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AN EXPLORATORY STUDY ON THE EFFECTS OF GOAL ALIGNMENT, INTERVENTIONS, AND MOTIVATIONAL FACTORS ON INNOVATIVE ENGINEERING DESIGN PROJECTS

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AN EXPLORATORY STUDY ON THE EFFECTS OF GOAL ALIGNMENT, INTERVENTIONS, AND MOTIVATIONAL FACTORS ON INNOVATIVE ENGINEERING DESIGN PROJECTS

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ABSTRACT

Innovation has become an important facet of engineering design, both in industry and the academy. Many senior-level engineering design courses encourage students to develop innovative solutions to open design projects from industry sponsors. Like industry, these academic problems are tackled by teams of students. Student teams that function at the highest level are more likely to reach the innovative solutions for which they are searching. The research presented in this work focuses on two main areas: (1) understanding what motivates engineers when working on innovative design projects and (2) determining the effects of goal alignment interventions on design teams working on innovative design projects. An exploratory survey was developed, validated, and administered to students in the capstone course at Clemson University to determine which motivational factors engineering students perceive to be most effective when working on innovative design projects. The initial results show that (1) "passing the class", (2) "impressing the industry sponsors", and (3) "making an 'A' in the class" are the three factors that most effectively promoted innovative design. Conversely, (1) "cash prizes", (2) "increased project budget", and (3) "receiving patents" are the three factors that least effectively promoted innovative design. A second exploratory study was conducted to determine if the effects of setting common goals could be quantified. Five of eighteen design teams were selected and guided to set common goals as a team during week five of their design experience. It was found that the teams that received interventions had an immediate increase in level of performance (p-value = 0.14) and motivation (p-value = 0.19) when compared to teams that did not receive interventions.

This thesis is dedicated to my parents, Scott and Barb Linnerud, for their continued support and prayers

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I would like to thank my parents, Scott and Barb Linnerud, for their constant encouragement, prayers, and support of the life decisions that I have made leading to this point. Their wisdom in decision making throughout my upbringing allowed me to make it to this point in life and I will always be grateful to them for that. Their hard work and dedication in their own lives instilled in me an appreciation for the work ethic needed to be successful in life.

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- Identify research gaps and opportunities within current literature
- Present the research questions and hypotheses that guided this research, and
- Discuss the deliverables which were established to keep this research on task.

The following sections provide a snippet of current literature, a comprehensive overview of the objective of this research through the identification of research opportunities in current work, the establishment of research questions and hypothesis, and the development of research tasks to meet key gaps that have been identified. An outline of this thesis is also presented to assist in the navigation of this work.

1.1 The Forest before the Trees

For engineering companies striving to be competitive in today's economy, it is essential that innovation is the crux of their strategy and decision making process [1–8]. An innovation can be defined in two ways: (1) generating a creative idea or (2) finding an application for a creative idea and nurturing the idea into a product or process. While there is not a single agreed upon definition, many researchers contend that the latter is a more accurate definition of an innovation [9–11]. Innovation is especially important to the field of engineering as the community is constantly evolving to keep up with the desires of the customer. Engineering designers are constantly pushed to develop new and innovative solutions to design problems. Similarly, engineering students working on their capstone design project are pushed to develop solutions to innovative design problems.

This increased need for innovation has caused the focus of motivation research to shift towards understanding what motivates individuals to be innovative. Motivation can be divided into two distinct types: intrinsic and extrinsic. Intrinsic motivation comes from the internal drive of the person that is often a direct result of an individual's level of engagement in a problem or task [12,13]. Conversely, extrinsic motivation is caused by some external factor that is in place to incentivize the individual to be innovative (e.g. monetary and non-monetary incentives).

Recent advancements have been made in terms of motivation research, especially within the fields of management, psychology, and finance. Researchers have shown that certain financial incentives at the highest level of management can have a "trickle-down" effect to all members of an organization [1,14]. Other groups have posited that an innovative environment can be promoted through the use of long-term rewards rather than short-term incentives [9,15,16]. Several researchers have shown that intrinsic motivation has a greater effect on an individual's performance than extrinsic factors [17–21] and can at times overcome an individual's lack of creativity [22]. Other researchers have shown that extrinsic factors can have a negative effect on the motivation of an individual altogether [23]. Recent research has begun to determine the feasibility of crowdsourcing as a tool to drive innovative design of new products [24–26].

Understanding individual motivation is not sufficient when looking to maximize the motivation of a group. Past researchers have recognized that people working in a group setting are motivated differently than if they were working on a problem alone [27,28]. Group development thus becomes important in the process of motivating groups to develop innovative solutions to problems. Tuckman [29] has proposed a development process in which all groups undergo four distinct phases of evolution: forming, storming, norming and performing.

1. Forming – team forming and problem definition
2. Storming – concept generation and early testing of solutions
3. Norming – development of team cohesion and **setting of common goals**
4. Performing – working at the highest level towards defined goals

The key to this development process lies in the norming phase: establishment of common goals within the team. Research has shown that teams tend to perform at a higher level when working as a cohesive unit to achieve common goals [30–35]. The challenge that is faced by many design teams is the conflict that can naturally evolve when group members are arguing over which concept is the "best". Furthermore, no methods have been explored to facilitate the alignment of goals within a design team. Interventions have been used within the fields of primary healthcare, sports, and even engineering to facilitate some shift in belief or action. These effects have been mostly positive, although some research has shown that interventions can have a negative effect [36].

1.2 Research Gaps and Opportunities

The three main research areas that were reviewed were motivation (primary focus), goal alignment, and interventions; note that an emphasis was put on works within these three areas that contained discussion on innovation. The goal of reviewing these topics was to better understand student motivation and goals when working on innovative engineering design projects.

1.2.1 Motivation Literature

Six main research gaps are identified in the area of motivation:

1. Motivating different types of engineers: As all engineers are not alike, it is important to understand how to motivate different kinds of engineers (technical versus business minded), as they will presumably be motivated by different aspects [12]. Thus, it is important to determine how to effectively motivate both technical and business minded engineers.
2. Understanding student motivation: There has been little research on student motivation within the field of engineering design; furthermore, the few published works on student motivation were mostly based on anecdotal evidence, not scientific research [27,37]. To improve the overall performance of students working on innovative engineering design projects, it is essential to know what motivates students to develop innovative solutions.
3. The innovative nature of capstone courses: Within engineering design courses (specifically capstone classes), students are generally able to develop successful and innovative solutions to the problems with which they are tasked. There have been some anecdotal claims as to why students are generally successful [27,37]; however, more formal research needs to be done to either support or disprove these claims.

4. Understanding the differences between group and individual motivation: Due to complexity of engineering design problems as well as time constraints, engineering projects are generally assigned to a group of engineers rather than an individual [27,28]. Having said that, the focal point of current research is on motivating individuals to perform at a high level when working on innovative design problems [15–17,38,39]. Because of this, it is important that research be done on the most effective ways to motivate engineers within a group setting.

5. Creating an environment that promotes innovation: While leaders can use different forms of extrinsic motivation to promote innovative thinking, researchers have proposed that other methods can be used to create an environment that promotes innovative thinking [17,24–27,37–41]. By giving designers freedom to do as they wish, time to think about the design problems, and creating a low-stress environment in which they can work, engineering designers tend to be more innovative [9,15,16,27,42]. While these proposed methods make intuitive sense, extensive research on these methods has not been conducted to confirm the validity. Also, it needs to be determined which incentive schemes are most effective on CEOs [1,16,37,40].

6. Crowdsourcing in engineering design: With an increased popularity in the usage of crowdsourcing, it is important to determine how companies can most effectively attract innovators to work on their projects; and, once said

innovators start working on the project, it is important to find out which incentive schemes most effectively push them to perform at a high level [24–26].

It is important to note that these topics are not mutually exclusive and in fact there is a great amount of overlap within them. While these certainly are not all the topics that need to be researched further, these are a good starting point for anyone looking to contribute to research being done on motivation for innovation in the engineering design community.

1.2.2 Goal Alignment Literature

The group development model proposed by Tuckman [29,43] is generally accepted due to the thorough nature of his work and the validation of the model by other researchers [44,45]. His model is defined by four stages of development:

1. Forming – The first stage of group development involves getting to know the team members, assigning roles, and problem definition.
2. Storming – The storming stage of group development is when individuals begin to develop solutions to the problem. Often this stage will involve turmoil between group members as there will be competition over who has developed the best idea.
3. Norming – During the norming stage, group members will come together as a team to work toward a common set of goals.
4. Performing – The last stage is when teams perform at a highest level to meet goals.

The third stage of Tuckman's model (norming) calls for the need to set common goals as a team before being able to perform at the highest level [29]. While the effects of goal setting have been researched within some fields of study [30–34,46] (e.g. human relations, management, and psychology), there has been no work within the field of engineering. Thus, there is an opportunity to determine the quantitative and qualitative effects that goal alignment has on an engineering design teams' performance and motivation throughout the design process.

1.2.3 Intervention Literature

The effective use of interventions has been extensively researched within the field of healthcare [47–54]. There has also been some initial work done within the fields of sports [55–57] and engineering [58,59]. From an engineering perspective, two research gaps are identified with respect to interventions:

1. Further work is needed to validate the use of interventions in the field of engineering. More specifically, it needs to be determined if interventions can be used for underperforming engineering design teams.
2. As was presented in Section 1.2.2, having common goals is essential for design teams to perform at the highest level [29,43]. Work is needed to determine if interventions can be used to facilitate goal alignment of teams working on engineering design projects.

1.3 Research Questions and Hypotheses

The following research questions (RQ) and corresponding research hypotheses (RH) were formulated in an attempt to fill some of the gaps presented in Section 1.2.

1.3.1 Research Questions

RQ1. Which factors most effectively motivate engineers when working on innovative design projects?

RQ2. How does group motivation differ from individual motivation? Furthermore, how do you effectively push a group to perform at a high level?

RQ3. Can interventions be used to facilitate goal alignment of engineering design teams?

RQ4. How does goal alignment effect the motivation and performance of engineering design teams?

RQ5. Does a relationship between motivation and performance exist?

1.3.2 Corresponding hypotheses

For the first research question, no hypothesis was made as it is an exploratory question.

RH2. The performance of a design team is maximized if the goals of individual group members are aligned.

RH3. Interventions can be used to effectively facilitate goal alignment for engineers working on design projects.

RH4. The sooner design teams explicitly set common goals (exit the Norming Stage), the sooner they can maximize their level of performance (Performing Stage).

RH5. There is a positive correlation between level of motivation and performance; that is, as teams are more motivated, they will perform at higher levels.

1.4 Research Tasks

Five research tasks (RT) were established on which research efforts were focused. These research tasks served as deliverables that had to be met to answer the five research questions. The five research tasks were as follows:

RT1. Develop, administer, and analyze responses to a motivation survey to determine what students perceive to be the most effective motivational factors when working on an engineering design project.

RT2. Record the individual goals of all team members to determine if the team is working towards the same goals. These goals should be recorded at the beginning and end of the project.

RT3. Select and administer interventions to a group of engineering design teams while they are working on design projects. Provide these design teams with the tools to explicitly set common goals as a team. Determine if these teams actually perform the goal alignment activity by giving them a deliverable (goal alignment form) to complete.

RT4. Take weekly evaluations of design teams' levels of motivation and performance throughout a project. Analyze this information using statistical methods to determine if the interventions had any positive effects on the performance and motivation of design teams.

RT5. Use established methods to determine if a statistical correlation exists between motivation and performance. The weekly evaluations used for RT4 should be reused to perform this analysis.

1.5 Thesis Outline

The research presented in this thesis is organized into seven chapters, as seen in the thesis framework in Figure 1. Chapter One aims to present research opportunities that were realized when reviewing literature and the research questions, hypothesis, and tasks that were formulated to fill some of the key gaps that were recognized. Chapter Two gives an in-depth look into the literature that was reviewed with respect to innovation, motivation, goal alignment, and interventions. Chapter Three discusses the approach that was taken to answer the research questions that were developed. Chapter Four and Chapter Five aim to present the findings from the research that was conducted in parallel with one another. More specifically, Chapter Four presents findings from the motivation surveys that were developed while Chapter Five gives an in-depth look at the trends that were seen with engineering design teams when receiving goal alignment interventions. Finally, some conclusions about the research and discussion about future work that can be accomplished to expand and refine the work is presented in Chapter Six.

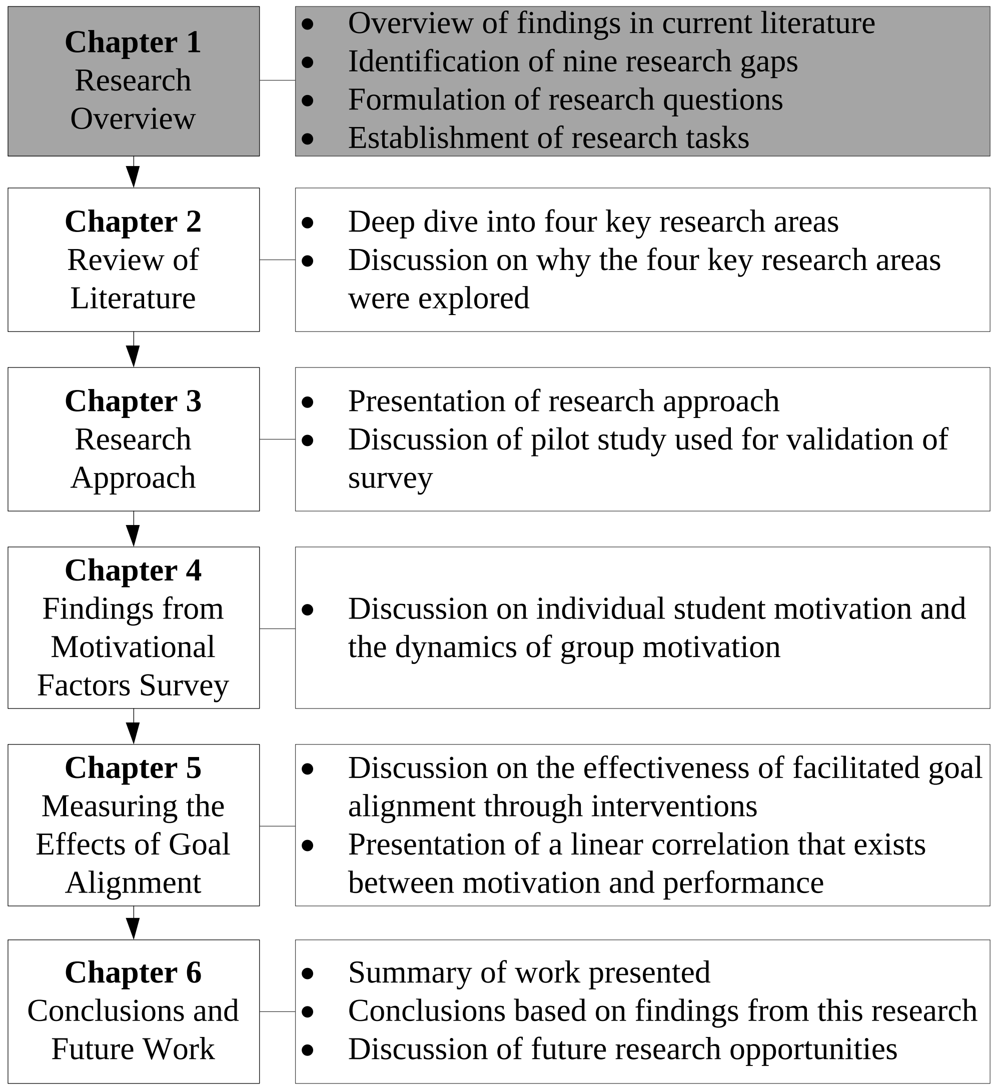

Figure 1: Thesis framework.

Chapter Two:
INNOVATION, MOTIVATION, GOAL ALIGNMENT, AND INTERNTERVENTIONS IN CURRENT LITERATURE

Chapter Aims:

- Critique current research in the fields of motivation, goal alignment, and interventions with an emphasis placed on innovation, and
- Explain why these fields of research were chosen for review.

The objective of this chapter is to present innovation as a frame of reference and then give an in-depth discussion regarding the current state of motivation, goal alignment, and intervention literature. The literature discussed in this chapter is used as the basis for the formulation of research opportunities presented in Chapter One.

2.1 Innovation in the World

There is an overarching need for companies to develop innovative products and services to stay competitive in today's economy [1–8]. Makri and colleagues [1] point out that with this increased focus on innovation, the rate at which innovation occurs has increased drastically. Due to this need for innovation, increased research has focused on innovation and what it takes to develop innovative products. This research spans across many fields of study including psychology, economics, and engineering. Even with this increased focus on innovation, many research opportunities exist within innovation, especially from the motivational standpoint.

Pahl and Beitz [60] define innovation as "a product that realizes new functions and properties. This can be through novel or new combinations of existing solutions". Some people believe that an innovation is simply a novel or creative idea that may or may not have a practical application; however, many researchers in the field of innovation would argue that this is not the case. An innovation is not simply developing a creative idea, it requires an investment in that idea to turn it into a functional and useful product [9–11]. Without a practical application for a creative idea, the idea is useless and has no value to a company (besides a potential solution to a problem somewhere in the future). Dearden and colleagues [10] contend that being creative is not the difficult part of innovation, but instead the difficult part is the implementation of these creative ideas into working prototypes.

There is a growing need for a more systematic way to motivate people to develop innovative solutions to engineering design problems. Within the current field of engineering research on innovation, the findings are difficult to apply, specifically in the context of engineering. Some researchers believe that in order to be innovative you need the right people, at the right place, at the right time [6,42,61]. Others recommended avoiding non-innovative people all together [15,16]. While these may be true on some levels, this does not help companies attempting to develop innovative solutions.

There are two sources where innovative needs arise: market need or technical need [28,62,63]; it is rare for an innovation to be developed without some form of technical or market need [1,5]. Within their research on innovation, Riggs and Hippel [62] emphasize that innovative products that fill a market need are generally developed by manufacturers of the product whereas technical innovations are usually developed by designers or users of the product. This makes intuitive sense as manufacturers attempt to always meet the desires and needs of the customers. Conversely, designers are generally trying to implement new and innovative technologies into products they are developing.

Research has been conducted to determine the effect that engagement has on the performance of individuals. Generally, as people become more emotionally invested and engaged in a problem, their level of performance tends to increase. Within the field of engineering, Allen and Katz [12] have researched engagement of two types of individuals: "cosmopolitan" and "local". The "cosmopolitan" engineers would be more likely to develop technical innovations whereas the "local" engineers would most likely develop products that fulfill a market need. Within their work, they point out that engineers tend to perform better on assignments in which they are interested [12]. Similarly, Britt [13] has researched engagement within the field of psychology which has shown that people perform better as engagement increases.

