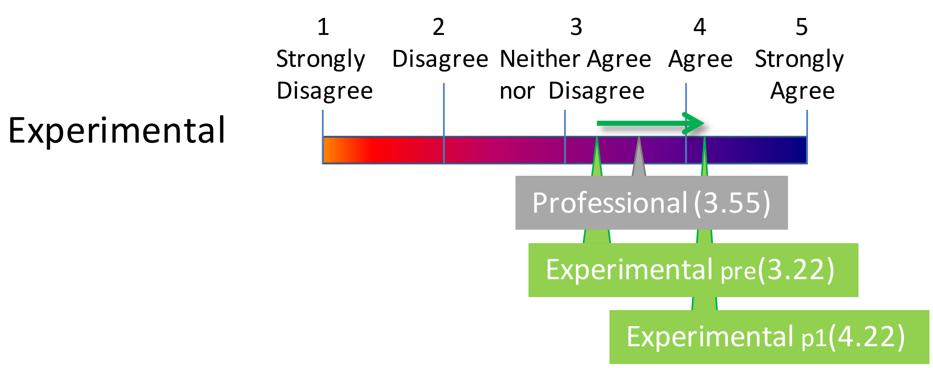


Figure5. Design Conception Survey Part 2, Question 4 Experimental Group Pre-Post Results

- Survey 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.

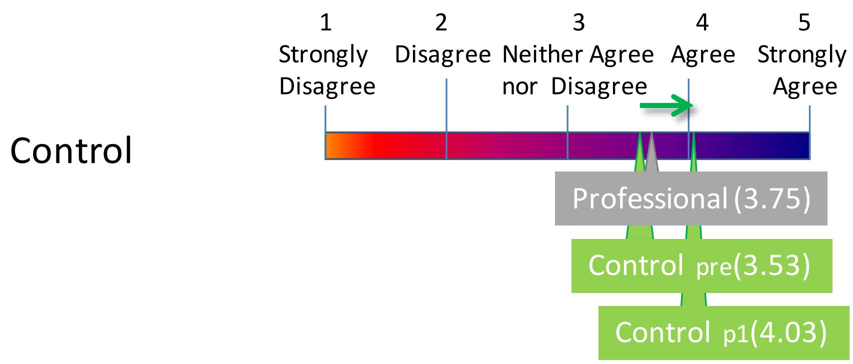


Figure 6. Design Conception Survey Part 2, Question 14 Control Group Pre-Post Results

Design reports and presentations

The design reports and design presentations of these groups were evaluated at the end of the first semester of design using the modified version of the TIDEE rubrics. Two design teams, one consisting of a majority of experimental group participants and one consisting of a majority of control group participants, had the top two average TIDEE rubric scores. The mostly control group participant design team (which had a large number of students with industrial internship experience) had the highest average score of all teams.

Interviews

Interviews were conducted with eight student participants (four experimental group students / four control group students) and five aerospace engineering professionals using the protocol discussed earlier. All interviews were voluntary and student interview participants were compensated with a $25.00 University Gift Certificate for their time. 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 (views of industry and how it works), a view of university (views of academia and how it works) , the gap between university and industry (expressions of disconnect between university preparation and industry expectation), engagement (items relating to feeling engaged in the class or exercise), disengagement (items relating to feeling not engaged in the class or exercise), lecture benefits (expressions of the benefits of the lecture format of teaching), new technical understanding (new technical insights and understanding gained in the class or exercise), experimental class areas for improvement (areas where the LSBL class could be improved), lecture class areas for improvement (areas where the lecture class could be improved), and inductive learning (comments that relate to an inductive learning experience). In general students in the LSBL class found it to be engaging, useful and a little too fast paced. Relative to the control class, the students felt that the class was well organized and that important information was presented but that the lecture itself was not the most engaging experience at times.

An interesting find during the interviews was the theme of a gap between industry and academia. An example of this theme was given by one of the students with industry internship experience who was part of the experimental group:

> *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…*

Here we see that a student participant volunteered that in summer internship experiences, he had encountered the very issues raised by this research. This sentiment was also expressed by other student participants who found a distinct difference between their university training and what was expected of them in the work world.

Discussion

Revisiting the research questions in light of the data collected, the following responses and conclusions were made:

Research Question 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?
Response:

- Yes, LSBL can alter student conceptions of engineering design and lead students to respond like industry professionals in the area of aircraft design.
- 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.
- Student views evolved over the course of the regular design class and became more like the sampled industry professionals.

Research Question 2:
How do LSBL students, lecture-based students, and aerospace industry professionals view aerospace engineering design?
Response:

- Both LSBL and lecture based students with design or industry experience held comparable views of aircraft design to the aerospace professionals.
- Aerospace design professionals viewed aircraft design as a mixture of science and art. They viewed teamwork, compromise, and communication as all playing an important part in the mix of design and analysis.
- Both interviewed student groups valued communication, interpersonal skills, professionalism and compromise as being key parts of teamwork. They also viewed teamwork as playing an important part in design as it is practiced in 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 of aircraft design.

Research Question 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?
Response:

- There was a direct relationship between student views of aerospace design 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 provided views comparable to professionals in general terms.
- Industry experienced students 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 expressed this belief.

<u>Additional Limitations & Suggestions</u>

This study provided some insight into student thinking about aircraft design and aerospace engineering in general. It also provided some indication of the effectiveness of the LSBL approach. As with any study, there were some limitations and some of these have been discussed earlier. In addition to those, it may be noted that 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 provided information on the impact of a brief intervention with LSBL. The lead researcher was a participant in some of the instruction during the study 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 through review of data by personnel outside of the study and the use of additional personnel to collect data and do part of the class instruction. LSBL should be further tested and refined with larger samples and for longer duration in a range of classes and engineering fields.

Conclusions

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.

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, Macatangay, Colby, and Sullivan 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”[38]. The study results indicate that the students were more engaged and began 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, in order to bring them one step closer to expert level engineering performance, thinking and attitudes[39].

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