Within the field of psychology, research has been conducted on creativity. Psychologists point out that everyone is inherently creative to some degree [22]; they also point out that creativity can be improved within people through practice [64]. Often people believe that it is difficult to recognize and reward the creativity in people. However, psychologists believe that people who are experts within a particular field can generally tell whether or not an idea is creative [22].

Psychologists assert that there are three major components of creativity that are essential for generating creative ideas: motivation, expertise, and creativity skills. As far as motivation goes, there are two types that can motivate people to be creative: extrinsic and intrinsic. Extrinsic motivation comes from an external source (i.e. incentives) that may drive people to develop innovative solutions. Intrinsic motivation comes from within a person and it is their internal drive that comes from being personally invested or engaged in a specific product. A highly intrinsically motivated person can make up for a lack of creative skills [22]. People with an emotional investment in a project or task tend to be more engaged than others [13]. This engagement could be due to many things such as curiosity, a sense of challenge, a desire for knowledge, or taking pride in ones work. Research on engagement has shown that people with this emotional investment tend to be more engaged, increasing their overall performance in the task at hand [13].

Participants of an NSF workshop have pointed out that there is a significant gap between engineering and psychology. Due to this gap, it is essential that innovation is studied within the field of engineering [7]. It is important to note that discussions with psychologists about the methods testing engineering innovation are necessary to draw parallels between the fields of engineering and psychology [13].

2.2 Motivation Literature

Generally speaking, motivation has been grouped into two types: extrinsic and intrinsic. Something that serves as extrinsic motivation to a person is something that can be given or received; these are often referred to as “incentives”. Intrinsic motivation is something that comes from within an individual and their desire to be involved in a task or activity. This section will discuss extrinsic and intrinsic motivation, the differences between group and individual motivation, a discussion on environments that promote innovation, and past work on student versus industry motivation. An overview of the motivation discussion in subsequent subsections is presented in Figure 2.

	Groups	Individuals
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 2: Overview of motivation discussion in Section 2.2.

2.2.1 Intrinsic Motivation

Intrinsic motivation is the internal drive that comes from within a person to perform task or activity. Amabile [22], an expert on motivation, states the following about intrinsic motivation: "Intrinsic motivation is driven by deep interest and involvement in the work, by curiosity, enjoyment or a personal sense of challenge. Extrinsic motivation is driven by the desire to attain some goal that is apart from the work itself—such as achieving a promised reward or meeting a deadline or winning a competition." Work by past researchers has shown that intrinsic motivation is more powerful than extrinsic motivation [17–21] and a person who is highly intrinsically motivated can overcome a lack of creative skills [22].

Intrinsic motivation is believed to be the most powerful form of motivation because of the engagement in the problem that comes along with it. If a person is intrinsically motivated, they are more likely to be emotionally invested in the project which will drive them to work harder than any extrinsic factor can push them. Furthermore, as engagement in a problem increases, the level of performance is shown to directly increase [13]. The areas of motivation research discussed in this section are highlighted in grey in Figure 3.

	Groups	Individuals
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 3: Overview of motivation discussion in Section 2.2.1.

2.2.2 Extrinsic Motivation

Forms of extrinsic motivation are roughly classified into two types: monetary and non-monetary incentives. The monetary incentives include all incentives that involve any kind of financial reward and the non-monetary incentives include all other possible incentives.

2.2.2.1 Monetary Incentives

Within their work on motivating innovation, Ederer and Manso [15,16] propose the following monetary incentive schemes that reward long term performance: stock options with long vesting periods, option re-pricing, golden parachutes, and managerial entrenchment. All of these financial rewards take a long time to mature and are much more valuable in the long term. By using incentives that take a long time to mature, these authors believe that people will be more willing to pursue riskier, more innovative solutions to problems.

While these methods may promote more innovative thinking, people often have innovative ideas but no application for that use. As an employer, you only want to pay for useful innovations that can be made into working prototypes. Kremer and Williams

[38] propose three methods which give financial incentives to engineers that come up with innovative solutions:

1. Ex Ante Technical Specifications – pay for a proven working product, not a concept.
2. Ex Post Use, Willingness to Pay, or Impact – pay for something useful/something that consumers want to buy. Base the pay on how successful it is in the market.
3. Ex Post Discretion – rewarding successful innovation based on certain criteria the company may have set. It also allows the company to use discretion to award the innovation as they see fit.

None of the proposed methods reward engineers for developing creative products; they all must have some function, fill some market need, or be useful in the eyes of the company for which it was made.

While receiving a paycheck or a financial bonus of some kind are both effective monetary incentives, they will not be extensively discussed in this section as these are commonplace and are generally overlooked in current literature.

2.2.2.2 Non-Monetary Incentives

Non-monetary incentives are common in academia and research driven organizations. Scotchmer [11] points out that useful innovations come more so from universities than industries as is evidenced by the number of patents per funding dollar (four times more for universities than industries). This is interesting as people working in academia are primarily motivated to develop innovative solutions for the purpose of publishing papers and becoming more knowledgeable [11]. As neither of these are monetary rewards, perhaps the best way to motivate engineers to develop innovative results is through public recognition and the advancement of the field in which they are researching.

Only a small portion of current research pertains to the motivational properties of tangible incentives. What these researchers have found is that non-monetary incentives of equal value to monetary incentives can often be more effective motivators [17,39]. This may be the result of people seeing tangible incentives as luxuries that they would not feel comfortable buying, even if they had been given the money as a bonus. In addition to this, if the incentives given are perceived as being unobtainable, then they have added value (e.g. super bowl tickets). If rewards are given publicly, pride is also used as an incentive [39]; furthermore, public recognition of certain individuals may not only motivate said individuals but also motivate others as well [4].

One important caveat to giving non-monetary incentives is the importance of choices. People want to be able to choose their reward: it is important to have a wide array of prizes from which the employees can choose. These prizes must be frequently changed so people remain motivated to earn the prizes.

2.2.2.3 Summary of Extrinsic Motivational Factors

In general, research on monetary and non-monetary incentives are discussed and presented separately. As was discussed in the previous sections, there are researchers that argue the effectiveness of both types of incentives, yet there is little first-hand comparison between the two types. This area of research on incentives is ripe with opportunity to see which forms of incentives provide the most motivation (both extrinsic and intrinsic) to design innovative products. The areas of motivation research discussed in this section are highlighted in grey in Figure 4.

	Groups	Individuals
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 4: Overview of motivation discussion in Section 2.2.2.

2.2.3 The Nuances of Motivating Groups Versus Individuals both Internal and External to an Organization

Within a company, engineering design is generally performed by either individuals working alone or in a single cohesive unit (group). These individuals can either work for the company or be hired as an outside consultant (contractor) to help solve the engineering problem. Although these two groups of people are not the exact same, they can be motivated the same basic ways. Sometimes people working internal to the company cannot find an acceptable or innovative solution to the problem. On such occasions, there is one other method that has become increasing popular as of late. This method is known as crowdsourcing which simply means the engineering problem is opened up to the general public so that it can be solved by anyone. From these, there are three different targets that all need their own motivation schemes to maximize performance: individuals, groups, and people in an open format (crowdsourcing).

2.2.3.1 Individual Motivation

The focal point of the works that were reviewed discussed motivating individuals. The majority of the work discussed in the previous sections (Sections 2.2.1 and 2.2.2) was in regards to individual motivation. Rather than repeat information that has already been discussed, it is recommended that the previous sections be reviewed if more information is needed regarding individual motivation.

2.2.3.2 Group Motivation

In most cases, engineering design projects are addressed by teams of individuals. This is done for four main reasons: the complexity of most design project can be overwhelming for an individual to tackle alone; the amount of work that needs to be accomplished in a certain amount of time is generally not feasible for one individual to accomplish; multiple people working on a project minimizes the chance that things get overlooked in the design process; and having multiple individuals working on the same project allows the team to leverage the strengths of the individuals into a stronger team as a whole. There are opportunities to explore group motivation within engineering design. Utterback [28] has discussed how developing innovative solutions can often be easier in a group as seeing other people's ideas helps one to be innovative. This also shows the importance of working with people outside of the group and having people review the work in order to minimize the chance that things get overlooked [27]. Delson however makes these claims based on observations he has made as an instructor of capstone design courses, not via formal research.

The only other area of research found to discuss group motivation is research on motivating a group leader. Researchers believe that by correctly motivating a group leader, there will be a trickle-down effect to the remainder of the organization [1,16,40]. Furthermore, Ferrante and colleagues [37] have found that by correctly motivating a group leader, the performance of a group can increase. Some researchers believe that CEO incentives are the most important form of motivation as there can be a cascading effect all the way down to lower levels of a company [1,40].

2.2.3.3 Crowdsourcing

Within a crowdsourcing setting, it is important that the incentives for solving a problem are enough that people will want to solve said problem. If a company does not offer enough incentives, then people will not be motivated to develop good solutions to the problem. One of the first examples of crowdsourcing occurred in the 1700s: British parliament offered a prize for anyone that could create a device that could correctly tell the longitude of a ship at sea. They offered this prize because to that point in time, no one had been able to solve this problem of longitudinal coordinates. After many years of developing a solution, the problem was solved by a clockmaker named John Harrison. By using the position of the stars, Harrison was able to create a clock (named the marine chronometer) that was so accurate it could be used to develop the longitude of ships at sea. This example shows the power of open source innovation. While a problem may be considered an engineering problem, it does not mean that engineers are always the most capable of solving the problem. Thus, there can be many advantages to opening up problems to the public in a crowdsourcing setting.

With the growing increase in popularity of crowdsourcing websites, research on the rewards offered has increased. Some companies pose their problems as a competition so that it can attract as many innovators as possible [24]. For example, NASA did this for its Astronaut Glove Challenge allowing anyone to solve the problem. Aaron and colleagues [25] have done extensive research on different incentives and their effectiveness on innovation within a crowdsourcing community. More specifically, they tested fourteen different incentive schemes to determine which most effectively promoted the development of innovative solutions. They found that punishment and fear are the best motivators (for most people) for open source innovation [25]. In addition to this, Antikainen and colleagues [26] suggest that "contributors appreciate many intangible factors, such as community cooperation, learning new ideas, and having entertainment."

2.2.3.4 Summary of Target Groups for Motivation

While there has been a substantial amount of research on motivating individuals, there is still very little on motivating groups. As most engineering problems are solved by groups, there is a need for more research on this topic of group motivation. Also, the research that has been conducted regarding individuals within an open source community has laid a good foundation, but more work is still needed to determine how to effectively motivate individuals to develop innovative solutions. The areas of motivation research discussed in this section are highlighted in grey in Figure 5.

	Groups	Individuals
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 5: Overview of motivation discussion in Section 2.2.3.

2.2.4 Environments that Promote Innovation

When attempting to create an environment that promotes innovative thinking, some people believe that management should allow the designers freedom to do as they wish; if management were to step in and critique early decisions, it may stifle innovation and ultimately hurt the team [27,63]. Within senior capstone design classes, this may be why most teams are successful in finding an innovative solution. By allowing the teams to be innovative early on, they can ultimately come up with the best solution over time. Being innovative early on is encouraged and recognized by the advisors even if it does not appear to be a feasible solution, allowing the students to more broadly explore the solution space.

Many researchers believe the optimal way to motivate employees to be innovative is to allow for early failure (while even rewarding it at times) [9,15,16]. Furthermore, if compensation rewards long-term success, people will be willing to pursue more risky and innovative ideas early on in the design process [15,16]. In order to reward long term success, organizations must put in motivation schemes for a long period of time. Motivating innovation is harder to do over a short period of time than it is over a long period of time. Researchers point out that you cannot simply turn the motivational mechanisms on and off; you must be fully invested in promoting innovation [17,24–27,37–41].

Creating an atmosphere with a high level of job security can allow engineers to pursue innovative ideas without the fear of losing their jobs. Delson [27] believes that teams of engineering students working on capstone design projects provide an excellent example of how job security can promote innovative thinking because students do not have the fear of losing their job if the project does not go well. Conversely, too much job security can cause some engineers to become complacent. Often within industry you see engineers that have been working the same job for long periods of time doing all the easy, less risky jobs because they have been doing it so long. Similarly, if employees feel they have a substantial amount of job security then they lose the motivation to be innovative.

Allowing a reasonable amount of time for the development of products is essential for finding innovative solutions. This is due in part to the lower level of stress felt by the designers when given ample time to fully explore the solution space. In regards to developing innovative solutions, Pahl and Beitz [60] discuss the importance of time management by saying the following: "realistic time planning has a positive effect on thinking processes, and new developments should take place under reasonable time pressure". Like Pahl and Beitz, Salter and Gann [61] discuss the importance that a low stress work environment has to generating innovative solutions. They also contend that if the designers are overworked, they will not have ample time to develop innovative solutions.

2.2.4.1 CEO Incentive Structures

Some researchers believe that by correctly motivating upper level management, there will be a "trickle down" effect to the rest of the employees. Along these same lines, some research has been conducted regarding which incentive schemes should be used on CEOs so that they promote innovative thinking within their companies. There are two general incentive schemes that are currently used within industry: outcome based incentives (OBI) and behavior based incentives (BBI).

Compensation for CEOs under OBI is based solely on the financial outcome of their companies [1]. The strength of OBI is that one can easily track and evaluate the financial performance of a company; the compensation is straight forward and not subjective. The issue with this incentive scheme is the fact that innovative ideas can often take many years to develop into profitable, marketable products. If CEOs are incentivized using OBI, there is potential for them to be less risky; this is because managers may avoid innovative projects as they are inherently risky. Due to the quick turnover of many executives, this can often lead management to promote safer, less innovative solutions.

For companies employing the BBI incentive schemes, compensation of the CEOs is based on the how innovative the company is perceived to be [1]. Metrics such as the number of patents produced by a company over the course of a year are evaluated by executives to determine the financial compensation rewarded to the CEO. This allows executives to make decisions purely based on perceived performance for that year, eliminating the problem of long development times. The main issue with this method is the inherently subjective nature of the rewards. Because incentives are based on perceived performance, CEO's may attempt to file for as many patents as possible while not actually developing any of the promising and innovative ideas.

Because of the negative aspects of both BBI and OBI, research has been conducted in an attempt to combine the good aspects of both methods; researchers argue that by combining OBI and BBI, one can create an ideal incentive scheme [1,14]. Within their work, Makri and colleagues [1] talk about this by saying the following:

> *We proposed that technology-intensive firms can be more effective if they base CEO incentives on a combination of short-term financial results and behavioral indicators of long-term innovation quality. Such a compensation system leverages the strengths of each approach and offsets their weaknesses. It encourages a CEO to commercialize innovations but also reinforces behaviors that enhance the firm's ability to innovate in the future.*

While this seems like a valid approach to CEO compensation, no testing has been done on the effectiveness of the proposed incentive scheme.

2.2.4.2 Summary of Innovative Environments

Research is currently being conducted to determine which factors promote innovation within a working environment. Of the topics discussed in Section 2.2, research on creating an environment that promotes innovation has shown the greatest progression. There is still a great opportunity to link the findings to academia and, more specifically, capstone engineering design classes. The areas of motivation research discussed in this section are highlighted in grey in Figure 6.

	Groups	Individuals
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 6: Overview of motivation discussion in Section 2.2.4.

2.2.5 Targets for Motivation

Motivation research is classified into two focal groups: practicing designers in industry and students. The focal point of current motivation research (as discussed in Sections 2.2.1, 2.2.2, 2.2.3, and 2.2.4) is on practicing designers in industry. Furthermore, the findings on motivation of engineering students were mostly based on observations, not the outcome scientific research.

Within his work on capstone design courses, Delson [27] makes anecdotal claims on how to motivate teams of engineering students while working on their capstone design projects. Additionally, Delson argues that in order for a team to perform at a high level and come up with an innovative solution, they must first work independent from the instructor. Therefore, the independence and dearth of criticism allows for innovative thinking on the students part. He points out that when working on design projects, it is important to work with people outside of the group to have things reviewed, hopefully minimizing the chance that things get overlooked. He also points out that students are usually motivated because capstone design projects are one of the first opportunities that students have to work on a real engineering project; they also have the luxury of working on this project without the pressure of losing their job if the project does not go well. While all of Delson's claims seem valid, all of his conclusions are based on anecdotal evidence, not scientific findings. Therefore, there is great opportunity to verify the validity of these claims.

One potential issue that must be considered with student group motivation is social loafing. Social loafing is when some members of a group do not put forth their full effort because they believe others will "pick up the slack". Ferrante and colleagues [37] researched this issue and proposed that by correctly motivating a group leader, the overall performance of a group can increase. They also researched what would happen if the group leader was given the power to reward or punish the group members based on their performance. This model is similar to what would normally take place within a company (see Section 2.2.4.1).

With the increased need for innovation, education on engineering design that promotes innovation and entrepreneurship has also increased. These classes are similar to capstone design courses with an increased focus on generating innovative engineering products. The "E-teams" (the name they use for the groups) do not simply come up with creative ideas; they go all the way through market research to assess the feasibility of the innovative products [8]. These E-teams pair engineering students with MBA students so that students can truly understand the important part that business plays within the world of engineering.

There are several opportunities for validation of current research. For example, there are a number of different motivational factors (both intrinsic and extrinsic) that promote innovative thinking within both students and design engineers. A formal list of the effectiveness of different motivational factors is essential to lay the framework for future research. These lists could also be used to compare motivational factors of students and practicing designers in industry. The areas of motivation research discussed in this section are highlighted in grey in Figure 7.

	Groups	**Individuals**
Intrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.1 Section 2.2.2 Section 2.2.4
Extrinsic	Section 2.2.3 Section 2.2.5	Section 2.2.2 Section 2.2.4

Figure 7: Overview of motivation discussion in Section 2.2.5.

2.3 Goal Alignment Literature

As the use of groups has become commonplace in different fields (especially engineering), research on group development has increased. One of the leading models of group development is proposed by Tuckman [29]; this model contains four main stages of group development:

1. Forming – This phase involves the establishment of team organization, roles, and meeting times. Individuals try to avoid controversy during this phase.
2. Storming – This is the phase where the individuals on the team begin to develop solution concepts to the given design problem. The majority of

controversy will take place in this phase as students will compete with each other over whose idea is the best. The controversy is necessary in the development of a high functioning team.

3. Norming – The Norming Phase involves the establishment of team norms and goals. Only after establishing common practice and goals can a team begin to function at its highest level of potential.

4. Performing – The Performing Phase occurs after the development of common goals; during this phase the team will perform at its highest levels, working as a cohesive unit towards their goals.

A fifth stage (adjourning) was later added to the model by Tuckman and Jensen [43] but is not the focus of most research. Runkel and colleagues [44] were the first researchers to validate the stages proposed in Tuckman's model; additional research groups have provided further validation of the model such as the strong statistical support provided by Miller's work in 2003 [45].

The Norming Phase and, more specifically, goal alignment is the focus of this work (Phase Three). The practice of setting goals as a team is known as participative goal setting. By setting goals together, the team can ensure goal alignment, which has been postulated to improve team performance by past researchers [30–35]. Some initial testing performed on railway track maintenance gangs by Pearson [46] has also supported the importance of goal alignment.

2.4 Intervention Literature

The use of interventions has become commonplace in primarily healthcare [47–54] with a growing focus on sports [55–57] and some initial work in the field of engineering [58,59]. Interventions are used within healthcare to improve the health conditions and outlook of infants [50–52], addicts [53,54], and others. Sports interventions have been shown to effectively improve aspects of team performance [55–57]. Within engineering, interventions have been used to guide students through their collegiate careers [58]. Additionally, an advanced intervention method has been proposed by Rivera and colleagues [59] using engineering control principles; they propose trying to simulate the interventions so the outcome can be optimized [59].

Interventions can be either fixed or adaptive. Fixed interventions occur when all participants receive the same type of treatment [59]. Conversely, the participants receive different treatments dependent on their specific needs in adaptive interventions [65]. The research discussed in this work (Chapter Five) employed adaptive interventions such that all engineering design teams receive a slightly differing experience.

When developing interventions aimed to affect the performance of participants, it must be determined whether feedback will be given to participants about their current levels of performance. The use of interventions generally has positive effects on performance; however, some previous research has shown that feedback interventions can have a negative effect on the performance of the subjects [36].

2.5 Chapter Conclusions

Current research in the areas of innovation, motivation, goal alignment, and interventions were reviewed to understand the current state of research on these topics. The following is meant to give some clarification as to why these four specific topics were reviewed:

- Innovation: The inherently innovative nature of engineering design courses paired with the increase focus on innovation by companies resulted in the desire to review works with an emphasis on innovation
- Motivation: Understanding motivation is a challenging issue that is rarely discussed or researched within the fields of engineering. The purpose behind researching motivation in engineering was to develop a baseline understanding of motivation in current literature to allow for the development of an effective motivation survey.
- Goal Alignment: The establishment of team goals was a practice that the author believed was instrumental in the success of past research projects on which he was involved. As such, research on the establishment of common team goals was researched to determine if previous work had been conducted to validate the importance of goal alignment within a group.
- Interventions: Interventions were chosen as the tool to facilitate goal alignment within engineering design teams. As such, works were

reviewed to determine past uses of interventions and the effectiveness of said interventions.

The subsequent chapter discusses the research approach used to fulfill the research objectives established in Chapter One.

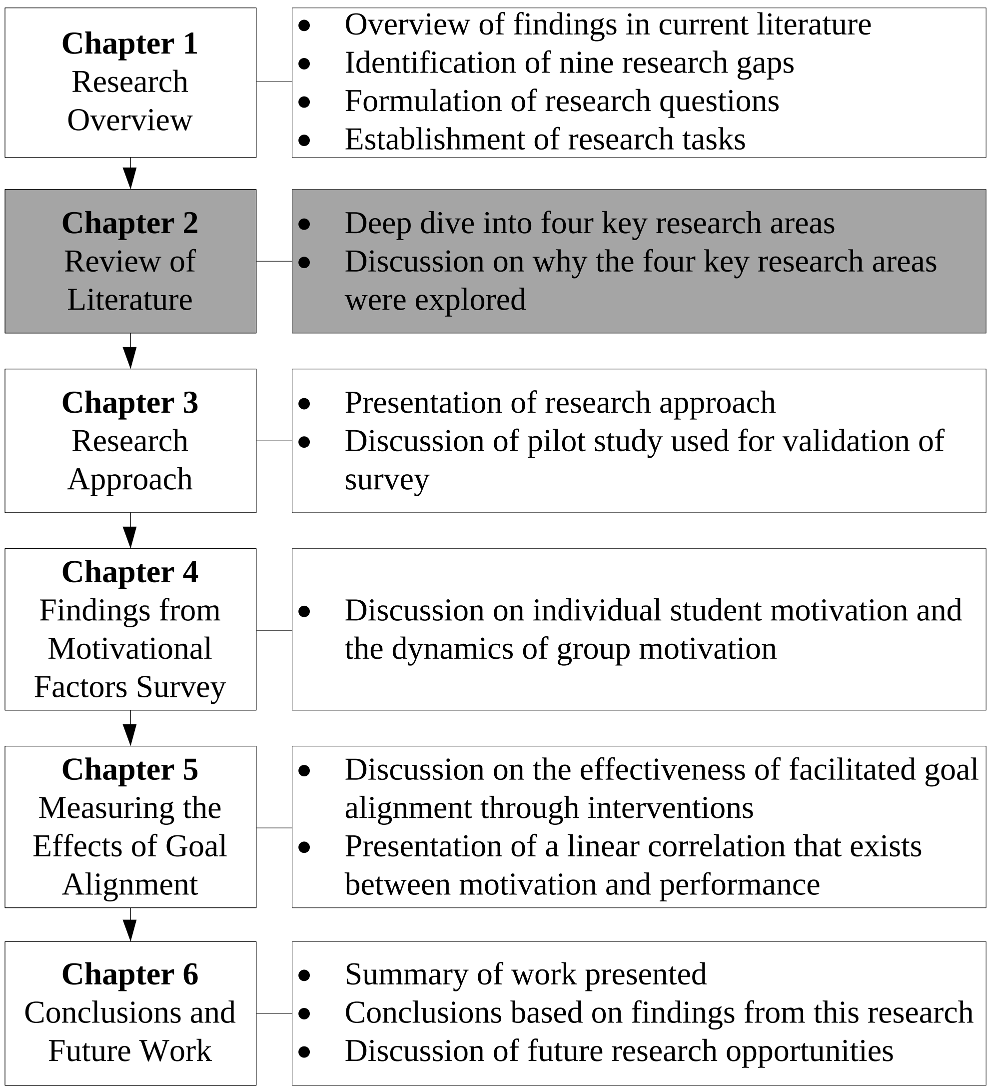

Figure 8: Thesis framework.

Chapter Three:
RESEARCH APPROACH

Chapter Aims:

- Discuss the initial methodology used for survey formulation,
- Present the results of a pilot study and discuss how this information was used to refine the surveys,
- Describe the general approach used to obtain data to be analyzed, and
- Describe the test subjects, time frame, and raters used for this research.

This chapter describes the experimental procedure in detail including the development of a motivation survey, the test subjects, raters, time frame, and general approach used to arrive at the results.

3.1 Overview of Surveys

The work presented in this thesis is focused on the findings from academic surveys (findings discussed in Chapter Four) with the industry portion being discussed in future work (Section 6.3). The test subjects were senior mechanical engineering students working in design teams on their capstone design projects. Initially, two surveys were developed to determine (1) which motivational factors most effectively push students when working on innovative design projects and (2) which motivational factors most effectively push engineers working on innovative design projects in industry (academia versus industry).

In addition to motivational survey data, weekly evaluations of all design teams' levels of performance and motivation were recorded. These weekly evaluation scores were to be used for two main purposes: (1) determine if a correlation exists between motivation and performance and (2) quantitatively determine the effects that goal alignment interventions have on the performance and motivation of design teams (findings discussed in Chapter Five).

3.2 Development and Testing of Initial Survey

An initial survey was developed in an attempt to determine which motivational factors students perceive to be most effective when working on innovative design projects. The initial survey was tested on twenty students in a pilot study to improve the quality before implementation.

3.2.1 Survey Formulation

As Del Greco and Walop [66] have pointed out, it is important to determine what you are trying to learn from the survey and then carefully formulate the questions. The researchers must also know the area of research well if they want to make an effective survey [67]. For this survey, this knowledge was gained by reviewing over forty papers on incentives, motivation, and innovation (as discussed in Chapter Two).

The survey that was administered contained four questions. The first was a closed question asking users to rate on a Likert scale the following thirteen motivational factors:

1. Making an "A" grade in the class
2. Making a passing grade in the class
3. Professional contacts (industry sponsors)
4. Professional contacts (fellow students)
5. Professional contacts (instructors/advisors)
6. Cash prizes

7. Impress faculty
8. Impress peers
9. Impress sponsors
10. Developing an "elegant" solution
11. Patents
12. Coming up with a better solution than other groups (pride)
13. Best solution being posted on the Clemson University webpage (public recognition)

The second and third questions allowed users to select the five factors (from the previous thirteen) that they believed would have the greatest and least impact on their performance when completing an engineering design project. Finally, an open-ended question was used, allowing participants to expand on previous answers or recommend other motivational factors that may have been omitted (as recommended by several researchers [68,69]). The responses to question four were used to improve the surveys for future use; these responses were not used for any statistical analysis as that was not the purpose of this question. The survey used for the pilot study can be found in Appendix A.

Triangulation is a common method that is used to validate questionnaire findings; by asking a similar question using multiple methods, one can ensure that the same response is given on every occasion [70,71]. The method of triangulation was considered when developing the survey. By asking the same basic question in three different ways, the results can be compared to ensure the consistency of responses; note that this is a very basic form of triangulation as it often refers to using multiple methods whereas this survey asks the same questions in different forms. In addition to this, Del Greco and colleagues [72] point out that the survey should only be given to people within the target group to ensure valid results are found. For this reason, the survey was only administered to individuals within the target study group.

As was recommended by Del Greco and colleagues [73], the research questions were posed such that the responses could be easily analyzed. By using a Likert scale and asking the participants to select the five best and worst motivational factors, the results can be easily analyzed and presented (reflected in the subsequent section). The initial data that was gathered served two main purposes: (a) to serve as a pretest to determine the effectiveness of the survey and (b) to begin to develop a baseline of motivational factors that most effectively promote innovative thinking and design.

3.2.2 Pilot Study

The initial survey was administered to twenty mechanical engineering students at Clemson University (both graduate and undergraduate). These students volunteered five minutes of their time to fill out the survey and give feedback (question four) on the effectiveness of the survey. In order to protect the identities of the participants, the results were recorded in a spreadsheet (without the names) and the original surveys were shredded. The scoring system that was used to analyze the results was the following:

- a value of "1" was given to responses when students indicated that said response was one of the top five most impactful motivational factors (question two)

- a value of "-1" was given responses when students indicated that said response was one of the top five least impactful motivational factors (question three)
- a value of "0" was given to all remaining factors which did not receive a response (questions two and three)

After these values were applied to the responses of the twenty participants, the values for each of the thirteen factors were summed to get an overall score. This score was deemed to be the level of effectiveness for each particular motivational factor. These scores were organized from greatest to least and plotted (as seen in Figure 9).

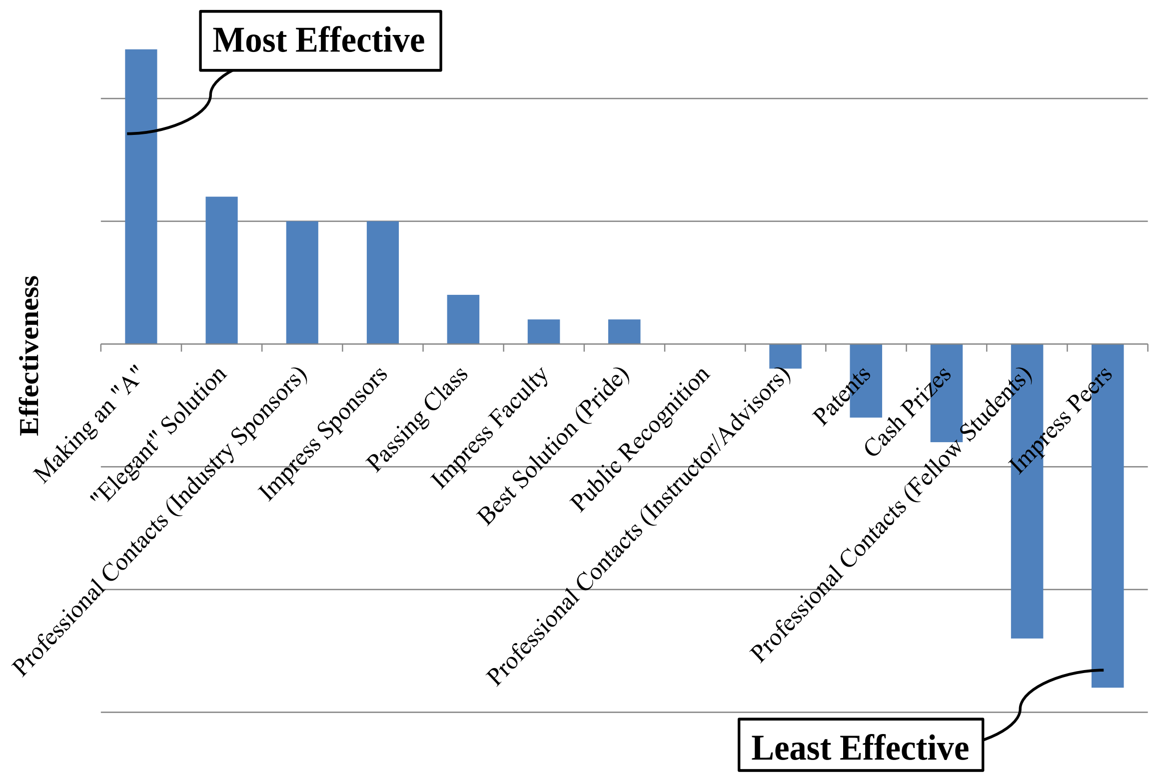

Figure 9: Level of effectiveness plot from the twenty participants involved in the pilot study.

Furthermore, Table 1 shows the percentage of responses that students gave to each of the thirteen factors. Note that the percentages do not add up to one hundred percent for all the responses because the respondents only needed to select ten out of the thirteen options.

Table 1: Most and least impactful motivational factors as graded by the twenty participants in the pilot study.

Motivational Factor	Most Impactful Factors (%)	Least Impactful Factors (%)
Making an "A" in the Class	80	20
Creating "Elegant" Solution	45	15
Professional Contacts (Industry Sponsors)	55	30
Impress Sponsors	45	20
Impress Faculty	35	25
Making a Passing Grade in the Class	35	25
Developing the Best Solution (Pride)	45	40
Public Recognition	45	45
Professional Contacts (Advisors/Instructors)	25	30
Patents	30	45
Cash Prizes	30	55
Professional Contacts (Fellow Students)	5	65
Impress Peers	5	75

From the survey responses, it was determined that "making an A grade" in the class was the motivational factor that would most effectively push students to perform at a high level when working on innovative design projects. This aligns to the findings of past psychology researchers in that students generally work hard so that they can receive a good grade in the class [74,75].

Ideally, the answers with the greatest amount of positive responses would have the least amount of negative responses, and vice versa. While the results did not perfectly follow this trend, the findings show that the factors with the highest amount of positive responses had the least amount of negative responses, and vice versa. This confirms the consistency of the results at the extreme ends of the spectrum. This is important as the most and least impactful factors are of the most interest. The discrepancies that can be seen (mostly in the middle of the table) are due to the differing opinions of students.

The final question of the survey was open-ended allowing the respondents to recommend any other motivational factors that may have been omitted. The following is the additional motivational factors that were recommended and a brief description as to why they were or were not included in the refined survey:

1. <u>Salary</u> – as these motivational factors are for students, giving them a regular salary is not realistic (however it was included in the survey that will be administered to design engineers working in industry)
2. <u>Making my family proud</u> – although this is a key motivational factor, this is not something that cannot be applied into an extrinsic motivator

3. Being awarded with a certificate – this is similar to the final factor of the existing survey (best solution being posted on the Clemson University webpage); some re-phrasing will be done to make this be a more generic factor (e.g. "public recognition")
4. Wanting to "improve the world" or "move the world forward" – this is an outcome of a successful project and thus is not something that can be considered as a motivational factor
5. Passion to design things in the best way possible – this is dependent on the internal drive (intrinsic motivation) of the individual and thus is not an extrinsic motivator
6. Working on a project in which I had an emotional investment – as has been pointed out by researchers in the field of psychology [13], having an emotional investment in a project can increase the overall performance of the group; thus, there is a desire to keep design groups invested in the project however this is not something that can be made into a single motivational factor
7. Learning about new ideas and products (self-improvement) – this is dependent on the internal drive (intrinsic motivation) of the individual and thus is not an extrinsic motivator
8. Self-Approval: doing the best that I know I can – this depends on the performance of the students and thus cannot be an extrinsic motivator

9. Increased project budget (after the start of the project) – this is an interesting concept which may not be a strong motivational factor at the beginning of the semester; however, when asked at the end of the semester, this may receive more votes once students understand the usefulness of the project; for these reasons, this was included on the revised survey as a motivational factor

10. Representing Clemson well (making my school proud) – this is dependent on the students' performance and thus is not something that can be easily made into an extrinsic motivator

11. Working as a team – while this is not an extrinsic motivator (since all respondents to this project are working on a team project) it is interesting to note that engineers often enjoy the camaraderie that develops within a design team as the semester progresses

While the feedback provided good ideas for what may motivate the students to perform well, the initial plan was to only look at extrinsic motivational factors and as such the only additional factor that was found to have merit was an "increased project budget". This factor was included in the refined version of the survey to see whether or not others believe that an "increased project budget" (based on performance) will drive them to develop more innovative solutions to design problems. Furthermore, the final factor of the original survey was changed to be a more generic "public recognition" so as to include extrinsic motivational factors such as certificates and being recognized on the school's website. The refined version of the survey used to collect all experimental data can be found in Appendix B.

3.3 Administering the Refined Motivation Survey

This section describes the procedure of how the surveys were administered, how responses were captured, to whom the surveys were given, and the time frame in which the data was collected. Note that the refined survey that was administered can be found in Appendix B.

3.3.1 Test Subjects

The test subjects were senior mechanical engineering students enrolled in the senior capstone course (ME 402) at Clemson University. The class of 87 students was asked to voluntarily fill out the survey on the first day of class (January 2013) and at the end of the semester (April 2013). Taking responses at the beginning and end of the semester enabled the researchers to not only understand what most effectively motivates students but to also begin to understand how motivation of students changes over the course of a design project (longitudinal study). There were 63 students who filled out the survey (72.4% response rate) at the beginning of the semester and 41 students who filled out the survey (47.2% response rate) at the end of the semester. Note that 35 students responded at the beginning and end of the semester (40.2% response rate).

3.3.2 Preparing the Data for Analysis

The survey that was administered to the students was nearly identical to the version used during the pilot study in that it only included one additional motivation factor (“increased project budget”) and a rewording to “public recognition”. As such, it contained the four same questions with slightly differing options. The likert values (question 1) needed no manipulation before analysis and as such were just recorded in an Excel spreadsheet. The responses for questions two and three were recorded using the following method to enable simple analysis:

- a value of “1” was given to responses when students indicated that said response was one of the top five most impactful motivational factors (question two)
- a value of “-1” was given responses when students indicated that said response was one of the top five least impactful motivational factors (question three)
- a value of “0” was given to all remaining factors which did not receive a response (questions two and three)

The textual responses to question four were left alone to be analyzed manually. Automation of the analysis of responses to question four is discussed in Section 6.3.

3.4 Procedure Used to Measure the Effects of Goal Alignment Interventions

Measuring the effects of goal alignment interventions was one of the main objectives of this research. In this section, the experimental procedure is described in detail including the test subjects, raters, time frame, and general approach used to arrive at the results.

3.4.1 Test Subjects

The test subjects were senior mechanical engineering students working in teams of four to five students to develop solutions to problems given to them by industry sponsors. More specifically, fifteen groups of four students and three groups of five students were studied (total of seventy-five students). The eighteen groups were working on six different projects (three teams to each project) and will henceforth be denoted as "design teams". A summary of the eighteen design team, their project type, and a generic description of their project can be seen in Table 2.

Table 2: Summary of design teams.

Project Type	Group	Group Size	Generic Project Description
Industry Sponsored	A-1	4	Design a tool to improve the ergonomics of a manufacturing process
	B-1	4	
	C-1	4	
Industry Sponsored	A-2	4	Design a fixture to assist in a manufacturing process
	B-2	4	
	C-2	4	
Academic Sponsored	A-3	4	Design a robust device to assist in outdoor research activities
	B-3	4	
	C-3	4	
Industry Sponsored	A-4	5	Design a fixture to assist in a manufacturing process
	B-4	5	
	C-4	5	
Industry Sponsored	A-5	4	Design a fixture to test the performance of an existing product
	B-5	4	
	C-5	4	
Industry Sponsored	A-6	4	Improve the design of an existing product
	B-6	4	
	C-6	4	

3.4.2 Raters

The raters consisted of six individuals (one for each of the six different projects). Four of the raters were mechanical engineering graduate students and the other two raters were professors. All six of the raters either teach or research engineering design. These raters were members of the technical advisory committees for the six respective projects. As members of the advisory committees, the raters had weekly interactions with their three respective design teams making them the best candidates to rate the design teams on a weekly basis.

3.4.3 Rating Process

The design teams were assigned two grades every week by their respective rater: a letter grade (A, B, C, D, or F) for level of motivation and a letter grade for level of performance. It is important to note that often the raters would select an in between grade for the week (A/B, B/C, etc.). Discussion with the raters resulted in the same general definitions of motivation and performance: performance grades were based on quality of work while motivation was generally based on quantity of work and level of excitement of the design teams. The raters were instructed that the grades given should in no way be affected by any work done outside of that specific week. Additionally, the grade was given by the same person every week to ensure consistency throughout the process. The weekly grades given by the raters were used to find the average level of motivation and average level of performance for each team during each segment of the semester. The weekly letter grades were transformed into corresponding numerical values to enable the analysis; these grades and their corresponding numerical values are summarized in Table 3.

Table 3: Weekly letter grades and their corresponding numerical values used for analysis.

Letter Grade	Numerical Value
A	5.0
A/B	4.5
B	4.0
B/C	3.5
C	3.0
C/D	2.5
D	2.0
D/F	1.5
F	1.0

3.4.4 Time Frame

The research discussed in this work was conducted during the spring 2013 semester (January to May) at Clemson University. The design projects with which the design teams were tasked lasted a total of fourteen weeks. Rather than analyzing the data week by week, the semester was broken up into three segments (summarized in Table 4). The notations (S1, S2, and S3) will be used for the remainder of this work.

Table 4: Breakdown of weeks included in each segment.

Segment	Weeks	Notation
1	1 - 4	S1
2	5 - 9	S2
3	10 - 14	S3

3.4.5 Approach

During the first week of the semester, each student was asked to fill out a one question survey asking the following about project goals: “What are your goals in terms of level of performance for this class?” The individual goals for all members of each design team were compiled and compared to determine if design teams had common goals. It was found that this was not the case and as such five design teams (treatment group) were randomly selected to receive a goal alignment intervention. The sample size was limited to five design teams so that each team receiving the intervention would have ample time for meeting and discussion. The remaining thirteen teams were left to proceed without any interaction from the researchers (control groups). At the end of S1 (prior to week five), the five treatment groups were asked to meet with the primary researcher to discuss and set team goals (intervention); the initial time frame allowed for the development of a baseline performance for all design teams (as recommended by Komaki and Barnett [57]). Figure 10 gives a visual representation of this process. The details of these interventions are discussed in the subsequent section (Section 3.4.6).

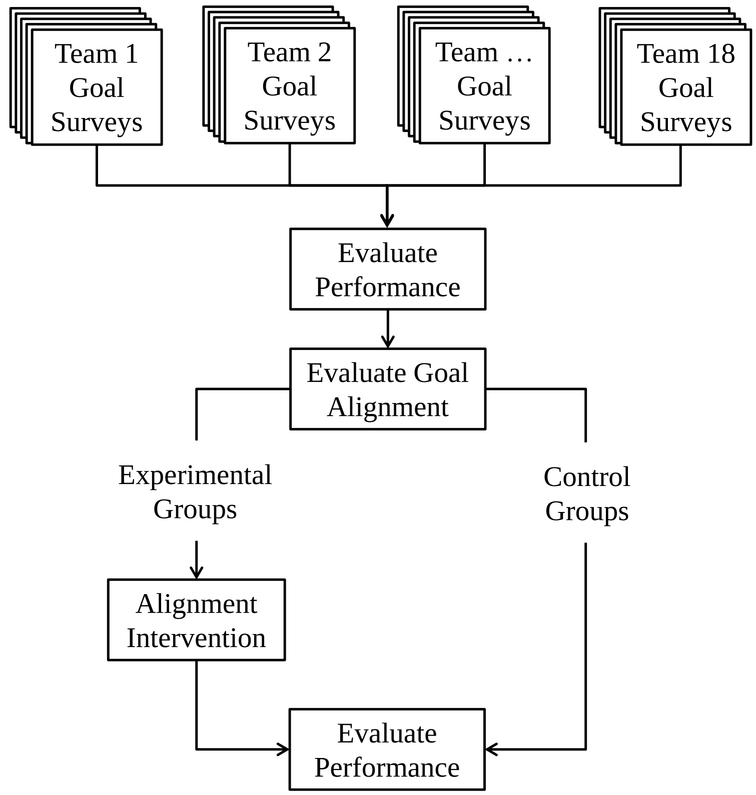

Figure 10: Plan to quantify the effects of goal alignment interventions.

3.4.6 Intervention Discussion

The objective of the interventions was the facilitation of a goal alignment contract for the design teams. During the twenty minute interventions the design teams were to discuss their goals, decide which goals they were trying to meet as a cohesive team, and explicitly record these agreed upon goals (contract). The interventions accomplished this in three parts:

1. <u>Presentation</u> – The presentation included a short discussion about the importance of innovation, an explanation of Tuckman's four stage model [29], a discussion about the necessity of goal alignment, and a presentation of the compiled list of individual goals.

2. Open Discussion – The open discussion afforded the students the opportunity to ask any questions about the research. This discussion often included clarification of the research purpose, selection process, or a discussion of how this same methodology had been applied to the intervention facilitators past experiences in two capstone projects. Note that Blake Linnerud (primary researcher) was the intervention facilitator for all design teams.

3. Goal Alignment – During the goal alignment phase of the intervention, the design teams were given a contract listing the individual responses to the initial survey (as seen in Figure 11). They were asked to rank these goals as a team and then turn it in to the primary researcher. The students were left alone during this portion of the exercise to be allowed to discuss in private. By turning in the forms at the end of the discussion, the researchers could verify that the students actually completed this step of the process. The presentation of design team specific goals made this an adaptive intervention [59].

As a team, rank your initial set of goals.

1	To make an "A" grade in the class
4	Help the team find an innovative solution
3	Develop a solution to the given problem
5	Develop a good solution
2	Find a solution that will be used by the sponsor
6	Do my best

Are there any other goals as a team that you would like to strive to meet?

- Do better than groups B & C (Rank #2)
- Long lasting solution (Rank #3)

Where would these additional goals rank in respect to the goals from the initial list?

See above

Figure 11: Example goal alignment form filled out by one of the treatment teams during the intervention.

3.5 Chapter Conclusions

The goal of this chapter was twofold: to present the approach used to administer the surveys and to present the approach used to facilitate the goal alignment of design teams. The pilot study validates the use of the proposed motivation survey; additional motivation factors were recognized that improved the robustness of the survey. There is a high probability that some of the motivational factors discussed in this chapter are related and as such will affect the others. For example, if students realize that they can receive an increased project budget based on their level of performance in the first half of the class they will most likely put a higher emphasis on “making an A in the class” at the beginning of the class. The next two chapters present the findings with respect to the two outlined research areas.

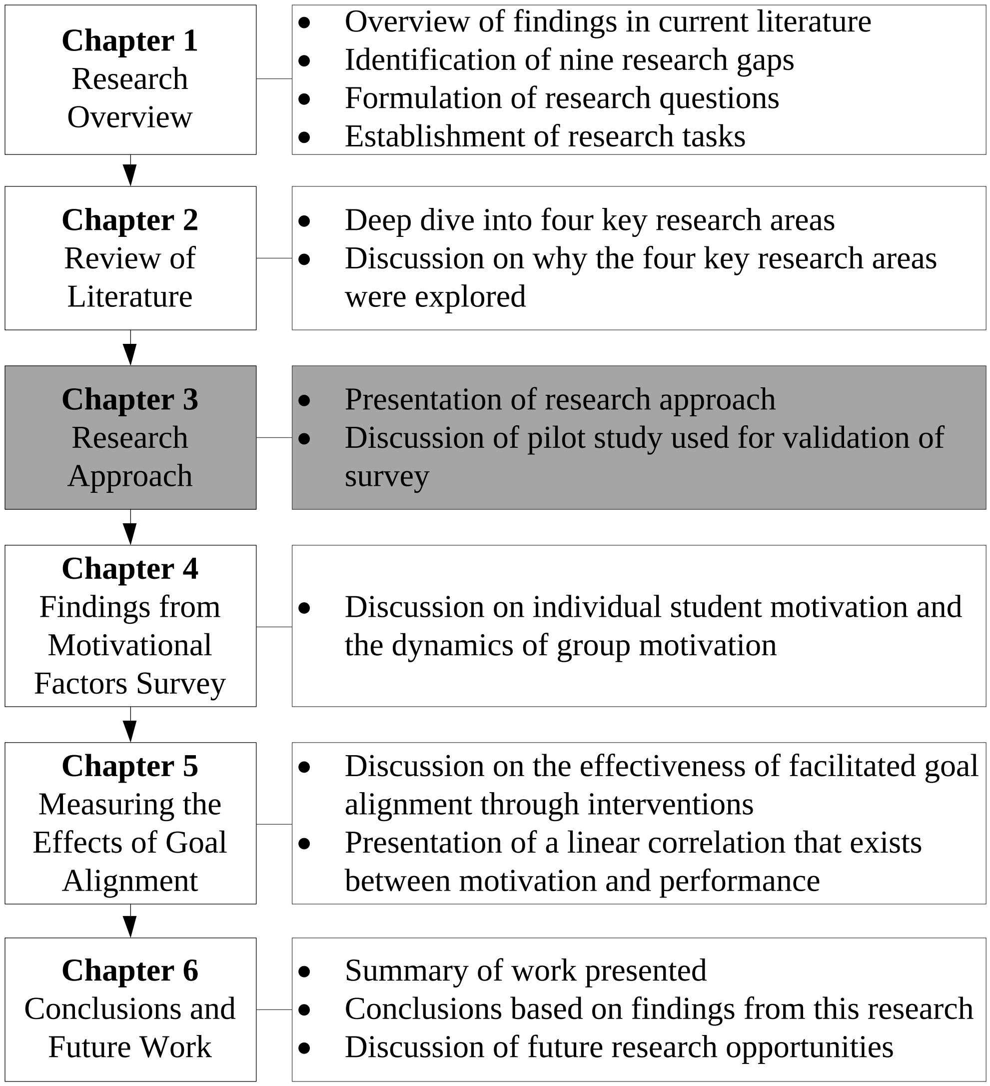

Figure 12: Thesis framework.

Chapter Four:
FINDINGS FROM MOTIVATIONAL FACTORS SURVEY

Chapter Aims:

- Present findings from the motivation surveys administered to the students,
- Prove the effectiveness of the survey via basic triangulation methods,
- Discuss how student motivation changes over the course of a design project, and
- Discuss group agreement of motivational factors.

Chapter Four presents and discusses findings recognized by the researchers when analyzing the motivation survey data. The motivation survey allowed the researchers to begin to understand what motivates students when working on innovative engineering design projects.

4.1 What Motivates Students?

As was discussed in Section 1.2.1, there has been little research done to understand what motivates students when working on engineering design projects. The findings from these surveys will serve as a baseline for understanding engineering student motivation when working on design projects. Having an understanding of student motivation can serve many purposes:

1. Determining which motivational factors most effectively push students when working on design projects (discussed in Section 4.1) and using this survey information to tailor design courses in a way that maximizes student motivation (discussed in Section 6.3)
2. Developing a motivational factor survey that produces reliable results (discussed in Section 4.2)

3. Understanding how student motivation changes after completing their first real-world engineering design project (discussed in Section 4.3)

4. And, determining if student agreement on motivational factors changes within a design team over the course of a project (discussed in Section 4.4).

Determining the effectiveness of motivational factors was accomplished by analyzing the beginning of semester survey data (survey can be found in Appendix B). Using the responses to question one (likert scale), the scores of the sixty-three respondents were averaged for each of the fourteen motivational factors; these values and their corresponding standard deviations are summarized in Table 5 and are presented graphically in Figure 13.

Table 5: Summary of survey responses to question one at the beginning of the project (average and standard deviation).

	Motivational Factor	Average	Standard Deviation
1	Passing Class	4.40	1.14
2	Impress Sponsors	4.29	0.89
3	Making an "A"	4.22	0.85
4	"Elegant" Solution	4.14	1.00
5	Professional Contacts (Industry Sponsors)	4.13	0.91
6	Professional Contacts (Instructor/Advisors)	3.97	0.84
7	Best Solution (Pride)	3.83	1.04
8	Professional Contacts (Fellow Students)	3.54	0.89
9	Impress Faculty	3.48	1.08
10	Impress Peers	3.22	1.08
11	Public Recognition	2.63	1.17
12	Patents	2.52	1.11
13	Increased Project Budget	2.51	1.12
14	Cash Prizes	2.25	1.24

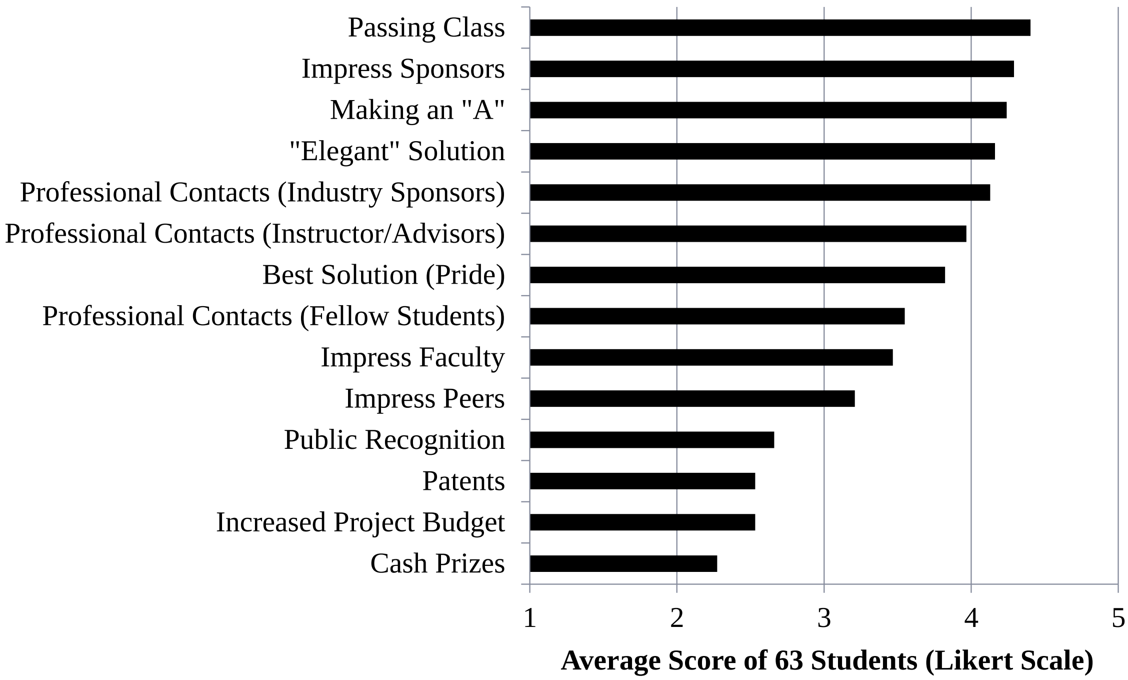

Figure 13: Average scores of responses to question one of the motivation surveys at the beginning of the semester.

It can be seen from Figure 13 that passing the class, impressing the sponsors, and making an "A" grade in the class were the three motivational factors that students believed would be most impactful when working on their design projects. Conversely, it can be seen that receiving cash prizes, an increased project budget, and patents were the three motivational factors that students believed would be the least impactful when working on their design projects.

4.2 Validation of Survey through Basic Triangulation

As was discussed in Section 3.2.1, a basic form of triangulation was used to validate the survey findings. The survey responses to questions two and three were compared to question one, increasing the confidence in responses. Table 6 summarizes the findings of questions two and three.

Table 6: Summary of survey responses to questions two and three of the motivation surveys.

	Motivational Factor	Most Impactful Responses (%)	Least Impactful Responses (%)
1	Professional Contacts (Industry Sponsors)	69.84	9.52
2	Making an "A"	68.25	15.87
3	Impress Sponsors	66.67	4.76
4	Passing Class	55.56	9.52
5	Professional Contacts (Instructor/Advisors)	52.38	11.11
6	"Elegant" Solution	52.38	17.46
7	Best Solution (Pride)	47.62	22.22
8	Impress Faculty	26.98	19.05
9	Professional Contacts (Fellow Students)	26.98	34.92
10	Impress Peers	14.29	58.73
11	Cash Prizes	7.94	77.78
12	Patents	6.35	65.08
13	Public Recognition	4.76	73.02
14	Increased Project Budget	0.00	80.95

Note that the responses highlighted in light grey at the top of Table 6 (one, two, and four) were the highest scoring factors in question one and the responses highlighted in dark grey at the bottom of Table 6 (twelve, thirteen, and fourteen) were the lowest scoring factors in question one. The consistency in responses seen between question one and questions two and three, particularly at the extreme ends of the spectrum, validates the effectiveness of this survey.

4.3 Does Perspective Change on Motivational Factors over the Course of a Project?

Upon completion of the semester, the same motivational survey (found in Appendix B) was administered to the same group of students. Of the original sixty-three students that responded, thirty-five responded again (forty-one responses in total). The responses of the thirty-five students that completed both surveys were analyzed to determine if perspective changes with regards to motivational factors over the course of the semester. First, the likert scores given to each of the fourteen motivational factors at the end of the semester were subtracted from the likert scores given to each motivational factor at the beginning of the semester. The average difference value for each of the thirty-five responses was then found and compared to determine which factors had the largest changes in score. The following steps simplify the analysis that was used for this information:

1. *StudentAResponse@Beginning – StudentAResponse@End = StudentADifference*
2. *StudentBResponse@Beginning – StudentBResponse@End = StudentBDifference*
3. ***Repeat Step 1 / 2 for all 35 students***
4. *Average (StudentADifference, StudentBDifference, etc.)*
5. *Standard Deviation (StudentBDifference, StudentBDifference, etc.)*

The average change in response for each of the motivational factors is summarized in Table 7. Additionally, a graphical representation of the responses at the beginning and end of the semester can be seen in Figure 14. It is important to note that the survey data for the thirty-five students was compared to all responses to ensure that the responses by the thirty-five students accurately represented the entire population of responses. It was found that the responses were nearly identical as can be seen in Figure 15.

Table 7: Summary of motivational factor score changes from beginning to end of the project (average and standard deviation).

	Motivational Factor	Average	Standard Deviation
1	Impress Peers	0.26	1.21
2	Impress Faculty	0.24	1.26
3	Best Solution (Pride)	0.21	1.41
4	"Elegant" Solution	0.15	1.19
5	Passing Class	-0.12	1.40
6	Making an "A"	-0.21	1.23
7	Public Recognition	-0.29	0.90
8	Impress Sponsors	-0.35	0.96
9	Professional Contacts (Fellow Students)	-0.44	1.07
10	Increased Project Budget	-0.53	1.45
11	Professional Contacts (Instructor/Advisors)	-0.59	1.09
12	Patents	-0.68	1.06
13	Cash Prizes	-0.79	1.24
14	Professional Contacts (Industry Sponsors)	-1.21	1.19

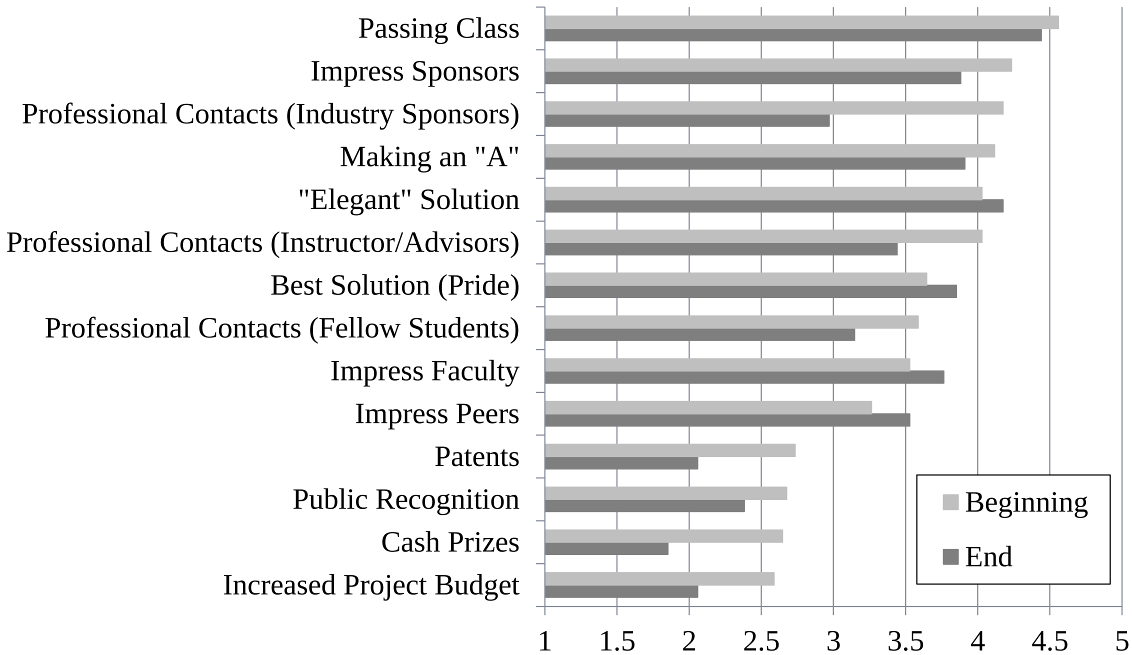

Figure 14: Average scores of responses to question one of the motivation surveys at the beginning and end of the project.

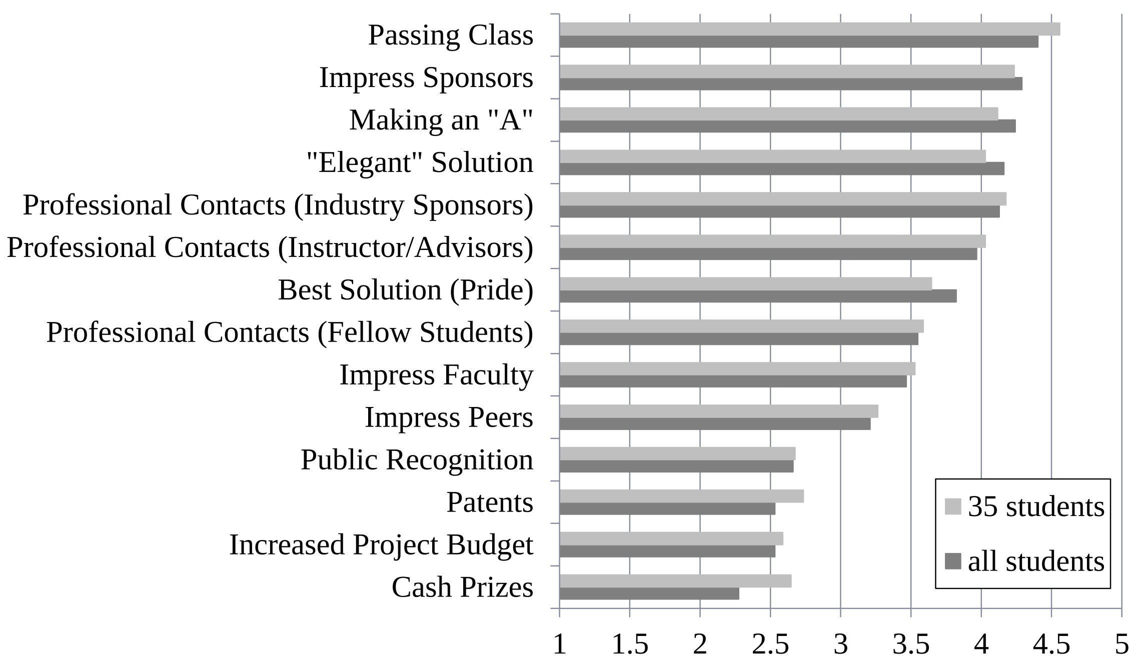

Figure 15: Comparison of 35 students average responses compared to all students.

As shown in Table 7, all but four of the average score values decreased over the course of the project. The only four motivational factors that saw an increase in score were the following: impressing peers (+0.26), impressing faculty (+0.24), developing the best solution of all design teams (+0.21), and developing an elegant solution to the problem (+0.15). The researchers believe that these factors can be grouped into two classes:

1. <u>Quality of Solution (Elegant and Best Solution)</u> – Development of a quality solution becomes the focus of students as they progress on a design project. That is, students want to come up with a solution that they believe is of the highest quality when viewed alone or compared to the solutions developed by other design teams.
2. <u>Perception of Solution (Impressing peers and faculty)</u> – As the project progresses, students begin to care more about how their solution is perceived. Students are working towards the development of a solution of which they can proud.

The motivational factor that saw the largest decrease (-1.21) over the course of the project was "making professional contacts with the industry sponsor". It is believed that this was a byproduct of the way the capstone design course is organized at Clemson University; that is, the students do not generally have the opportunity to get a job based solely on their performance on the project. As there are many well-known companies associated with the course (e.g. BMW, Boeing, GE), this is one of the top motivational factors at the beginning of the semester that declines drastically once students realize that they will most likely not receive job offers directly based on their performance.

4.4 Agreement on Motivational Factors within a Group

The final use of the motivation survey data was to quantitatively determine to what extent group members agree on the effectiveness of different motivational factors at the beginning and end of a design project. The reliability of agreement on motivational factors was calculated using Fleiss' Kappa on all teams which fully responded to the survey (e.g. four out of four group members filled out the survey). Furthermore, the Fleiss' Kappa values were calculated for each of the three survey questions; note that a Matlab code was written to automate this process (see Appendix C). A summary of Fleiss' Kappa values for each of eleven teams that fully responded at the beginning of the semester can be seen in Table 8.

Table 8: Summary of Fleiss' Kappa values for design teams responses at the beginning of the semester to the motivation survey.

Team	Question 1	Question 2	Question 3
1	0.16	0.48	0.27
2	0.31	0.33	0.43
3	0.25	0.43	0.38
4	0.31	0.33	0.17
5	0.28	0.69	0.69
6	0.02	0.12	-0.14
7	0.39	0.33	0.43
8	0.12	0.43	0.22
9	0.00	-0.04	0.07
10	0.14	0.22	0.33
11	0.15	0.17	0.27

Note: numbers highlighted in light grey show "moderate" agreement (0.41-0.60) and numbers highlighted in dark grey show "substantial" agreement (0.61-0.80).

As shown in Table 8, only team 5 showed substantial agreement on any of the questions; furthermore, only 6 of a possible 33 responses (18%) showed moderate agreement or better. It was thus concluded that student design teams do not generally agree on motivational factors on all levels. To further expand the understanding of group agreement, Fleiss' Kappa values were computed for responses to the end of semester surveys. Only three of the teams fully responded to the surveys at the beginning and end of the semester (teams six, seven, and eight). The Fleiss' Kappa values from the beginning of the project were subtracted from the corresponding Fleiss' Kappa values at the end of the project to determine a difference in score. Positive difference values indicate that there was some improvement in agreement while negative difference values indicate some decline in agreement. These values are summarized in Table 9.

Table 9: Summary of motivation agreement (Fleiss' Kappa values) of three design teams over the course of a design project.

	Team	Question 1	Question 2	Question 3
Beginning of Project (S1)	6	0.0208	0.1185	-0.1407
	7	0.3866	0.3259	0.4296
	8	0.1204	0.4296	0.2222
End of Project (S3)	6	0.1597	0.1704	0.0667
	7	0.3353	0.2741	0.2222
	8	0.1485	0.3259	0.3778
Difference	6	0.1389	0.0519	0.2074
	7	-0.0513	-0.0518	-0.2074
	8	0.0281	-0.1037	0.1556

Note: numbers highlighted in light grey show "moderate" agreement (0.41-0.60) and numbers highlighted in dark grey show "substantial" agreement (0.61-0.80).

From Table 9 it can be seen that no strong conclusions can be drawn either way. Four of the nine (44%) Kappa values actually saw a decrease over the course of the project indicating that there was even less agreement at the conclusion of the project. Furthermore, none of the nine teams had even moderate agreement on motivational factors at the end of the semester indicating that the agreement was low. Overall, there was little change in group agreement on motivational factors over the course of the design project, although it is hard to draw conclusions with such a small sample size (n=3). Rather than look at agreement of all fourteen motivational factors for each of the questions, it may be more useful to look at agreement on the far ends of the spectrum (e.g. agreement of top three motivational factors). This and other potential uses for this information are discussed further in Section 6.3.

4.5 Chapter Conclusions

The goal of this chapter is to present findings from the responses to the motivation surveys. It was found that (1) "passing the class", (2) "impressing the sponsors", and (3) "making an A in the class" were the three factors that most effectively promoted innovative design. Conversely, (1) "patents", (2) "increased project budget", and (3) "cash prizes" were the three factors that least effectively promoted innovative design. The use of triangulation validates the effectiveness of the survey. It was also found that student motivation changes over the course of the semester in that students were more motivated by developing a quality solution and how that solution was perceived by their peers and faculty advisors. Finally, it was found that students do not agree on motivational factors at all levels at any point in the design process.

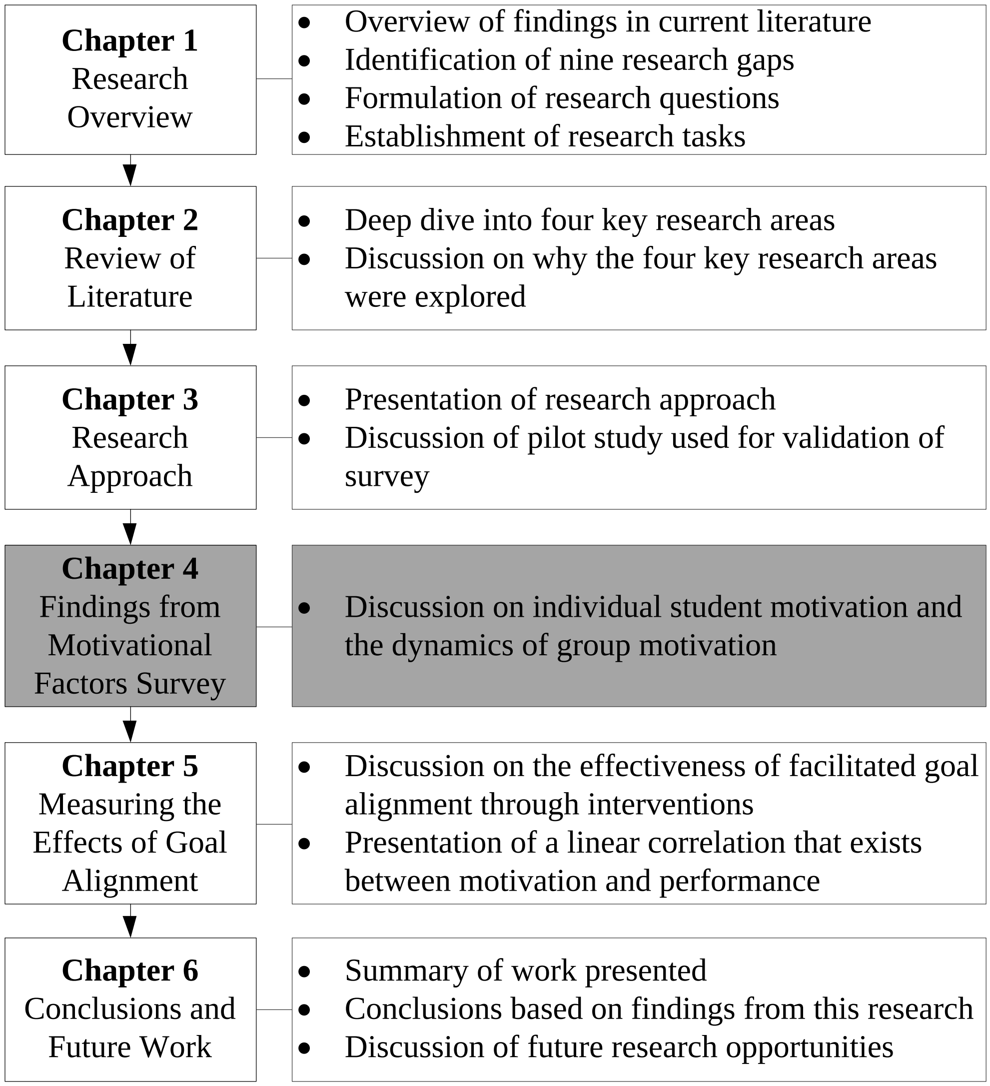

Figure 16: Thesis framework.

Chapter Five:
MEASURING THE EFFECTS OF INTERVENTION ENABLED GOAL ALIGNMENT

Chapter Aims:

- Present student design teams' levels of motivation and performance throughout a design project,
- Present some statistical findings about the performance and motivation data, and
- Present the relationship between motivation and performance.

The weekly evaluation data captured for this portion of the research served two main purposes: (1) to track the level of performance and level of motivation for all design teams over the course of the projects and (2) to determine the relationship between motivation and performance. The work presented in Chapter Five begins to quantify the positive and negative effects that goal alignment interventions can have on the design process. Additionally, a linear relationship between motivation and performance is presented and discussed.

5.1 Motivation and Performance throughout the Semester

As discussed in Section 3.4, each design team's level of performance and motivation was tracked and recorded by a rater on a weekly basis. The data is summarized in Table 10, Figure 17, and Figure 18. It is important to note that lines are used to connect data points between segments in Figure 17 and Figure 18; these are used to make the segment to segment changes more obvious and as such the trends between segments may not be linear.

Table 10: Comparison of average level of performance and motivation for student design teams throughout the spring 2013 semester.

Group	Time Segment	Performance ($\bar{x} \pm s$)	Motivation ($\bar{x} \pm s$)
Intervention (n=5)	S1	3.13 ± 0.38	3.57 ± 0.49
	S2	3.78 ± 0.25	4.20 ± 0.16
	S3	4.10 ± 0.64	4.10 ± 0.40
Non-intervention (n=13)	S1	3.55 ± 0.71	3.81 ± 0.86
	S2	3.76 ± 0.82	4.09 ± 0.80
	S3	4.40 ± 0.52	4.49 ± 0.58

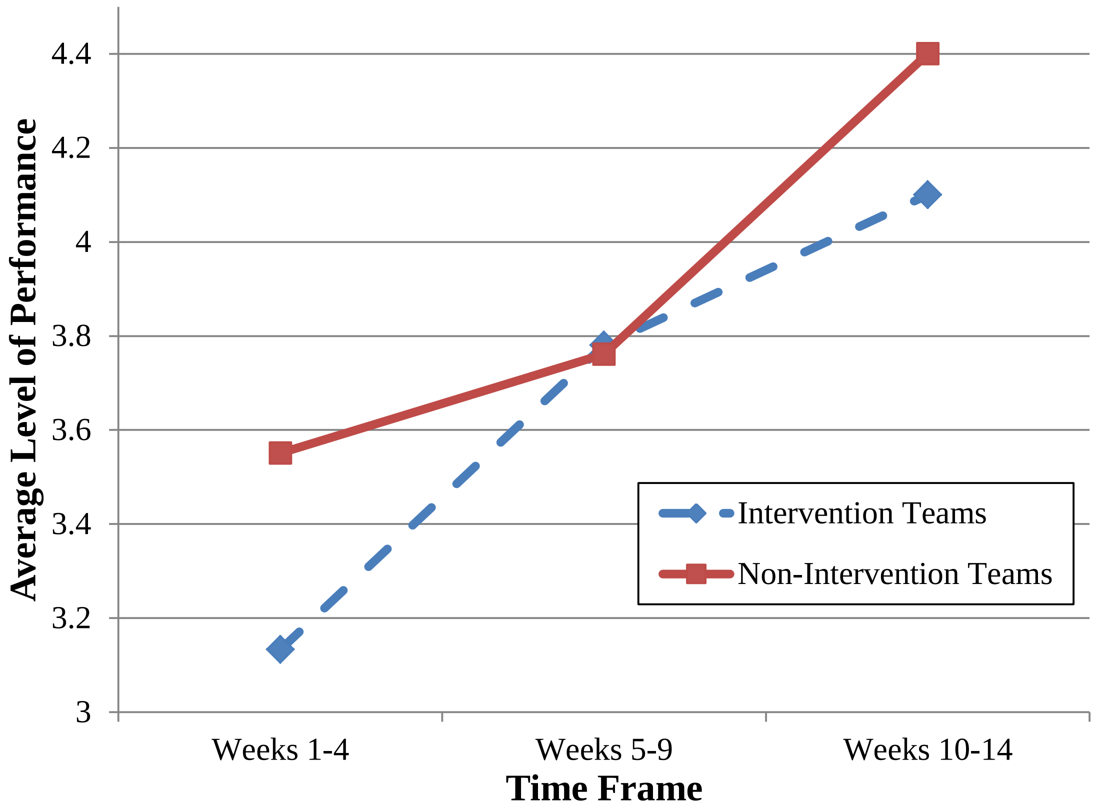

Figure 17: Average level of performance for student design teams throughout the semester.

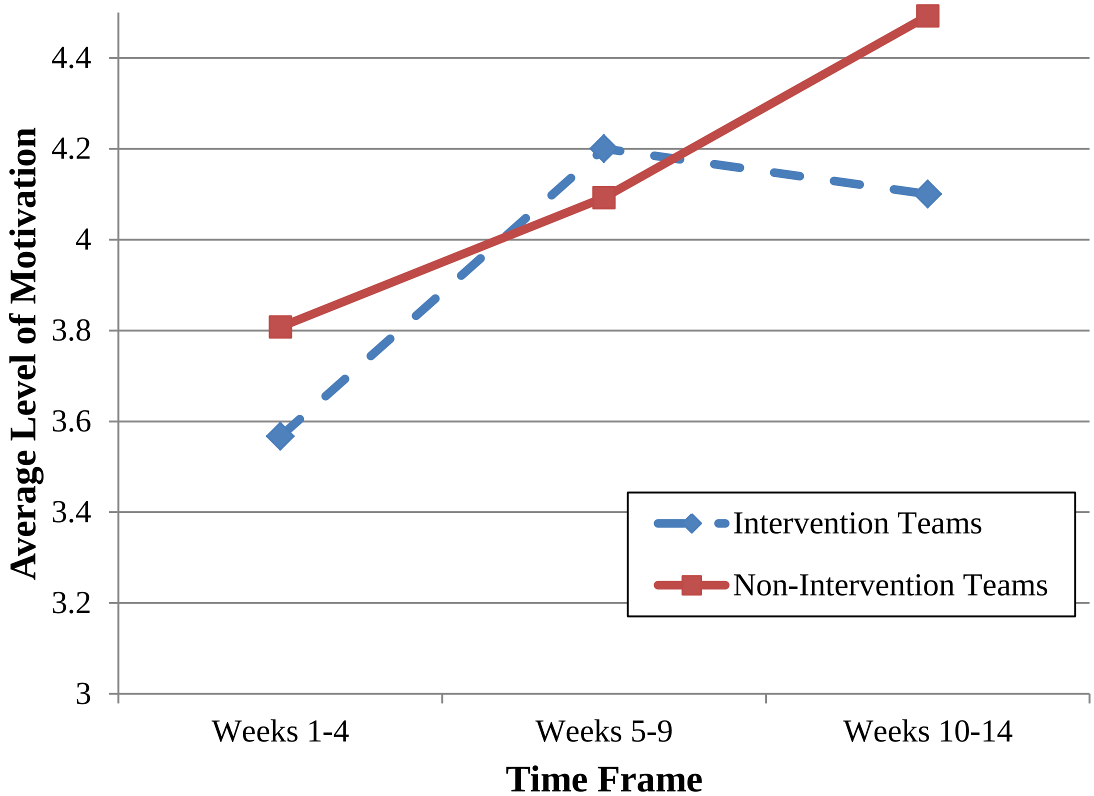

Figure 18: Average level of motivation for student design teams throughout the semester.

Three main trends can be seen from Figure 17 and Figure 18 that are discussed in detail:

1. There was significant improvement for design teams that received the interventions from segment 1 to segment 2 – The design teams that received the interventions saw a large increase in performance and motivation from S1 to S2. This corresponds to the time the design teams received the interventions and thus makes intuitive sense. The statistical implications of this are discussed in Section 5.2.

2. There were differing levels of motivation and performance for the teams that did and did not receive interventions during segment 1 – It was initially assumed that by randomly selecting the design teams that received interventions, the average levels of performance and levels of motivation would be statistically the same for all design teams; however, the inverse was found to be true for performance ($\alpha = 0.1$) and motivation ($\alpha = 0.3$) using an equal variance, unequal sample size t-test (the methods used are presented in Appendix D and Appendix E). It is believed that this discrepancy was caused by the small sample size and will be discussed in Section 6.3.

3. The design teams that received interventions saw a noticeable decline in levels of performance from segment 2 to segment 3 – The most concerning part of this study came in the form of the significantly lower performance (from S2 to S3) of those design teams that received interventions as compared to those that did not receive interventions. Statistically, this was the strongest finding of all the analysis ($\alpha = 0.99$) and is something that will be discussed in Section 6.3.

5.2 Statistical Analysis of Data

A pairwise comparison was done for the difference in performance and difference in motivation of control and treatment design teams. This was done in an attempt to determine the quantitative effects of the interventions on the design process. Table 11 summarizes the performance data compared and Table 12 summarizes the motivational data compared. Note the difference column (shaded in grey) contains the values of interest that were compared using t-tests.

Table 11: (a) Comparison of average level of performance for S1 and S2, (b) Comparison of average level of performance for S1 and S3, (c) Comparison of average level of performance for S2 and S3.

(a)

	Average Level of Performance		
	S1	S2	Difference
Intervention (n=5)	3.13	3.78	0.65
Non-intervention (n=13)	3.55	3.76	0.21

(b)

	Average Level of Performance		
	S1	S3	Difference
Intervention (n=5)	3.13	4.10	0.97
Non-intervention (n=13)	3.55	4.40	0.85

(c)

	Average Level of Performance		
	S2	S3	Difference
Intervention (n=5)	3.78	4.10	0.32
Non-intervention (n=13)	3.73	4.40	0.67

Table 12: (a) Comparison of average level of motivation for S1 and S2, (b) Comparison of average level of motivation for S1 and S3, (c) Comparison of average level of motivation for S2 and S3.

(a)

	Average Level of Motivation		
	S1	S2	Difference
Intervention (n=5)	3.57	4.20	0.63
Non-intervention (n=13)	3.81	4.09	0.28

(b)

	Average Level of Motivation		
	S1	S3	Difference
Intervention (n=5)	3.57	3.98	0.41
Non-intervention (n=13)	3.81	4.49	0.68

(c)

	Average Level of Motivation		
	S2	S3	Difference
Intervention (n=5)	4.20	3.98	-0.22
Non-intervention (n=13)	4.09	4.49	0.40

An equal variance analysis was performed before comparing the difference in average levels of performance and average levels of motivation. The statistical test that was performed for the six comparisons had the following null (H_0) and alternative hypotheses (H_A):

$$H_0: \sigma_1^2 = \sigma_2^2$$
$$H_A: \sigma_1^2 \neq \sigma_2^2$$

This analysis was initially performed using a 0.1 level of significance ($\alpha = 0.1$) because of the small sample size; it was found that the null hypothesis could not be rejected for any of the pairings and as such equal variance was assumed. Additionally, the same methodology was used to determine if a smaller significance level could be used ($\alpha = 0.05$) to increase confidence. Five of the six comparisons were found to have equal variance, with the level of performance from S2 to S3 being the only comparison that failed (by 0.01). The results of both hypothesis tests are summarized in Table 13 and the general methodology used for these tests can be found in Appendix D.

Table 13: Summary of the equal variance analysis performed for the six pairwise comparisons. Note that the only value that failed the equal variance test is highlighted in grey (failed by 0.01).

	Test Statistic (F value)	Equal Means? ($\alpha = 0.1$)	Equal Means? ($\alpha = 0.05$)
Performance, S1 → S2	0.59	Yes	Yes
Performance, S1 → S3	0.81	Yes	Yes
Performance, S2 → S3	1.56	Yes	No
Motivation, S1 → S2	0.62	Yes	Yes
Motivation, S1 → S3	0.60	Yes	Yes
Motivation, S2 → S3	0.49	Yes	Yes

Once it was determined that all groupings in the pairwise comparison had equal variances, a statistical test was conducted to determine if the interventions had a positive effect on the levels of performance and motivation of the student teams. This was accomplished by statistically determining if the mean performance and motivational scores for the intervention teams was greater than the non-intervention teams (alternate hypothesis). The null and alternate hypotheses for these six comparisons were as follows:

$$H_0: \mu_1 - \mu_2 \leq 0$$
$$H_A: \mu_1 - \mu_2 > 0$$

It is important to note that the "1" and "2" in the hypotheses correspond to the treatment and control groups, respectively. The analysis performed was a hypothesis test for two means with independent samples (due to the random selection of treatment teams) and equal variances (previously proven). The results of the hypothesis tests are summarized in Table 14 and the general methodology used for these tests can be found in Appendix E.

Table 14: Summary of the t-tests performed for the six pairwise comparisons. Note that the p-values from the comparison of interest (S1 to S2) are highlighted in grey.

	Test Statistic (t value)	Pr(>|t|) (p-values)
Performance S1 → S2	1.16	0.14
Performance S1 → S3	-0.44	0.66
Performance S2 → S3	-0.87	0.79
Motivation S1 → S2	0.94	0.19
Motivation S1 → S3	0.90	0.20
Motivation S2 → S3	-2.70	0.99

A brief discussion is included for each of the three pairwise comparisons:

1. S1 to S2 – As the interventions took place between S1 and S2, this is the key area of interest for the analysis. As can be seen in Table 14, the p-values for performance and motivation are 0.14 and 0.19, respectively (highlighted in grey). These values are encouraging due to the exploratory nature of the study as well as the small sample size. These numbers indicate that there is good evidence to support that the treatment teams

saw a greater increase in performance and motivation than the control teams.

2. <u>S1 to S3</u> – The comparison of S1 to S3 allows some insight into how the interventions affected the levels of performance and motivation across the entire project. The statistical analysis showed that these values, while not as strong as S1 to S2, present somewhat confusing results. The experimental teams saw a larger increase in levels of motivation from beginning to end of semester when compared to the control teams (p-value = 0.2); however, these same teams saw a decrease in levels of performance when compared to the control teams (p-value = 0.66). These findings conflict with the findings discussed in the subsequent section (Section 5.3) in that the teams who saw the greater increases in levels of motivation did not see greater increases in levels of performance. It is believed that this can be mainly attributed to the differing levels of the experimental and control teams at S1 and will be discussed further in Section 6.3.

3. <u>S2 to S3</u> – The results from the comparison of S2 to S3 indicate that the control teams greatly outperformed the treatment teams. It is believed that this can partially be attributed to the differing levels of motivation and performance for the treatment and control teams at S1. It is also believed that the interventions may have forced the design teams into a performing stage earlier than was necessary, causing their motivation, and thus

performance, to fade at the end of the semester. Both of these issues will be discussed further in Section 6.3.

5.3 Relating Motivation to Performance

The final use of the data was to determine if a correlation between performance and motivation existed. It was hypothesized that a positive correlation between performance and motivation exists. Using the weekly data taken from the student design teams (n = 234 data points), it was determined that a linear trend existed. This model was created by taking the average of each performance score at every available motivational score, and plotting these values against each other (as seen in Figure 19).

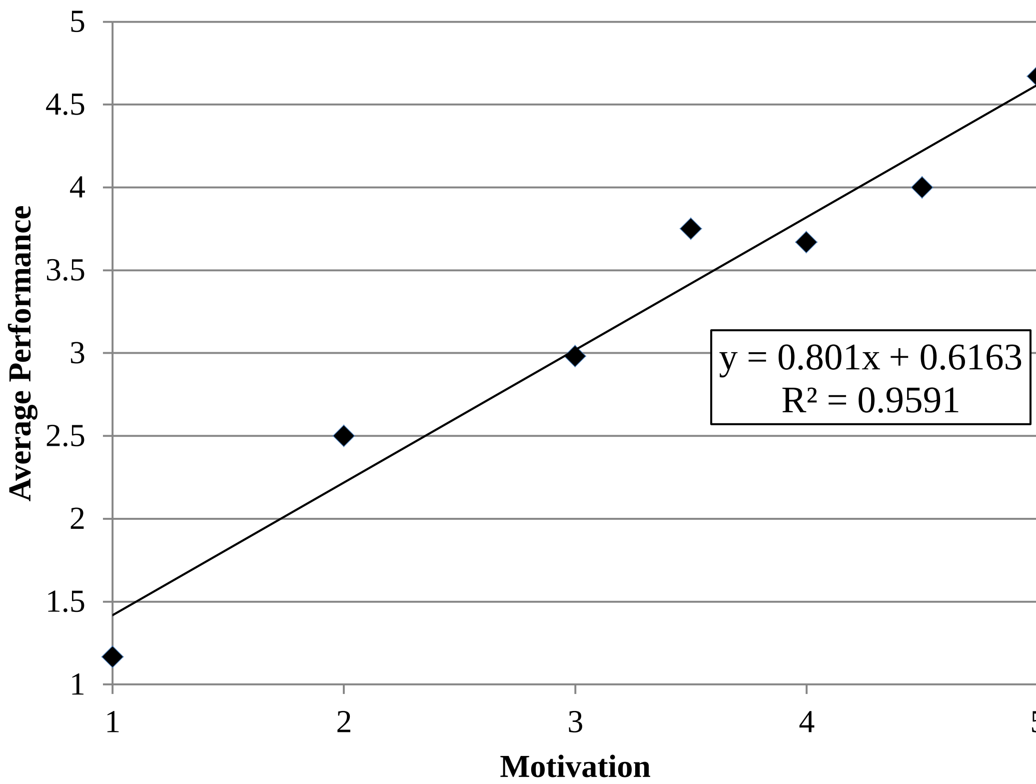

Figure 19: Visual representation of the relationship between motivation and performance.

The line has a slope of 0.8 indicating that for each "point" of motivation a team increases, their performance score should increase by 0.8 "points". The model presented has a strong linear relationship (R^2 = 0.96) and supports the initial hypothesis that was made.

Unpacking this information further, one can classify the data points in one of the following four quadrants (shown graphically in Figure 20):

I. These are teams that are performing at a high level even though they are not showing high levels of motivation. The model presented in Figure 19 shows that there should be little to no teams in this quadrant.

II. Teams in this quadrant are highly motivated and high performing teams. Ideally, this is where the majority of teams should operate when working on design projects.

III. Teams in this quadrant are teams that have very little motivation and thus a low level of performance.

IV. Quadrant four contains teams that are highly motivated but have under-performed. This can be caused by defining the problem incorrectly or working hard on unimportant side tasks along the way. Motivation alone is not enough to ensure a team will perform well, that motivation must be channeled to meeting goal-driven activities.

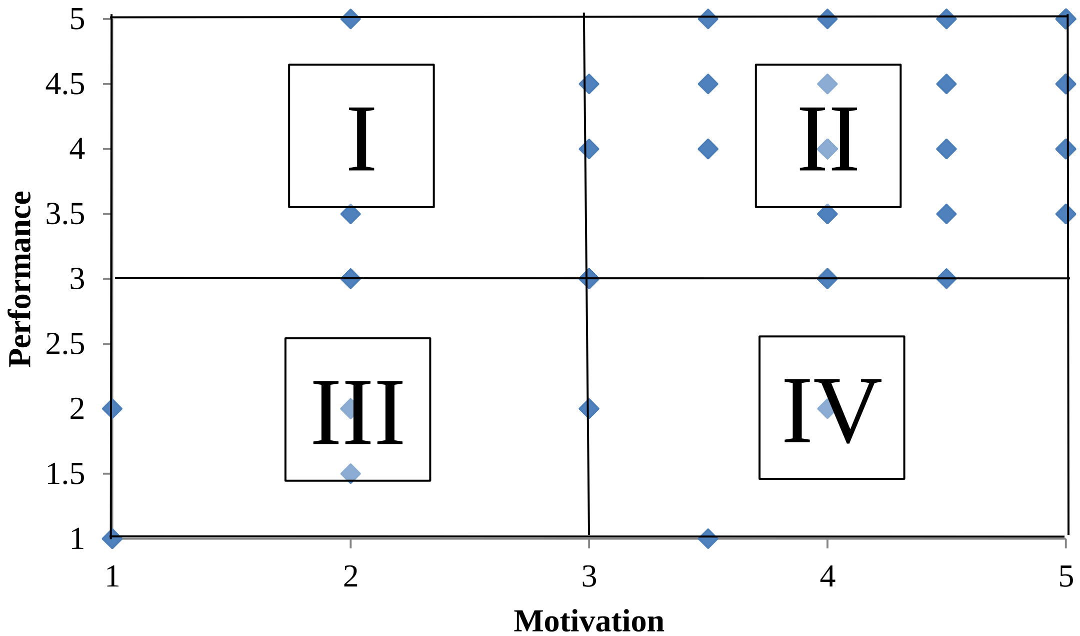

Figure 20: Breakdown of four quadrants in which design teams can operate. Note that all data points from the project are shown in this figure (n = 234).

As shown in Figure 20, the majority of data points lie in quadrants II and III. There are also a significant number of data points that fall on the boundaries between quadrants. A summary of the data points within each quadrant is shown in Table 15.

Table 15: Summary of all data point locations from the project.

Quadrant	Data Points	Percentage
I	2	0.9%
II	161	68.8%
III	15	6.4%
IV	2	0.9%
Border	54	23.1%
Total	234	100%

The majority of points (68.8%) can be found in quadrant II which is the highly motivated, high performing teams. This is a good indication of the quality of engineers participating in this experiment. Furthermore, only four of the data points (1.8%) were located in quadrants I and IV re-emphasizing the strong linear relationship between motivation and performance. The points that lie on the border between quadrants (23.1%) were not counted towards any of the four quadrants.

5.4 Chapter Conclusions

The data shows that goal alignment interventions have an immediate positive effect on the levels of performance and levels of motivation of design teams. However, these increases do not sustain over the course of the semester. Additionally, a positive relationship is found between motivation and performance in that as motivation increases, performance also increases ($R^2 = 0.96$).

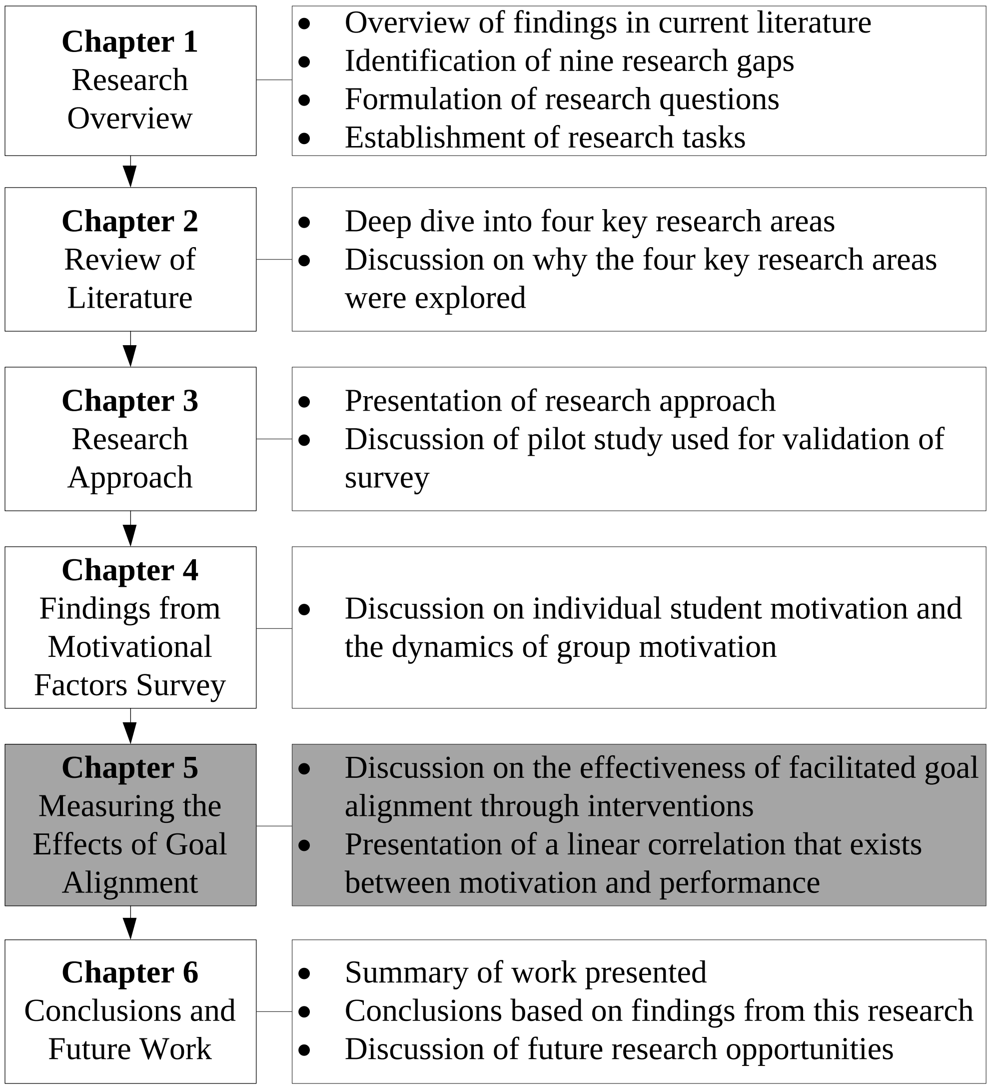

Figure 21: Thesis framework.

Chapter Six:
CONCLUSIONS AND FUTURE WORK

Chapter Aims:

- Summarize the research that is presented in this thesis,
- Draw conclusions based on the information presented in this thesis, and
- Discuss future work needed to expand and improve on the work presented.

6.1 Summary of Research Presented

The research tasks presented in Section 1.4 are discussed and summarized in this chapter with respect to the work accomplished as a whole. Furthermore, conclusions are discussed with respect to the research questions outlined in Section 1.3.1. Finally, research opportunities are presented to further refine and expand on the work presented.

6.1.1 Research Task One

RT1. Develop, administer, and analyze responses to a motivation survey to determine what students perceive to be the most effective motivational factors when working on an engineering design project.

A motivation survey was created and tested through the use of a pilot study. The pilot study allowed for the realization of flaws with the initial survey (as presented in Appendix A) that were addressed before deployment of the survey for research (as presented in Appendix B). The refined survey was administered to students working on their capstone design project at Clemson University. Findings from this survey are presented in Chapter Four.

6.1.2 Research Task Two:

> RT2. Record the individual goals of all team members to determine if the team is working towards the same goals. These goals should be recorded at the beginning and end of the project.

A one question goals survey was administered to mechanical engineering students at Clemson University (discussed in Section 3.4.5). The method for the use of these student goals was presented in Section 3.4.6. Student individual goals were compared to see if students were directed to achieve common goals.

6.1.3 Research Task Three:

> RT3. Select and administer interventions to a group of engineering design teams while they are working on design projects. Provide these design teams with the tools to explicitly set common goals as a team. Determine if these teams actually perform the goal alignment activity by giving them a deliverable (goal alignment form) to complete.

Goal align interventions were used to successfully facilitate goal alignment of the randomly selected engineering design teams. The method used to perform these interventions is presented in Section 3.4.6. All five of the intervention teams completed the goal alignment activity given them by the researcher performing the intervention.

6.1.4 Research Task Four:

RT4.	Take weekly evaluations of design teams' levels of motivation and performance throughout a project. Analyze this information using statistical methods to determine if the interventions had any positive effects on the performance and motivation of design teams.

The graduate student advisors evaluated and recorded weekly "grades" for the student design teams they were advising (method discussed in Sections 3.4.2 and 3.4.3). These evaluations were used to determine the quantitative effects that interventions had on the performance and motivation of design teams. The findings of the statistical analysis were presented in Sections 5.1 and 5.2.

6.1.5 Research Task Five:

RT5.	Use established methods to determine if a statistical correlation exists between motivation and performance. The weekly evaluations used for RT 4 should be reused to perform this analysis.

The weekly evaluation data was used to determine that a positive linear correlation exists between motivation and performance. The details of this analysis are presented in Section 5.3.

6.2 Conclusions

The goal of this research was to answer five main research questions about motivation, goal alignment, and design teams. For convenience, these research questions are listed below, with some discussion about each.

RQ1. Which factors most effectively motivate engineers when working on innovative design projects? Using the survey data from the beginning of the semester, it was determined that (1) "making an A grade in the class", (2) "developing an elegant solution", and (3) "making professional contacts with the industry sponsors" were the three factors that most effectively promoted innovative design. However, there was a noticeable shift in motivation throughout the course of the project. Using end of semester survey data, it was determined students were motivated to develop a good solution ("elegant solution" and "best solution") that was perceived to be of high quality ("impressing peers" and "impressing faculty"). This information is valuable when structuring design courses to effectively promote innovation and will be discussed further in the subsequent section.

RQ2. How does group motivation differ from individual motivation? Furthermore, how do you effectively push a group to perform at a high level? Fleiss' Kappa values were calculated to determine the level of agreement on motivational factors within a design group. It was determined that students within a group do not generally agree on motivational factors on all levels. Furthermore, it was determined that within a design team, student's agreement on motivational factors is consistent throughout the semester (validated by end of semester Fleiss Kappa comparison). It is important to note that no relation between group agreement on motivational factors and performance was found. It was instead evident that performance is directly related to goal alignment of a group, as presented in RQ4. The statistics driving these conclusions are discussed in Chapter Four.

RQ3. Can interventions be used to facilitate goal alignment of engineering design teams? As each of the five design teams that received interventions explicitly discussed and recorded common goals, it is believed that this work begins to show that interventions can be used to effectively facilitate goal alignment of engineering design teams. A larger sample size is needed to further validate this claim statistically.

RQ4. How does goal alignment effect the motivation and performance of engineering design teams? The results presented in this work begin to statistically show that interventions have some immediate positive effect on the levels of performance (p-value = 0.14) and levels of motivation (p-value = 0.19) of design teams that receive goal alignment interventions. However, initial statistical evidence does not show that this increase was sustained throughout the semester. Further work is needed to determine if a second intervention could be used to further assist design teams. Additionally, the average level of performance and average level of motivation of design teams during S1 need to be equivalent so as to remove this potential noise variable from the results. A larger sample size is also needed to be able to draw strong statistical conclusions about this work.

RQ5. Does a relationship between motivation and performance exist? It was hypothesized that there would be a positive correlation between performance and motivation; the model presented in Section 5.3 shows a strong linear correlation ($R^2 = 0.96$) supporting this hypothesis. Using this data we were also able to determine that the majority of Clemson University mechanical engineering students that participated in this experiment were a part of a highly motivated and high performing design team (68.8% in quadrant III). The researchers believe that this is a good indication of the quality of engineer involved in this study.

One of the key takeaways from this research is the overlap that often exists amongst goals and motivational factors; the lack of differentiation at the start of this research proved to be the key challenge in the early stages of development. Although people are often motivated to achieve their project goals, they can also be motivated by other factors external to the project goals (e.g. becoming a better engineer and receiving public recognition). The reason for presenting the findings in this work as separate was to make this differentiation apparent to all. As the initial findings have shown, students working as a team to achieve common goals may not guarantee high levels of performance if they are not motivated to meet said goals. Conversely, student teams may be motivated to do well on a project but will flounder aimlessly without the establishment of explicit goals. Communication of goals and motivation within a team is essential to performing at a high level. While this work has the potential to help improve students' performance through the establishment of goals and understanding of motivation, a substantial amount of work is still needed to formalize a method towards development of innovative solutions to engineering design problems. Some key areas of improvement are presented in the subsequent section.

6.3 Future Work

As the researchers were performing this work, many research opportunities were recognized that should be remedied by future work. The future work allows for refinement and expansion of the work presented in this thesis.

6.3.1 Expansion of Intrinsic Motivation

The initial intent of this work was to determine which extrinsic motivational factors were most effective. As such, only five of the fourteen motivational factors presented on the surveys can be considered intrinsic factors. Other key intrinsic factors will be included in the future to remove potential under-sampling bias. The following five intrinsic factors have been added to the survey that is currently used for the advancement of this research beyond the thesis presentation:

1. "Having fun"
2. "Representing my school well (making Clemson proud)"
3. "Making my family proud"
4. "Becoming a better engineer (self-improvement)"

These responses were selected based on feedback to the fourth question of the motivational survey. The inclusion of these factors allows for nine extrinsic and nine intrinsic factors going forward (this survey can be seen in Appendix F).

6.3.2 Mapping Academic Findings to Other Universities and Industry

The work presented in this research was only conducted on mechanical engineering students at Clemson University. As such, some initial work has been done to expand this research to other universities and industry. Researchers at Florida Institute of Technology have already administered this survey (see Appendix G) to students and have begun to analyze the findings. Furthermore, an industry version of the survey has been developed (see Appendix H) and should be administered. These steps are just the beginning towards expanding this research to have a broad impact.

6.3.3 Automation of Survey Data Processing

An initial attempt has been made to automatically analyze and manipulate the survey data that exists. Further work is needed to make this process fully automated. A database will be developed to store data responses. A web interface will be created to work in parallel with the database to make this storage process as easy as possible. Additional codes need to be created to then automatically process data from the survey into usable information. Furthermore, natural language processing should be added using Natural Language ToolKit (NLTK) to automate the processing of free responses to survey question four and goal surveys.

6.3.4 Group Agreement on Top Motivational Factors

The Fleiss' Kappa calculations performed for this research indicated that students within a design team do not generally agree on motivational factors. The flaw with this agreement metric is the comparison of all fourteen factors. Realistically, the top motivational factors are most useful when attempting to leverage this knowledge. As such, a Fleiss' Kappa evaluation was performed for the top three factors of each group (summarized in Table 16). A Matlab code was written to automate these calculations (see Appendix I).

Table 16: Summary of Fleiss' Kappa values for comparison of top three motivational factors within a design team.

Team	Question 1	Question 2
1	-0.20	1.00
2	-0.20	-0.20
3	-0.20	-0.20
4	0.25	-0.09
5	0.08	1.00
6	-0.07	0.00
7	-0.33	-0.20
8	-0.09	-0.20
9	0.02	-0.26
10	-0.27	-0.33
11	-0.17	-0.04

Note: numbers highlighted in dark grey show "perfect" agreement (1.00). All other values show an insignificant amount of agreement.

These Fleiss' Kappa values do not properly convey the message in this situation as the small nature of the data being compared results in only perfect agreement situations to have a score above 0.25. As such, joint probability or overlap analysis should be performed to more accurately characterize this information. This will enable a comparison of the top motivational factor responses of design teams, allowing researchers to determine the extent to which students agree on top motivational factors.

6.3.5 Tailoring Capstone Courses to Maximize Innovation

Understanding student motivation can be advantageous when structuring capstone design courses. One of the top motivational factors form the student surveys was "making an A grade in the class". Knowing this, one method that may be used to promote innovative design is rewarding higher grades to design groups that develop more innovative solutions to design problems. The increased emphasis and promise of higher grades for innovation may promote more innovative solutions. On the other end of the spectrum, "impressing one's peers" proved to be one of the least effective factors when attempting to promote innovative design. This may be desired as it would be difficult to develop a motivational factor in which the students are perceived to be impressive in their peers' eyes. These examples show the potential merits of understanding student motivation and must be researched further to maximize the innovation that occurs in capstone courses.

6.3.6 Increased Sample Size

One of the key shortcomings of this research was the small sample size. A course of eighty-seven students only accounted for eighteen design teams (n = 18). This small sample size could result in outcomes that do not accurately convey the norm. As such, the continuation and expansion of this research is essential to further validate the conclusions drawn in Section 6.2.

6.3.7 Removing Unnecessary Noise Variables

The confidence in some of the results presented in Chapter Five was directly affected by undesirable noise variables in the experiment. The key noise variable was the variation in starting levels of motivation and performance of design teams that received interventions as compared to the teams that did not receive interventions. This variation should be removed going forward by more strategic selection of intervention teams. This is something that has been accounted for in research being conducted in Fall 2013 and must continue to be considered going forward.

6.3.8 Intervention Adjustments

The findings indicated that the interventions had a positive short-term effect on the motivation and performance of design teams; however, these positive effects did not sustain throughout the semester. It is hypothesized that this may have been caused by forcing some teams into the performing stage too early in the design process. As such, future work should be focused on determining the point in time of a project in which interventions have the greatest positive effect.

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APPENDIX A: SURVEY USED FOR PILOT STUDY

1st question:
Please indicate which of the following factors will have an effect on your performance in completing your semester project. (1 – least impact, 5 – most impact)

Circle					**Item**
1	2	3	4	5	1. Making an “A” grade in the class
1	2	3	4	5	2. Making a passing grade in the class
1	2	3	4	5	3. Professional contacts (industry sponsors)
1	2	3	4	5	4. Professional contacts (fellow students)
1	2	3	4	5	5. Professional contacts (instructors/advisors)
1	2	3	4	5	6. Cash prizes
1	2	3	4	5	7. Impress faculty
1	2	3	4	5	8. Impress peers
1	2	3	4	5	9. Impress sponsors
1	2	3	4	5	10. Developing an “elegant” solution
1	2	3	4	5	11. Patents
1	2	3	4	5	12. Coming up with a better solution than other groups (pride)
1	2	3	4	5	13. Best solution being posted on the ME webpage (public recognition)

2nd question:
Choose the 5 factors that will have the greatest impact on your performance in completing your semester project.

Check	**Item**
	1. Making an “A” grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an “elegant” solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Best solution being posted on the ME webpage (public recognition)

3rd question:

Choose the 5 factors that will have the least impact on your performance in completing your semester project.

Check	Item
	1. Making an "A" grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an "elegant" solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Best solution being posted on the ME webpage (public recognition)

4th question:

Are there any other factors that would motivate you while working on your project?

APPENDIX B: REFINED SURVEY USED FOR EXPLORATORY STUDY AND GOAL CAPTURE

1st question:

Please indicate which of the following motivational factors will have an effect on your performance in completing your semester project. (1 – least impact, 5 – most impact)

Circle					Item
1	2	3	4	5	1. Making an "A" grade in the class
1	2	3	4	5	2. Making a passing grade in the class
1	2	3	4	5	3. Professional contacts (industry sponsors)
1	2	3	4	5	4. Professional contacts (fellow students)
1	2	3	4	5	5. Professional contacts (instructors/advisors)
1	2	3	4	5	6. Cash prizes
1	2	3	4	5	7. Impress faculty
1	2	3	4	5	8. Impress peers
1	2	3	4	5	9. Impress sponsors
1	2	3	4	5	10. Developing an "elegant" solution
1	2	3	4	5	11. Patents
1	2	3	4	5	12. Coming up with a better solution than other groups (pride)
1	2	3	4	5	13. Public Recognition (e.g. awards ceremony, name published on website)
1	2	3	4	5	14. Increased project budget

2nd question:

Choose the 5 factors that will have the greatest impact on your performance in completing your semester project.

Check	Item
	1. Making an "A" grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an "elegant" solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Public Recognition (e.g. awards ceremony, name published on website)
	14. Increased project budget

3rd question:

Choose the 5 factors that will have the least impact on your performance in completing your semester project.

Check	Item
	1. Making an "A" grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an "elegant" solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Public Recognition (e.g. awards ceremony, name published on website)
	14. Increased project budget

4th question:

Are there any other factors that would motivate you to be innovative?

5th question:

What are your goals in terms of level of performance for this class?

APPENDIX C: MATLAB CODE TO COMPUTE FLEISS' KAPPA

```
% Code to Calculate Fleiss' Kappa for 402 data
% Blake Linnerud
% 1/25/13

clear
clc

% Copy Group data here
A = [0  0   0   0   0   1   0   0   0   1   0   1   1   1
0   0   0   1   0   0   0   1   0   1   0   0   1   1
0   0   0   1   0   1   0   0   0   0   1   0   1   1
0   0   0   0   0   0   0   1   0   0   1   1   1   1
];

x = size(A);

% Create a menu box to determine which question it is
    prompt = {'From which question are the values from?'};
    name = 'Setup';
    numlines = 1;
    defaultanswer = {'1'};
    answer = inputdlg(prompt,name,numlines,defaultanswer);
    question_num = str2double(answer(1));

% 4 raters per team
n = 4;

% 14 options (subjects) per question
N = 14;

% Renumber Likert Values to 1-2-3 or keep values as 1-0 if they are
from
% question 1 or 2

for i = 1:x(1);
    for j = 1:x(2);
        if A(i,j) == 5;
            A(i,j) = 3;
        elseif A(i,j) == 4;
            A(i,j) = 3;
        elseif A(i,j) == 3;
            A(i,j) = 2;
        elseif A(i,j) == 2;
            A(i,j) = 1;
        elseif A(i,j) == 1;
            A(i,j) = 1;
        else A(i,j) = 0;
        end
    end
end
```

```
% Size nij appropriately
if question_num == 1;
    nij = zeros(3,14);
    xx = size(nij);

    % Create a matrix containing the nij values
    for i = 1:x(1);
        for j = 1:x(2);
            if A(i,j) == 3;
                nij(3,j) = nij(3,j)+1;
            elseif A(i,j) == 2;
                nij(2,j) = nij(2,j)+1;
            else nij(1,j) = nij(1,j)+1;
            end
        end
    end

else nij = zeros(2,14);
    xx = size(nij);

    % Create a matrix containing the nij values
    for i = 1:x(1);
        for j = 1:x(2);
            if A(i,j) == 1;
                nij(2,j) = nij(2,j)+1;
            else nij(1,j) = nij(1,j)+1;
            end
        end
    end

end

nij_squared = nij.*nij;
n_diff = nij_squared-nij;
p = zeros(xx(1),1);

% Create the p matrix
for i = 1:xx(1);
    for j = 1:xx(2);
        p(i) = p(i) + nij(i,j);
    end
end

p = p/(n*N);
p_squared = p.*p;
Pe_bar = sum(p_squared);
P = zeros(x(2),1);

% Create the P matrix
for j = 1:xx(2);
    for i = 1:xx(1);
        P(j) = P(j) + n_diff(i,j);
```

```
    end
end

P = P/(n*(n-1));
P_bar = sum(P)/N;

% Calculate the final kappa value
Kappa = (P_bar - Pe_bar)/(1 - Pe_bar)
```

APPENDIX D: METHODOLOGY USED FOR EQUAL VARIANCE STATISTICAL ANALYSIS

The purpose of the equal variance hypothesis test was to determine if the level of performance and motivation averages had equal variance. This must be accomplished before doing any comparative t-tests. The steps used to conduct this equal variance test can be seen below; note that the comparison of the student teams' motivation from S1 to S2 is used as an example to showcase the methodology.

<u>Hypothesis:</u> $H_0: \sigma_1^2 = \sigma_2^2$

$H_A: \sigma_1^2 \neq \sigma_2^2$

<u>Level of Significance:</u> $\alpha=0.05$

<u>Test Statistic:</u> $F_{OBS} = \frac{s_1^2}{s_2^2} = \frac{(0.587)^2}{(0.744)^2} = 0.623$

<u>Important Info:</u> $n_1=5$, $n_2=13$, $df_1=4$, $df_2=12$

<u>Rejection Region:</u> The rejection region is graphically represented in Figure 22 (the two areas marked $\alpha/2$).

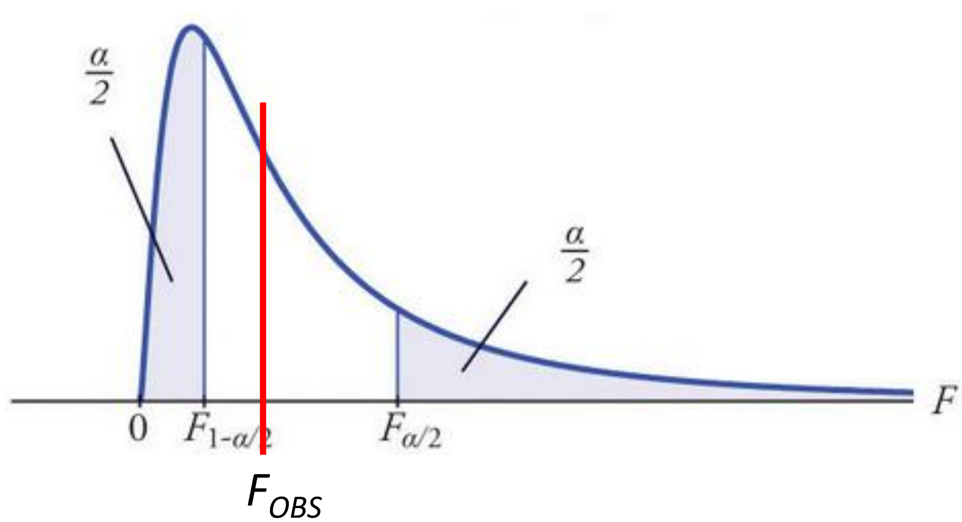

Figure 22: Graphical representation of the rejection region for an equal variance hypothesis test.

As the test statistic does not fall into either of the rejection regions, there is insufficient evidence, at the five percent level of significance ($\alpha = 0.05$), to conclude that there is a difference in variance for the level of motivation found in segments one and two. The F values used in this analysis were found using a standard F distribution table.

APPENDIX E: METHODOLOGY USED FOR COMPARATIVE T-TEST

An unequal sample size, equal variance, comparative t-test was performed on the levels of motivation and performance to determine the effects of the interventions. The steps used to conduct this comparative t-test can be seen below; note that the comparison of the student teams' motivation from S1 to S2 is used as an example to showcase the methodology.

Hypothesis: H_0: $\mu_1 - \mu_2 \leq 0$ Level of Significance: not specified

H_A: $\mu_1 - \mu_2 > 0$

Important Info: $n_1=5$, $n_2=13$, $df = n_1 + n_2 - 2 = 16$

Pooled Variance: $$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} = \frac{4(0.587^2) + 12(0.744^2)}{16} = 0.501$$

Test Statistic: $$t_{OBS} = \frac{(\overline{y_1} - \overline{y_2}) - D_0}{\sqrt{s_p^2(\frac{1}{n_1} + \frac{1}{n_2})}} = \frac{(0.633 - 0.285) - 0}{\sqrt{0.501(\frac{1}{5} + \frac{1}{13})}} = 0.936$$

Rejection Region:

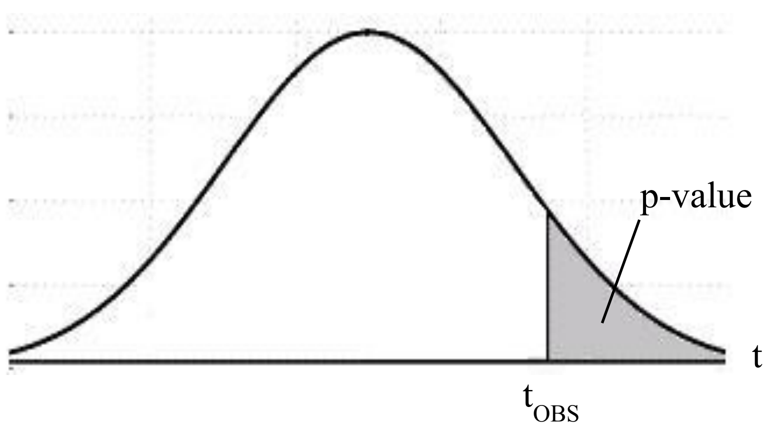

Figure 23: Graphical representation of the p-value and test statistic on a normal distribution.

The p-value method was used for this analysis; thus, for each of the six comparisons a p-value was found that indicates the strength of the comparison. The p-values correspond to the test statistic (t_{OBS}) calculated above. The locations of the test statistic and p-value for the test are graphically represented on a normal distribution in Figure 23. The corresponding p-value for $t_{OBS} = 0.936$ with 16 degrees of freedom (df) is 0.19. This means that there is sufficient evidence, at the nineteen percent level of significance ($\alpha = 0.19$), to conclude that the design teams that have received interventions have seen a greater increase in motivation from S1 to S2 than those that did not receive interventions. The t values used in this analysis were found using a standard student's t distribution table.

APPENDIX F: MOTIVATION SURVEY TO BE USED AT CLEMSON UNIVERSITY

In addition to the survey data taken below, the name, date, and group name is recorded for completeness.

1st question:

Please indicate which of the following motivational factors will have an effect on your performance in completing your semester project. (1 – least impact, 5 – most impact)

Circle					Item
1	2	3	4	5	1. Making an "A" grade in the class
1	2	3	4	5	2. Making a passing grade in the class
1	2	3	4	5	3. Professional contacts (industry sponsors)
1	2	3	4	5	4. Professional contacts (fellow students)
1	2	3	4	5	5. Professional contacts (instructors/advisors)
1	2	3	4	5	6. Cash prizes
1	2	3	4	5	7. Impress faculty
1	2	3	4	5	8. Impress peers
1	2	3	4	5	9. Impress sponsors
1	2	3	4	5	10. Developing an "elegant" solution
1	2	3	4	5	11. Patents
1	2	3	4	5	12. Coming up with a better solution than other groups (pride)
1	2	3	4	5	13. Public recognition (e.g. awards ceremony, name published on website)
1	2	3	4	5	14. Increased project budget
1	2	3	4	5	15. Having fun
1	2	3	4	5	16. Representing my school well (making Clemson proud)
1	2	3	4	5	17. Making my family proud
1	2	3	4	5	18. Becoming a better engineer (self-improvement)

2^{nd} question:

Choose the 5 factors that will have the greatest impact on your performance in completing your semester project.

Check	Item
	1. Making an "A" grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an "elegant" solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Public Recognition (e.g. awards ceremony, name published on website)
	14. Increased project budget
	15. Having fun
	16. Representing my school well (making Clemson proud)
	17. Making my family proud
	18. Becoming a better engineer (self-improvement)

3rd question:

Choose the 5 factors that will have the least impact on your performance in completing your semester project.

Check	Item
	1. Making an "A" grade in the class
	2. Making a passing grade in the class
	3. Professional contacts (industry sponsors)
	4. Professional contacts (fellow students)
	5. Professional contacts (instructors/advisors)
	6. Cash prizes
	7. Impress faculty
	8. Impress peers
	9. Impress sponsors
	10. Developing an "elegant" solution
	11. Patents
	12. Coming up with a better solution than other groups (pride)
	13. Public Recognition (e.g. awards ceremony, name published on website)
	14. Increased project budget
	15. Having fun
	16. Representing my school well (making Clemson proud)
	17. Making my family proud
	18. Becoming a better engineer (self-improvement)

4th question:

Are there any other factors that would motivate you to be innovative?

APPENDIX G: MOTIVATION SURVEY TO BE USED AT FLORIDA TECH

In addition to the survey data taken below, the name, date, and group name is recorded for completeness.

1st question:

Please indicate which of the following motivational factors will have an effect on your performance in completing your semester project. (1 – least impact, 5 – most impact)

Circle					Item
1	2	3	4	5	1. Public recognition (e.g. awards ceremony, name published on website)
1	2	3	4	5	2. Coming up with a better solution than other groups (pride)
1	2	3	4	5	3. Increased project budget
1	2	3	4	5	4. Impress sponsors
1	2	3	4	5	5. Impress peers
1	2	3	4	5	6. Having fun
1	2	3	4	5	7. Professional contacts (instructors/advisors)
1	2	3	4	5	8. Making an “A” grade in the class
1	2	3	4	5	9. Becoming a better engineer (self-improvement)
1	2	3	4	5	10. Developing an “elegant” solution
1	2	3	4	5	11. Making a passing grade in the class
1	2	3	4	5	12. Patents
1	2	3	4	5	13. Impress faculty
1	2	3	4	5	14. Professional contacts (industry sponsors)
1	2	3	4	5	15. Representing my school well (making Florida Tech proud)
1	2	3	4	5	16. Cash prizes
1	2	3	4	5	17. Professional contacts (fellow students)
1	2	3	4	5	18. Making my family proud

2nd question:

Choose the 5 factors that will have the greatest impact on your performance in completing your semester project.

Check	Item
	1. Public recognition (e.g. awards ceremony, name published on website)
	2. Coming up with a better solution than other groups (pride)
	3. Increased project budget
	4. Impress sponsors
	5. Impress peers
	6. Having fun
	7. Professional contacts (instructors/advisors)
	8. Making an "A" grade in the class
	9. Becoming a better engineer (self-improvement)
	10. Developing an "elegant" solution
	11. Making a passing grade in the class
	12. Patents
	13. Impress faculty
	14. Professional contacts (industry sponsors)
	15. Representing my school well (making Florida Tech proud)
	16. Cash prizes
	17. Professional contacts (fellow students)
	18. Making my family proud

3rd question:

Choose the 5 factors that will have the least impact on your performance in completing your semester project.

Check	Item
	1. Public recognition (e.g. awards ceremony, name published on website)
	2. Coming up with a better solution than other groups (pride)
	3. Increased project budget
	4. Impress sponsors
	5. Impress peers
	6. Having fun
	7. Professional contacts (instructors/advisors)
	8. Making an "A" grade in the class
	9. Becoming a better engineer (self-improvement)
	10. Developing an "elegant" solution
	11. Making a passing grade in the class
	12. Patents
	13. Impress faculty
	14. Professional contacts (industry sponsors)
	15. Representing my school well (making Florida Tech proud)
	16. Cash prizes
	17. Professional contacts (fellow students)
	18. Making my family proud

4th question:

Are there any other factors that would motivate you to be innovative?

APPENDIX H: MOTIVATION SURVEY TO BE USED IN INDUSTRY

In addition to the survey information taken below, the name, date, age, gender, company, job title, and number of years at the company are all collected for completeness.

1st question:

When working on engineering design projects, it is often desirable to be innovative. Please indicate which of the following would motivate you to be innovative when working on design projects. (1 – least impact, 5 – most impact)

Circle					Item
1	2	3	4	5	1. Paycheck (regularly scheduled)
1	2	3	4	5	2. Financial incentives (bonuses)
1	2	3	4	5	3. Public recognition (plaque, recognition in company newsletter, etc…)
1	2	3	4	5	4. Professional contacts (within the company)
1	2	3	4	5	5. Professional contacts (external to the company)
1	2	3	4	5	6. Impressing your superiors (manager, boss, CEO)
1	2	3	4	5	7. Impressing your peers
1	2	3	4	5	8. Promotion
1	2	3	4	5	9. Non-monetary incentives (e.g. new TV, gift certificate, vacations)
1	2	3	4	5	10. Satisfaction of improving your company or your company's product
1	2	3	4	5	11. Patents
1	2	3	4	5	12. Making my family proud
1	2	3	4	5	13. Becoming a better engineer (self-improvement)
1	2	3	4	5	14. Having fun
1	2	3	4	5	15. Developing an "elegant" solution
1	2	3	4	5	16. Getting a raise

2nd question:

Choose the 5 factors that will have the greatest impact on your performance when working on design projects.

Check	Item
	1. Paycheck (regularly scheduled)
	2. Financial incentives (bonuses)
	3. Public recognition (plaque, recognition in company newsletter, etc…)
	4. Professional contacts (within the company)
	5. Professional contacts (external to the company)
	6. Impressing your superiors (manager, boss, CEO)
	7. Impressing your peers
	8. Promotion
	9. Non-monetary incentives (e.g. new TV, gift certificate, vacations)
	10. Satisfaction of improving your company or your company's product
	11. Patents
	12. Making my family proud
	13. Becoming a better engineer (self-improvement)
	14. Having fun
	15. Developing an "elegant" solution
	16. Getting a raise

3rd question:

Choose the 5 factors that will have the least impact on your performance when working on design projects.

Check	Item
	1. Paycheck (regularly scheduled)
	2. Financial incentives (bonuses)
	3. Public recognition (plaque, recognition in company newsletter, etc…)
	4. Professional contacts (within the company)
	5. Professional contacts (external to the company)
	6. Impressing your superiors (manager, boss, CEO)
	7. Impressing your peers
	8. Promotion
	9. Non-monetary incentives (e.g. new TV, gift certificate, vacations)
	10. Satisfaction of improving your company or your company's product
	11. Patents
	12. Making my family proud
	13. Becoming a better engineer (self-improvement)
	14. Having fun
	15. Developing an "elegant" solution
	16. Getting a raise

4th question:

Are there any other factors that would motivate you to be innovative?

5th question:

Please briefly describe some of the primary responsibilities of your job (bullet points are fine):

APPENDIX I: MATLAB CODE TO COMPUTE FLEISS' KAPPA FOR TOP THREE FACTORS

```
% Code to Calculate Fleiss' Kappa for 402 data (Top 3)
% Blake Linnerud
% 10/2/13

clear
clc

% Copy Group data here
A = [1  1   0   0   1   0   0   0   1   0   0   1   0   0
1   0   0   0   1   0   1   0   1   0   0   1   0   0
0   1   1   0   0   0   0   1   0   1   0   1   0   0
1   0   1   1   0   0   0   0   0   1   0   1   0   0
];

x = size(A);

% Create a menu box to determine which question it is
    prompt = {'From which question are the values from?'};
    name = 'Setup';
    numlines = 1;
    defaultanswer = {'1'};
    answer = inputdlg(prompt,name,numlines,defaultanswer);
    question_num = str2double(answer(1));

    sum_responses = zeros(2,x(2));

% Sum the responses for the 14 questions and store them in a matrix
with
% their corresponding numbers
for i = 1:x(2);
    sum_responses(1,i) = i;
    sum_responses(2,i) = sum(A(:,i));
end

% Sort the responses and flip the matrix back to its original form
b = sum_responses';
c = sortrows(b,2);
d = flipud(c)';

% Select top 3
top1 = d(1,1);
top2 = d(1,2);
top3 = d(1,3);

A_top3 = zeros(4,3);
A_top3(:,1) = A(:,top1);
A_top3(:,2) = A(:,top2);
A_top3(:,3) = A(:,top3);
A = A_top3;
```

```
x = size(A);

% 4 raters per team
n = 4;

% 3 options (subjects) per question
N = 3;

% Size nij appropriately
if question_num == 1;
    nij = zeros(5,N);
    xx = size(nij);

    % Create a matrix containing the nij values
    for i = 1:x(1);
        for j = 1:x(2);
            if A(i,j) == 5;
                nij(5,j) = nij(5,j)+1;
            elseif A(i,j) == 4;
                nij(4,j) = nij(4,j)+1;
            elseif A(i,j) == 3;
                nij(3,j) = nij(3,j)+1;
            elseif A(i,j) == 2;
                nij(2,j) = nij(2,j)+1;
            else nij(1,j) = nij(1,j)+1;
            end
        end
    end

else nij = zeros(2,N);
    xx = size(nij);

    % Create a matrix containing the nij values
    for i = 1:x(1);
        for j = 1:x(2);
            if A(i,j) == 1;
                nij(2,j) = nij(2,j)+1;
            else nij(1,j) = nij(1,j)+1;
            end
        end
    end

end

nij_squared = nij.*nij;
n_diff = nij_squared-nij;
p = zeros(xx(1),1);

% Create the p matrix
for i = 1:xx(1);
    for j = 1:xx(2);
        p(i) = p(i) + nij(i,j);
```

```
    end
end

p = p/(n*N);
p_squared = p.*p;
Pe_bar = sum(p_squared);
P = zeros(x(2),1);

% Create the P matrix
for j = 1:xx(2);
    for i = 1:xx(1);
        P(j) = P(j) + n_diff(i,j);
    end
end

P = P/(n*(n-1));
P_bar = sum(P)/N;

% Calculate the final kappa value
Kappa = (P_bar - Pe_bar)/(1 - Pe_bar)
```